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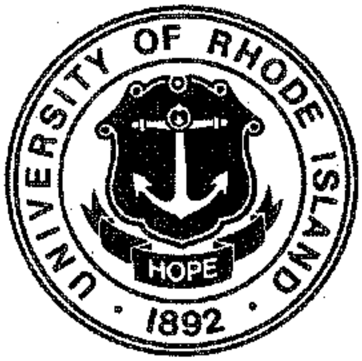
in
LABORATORY SOIL COLUMNS



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PHOSPHATE RELEASE IN LABORATORY SOIL COLUMNS

by

T.J. Bicki and W.R. Wright

September 1982

ABSTRACT

A soil column study was initiated to determine the magnitude of phosphorus release from phosphorus enriched soil treated with various rejuvenation products. Columns filled with soil collected at the base of seepage pits (cesspools) were treated with 100 ml solutions of 50% H_2SO_4, 16% H_2O_2, 1% Drainz, 1% enzyme and distilled water. Total phosphorus was determined on column extracts after contact times of 24 and 168 hours. The results indicate that the H_2SO_4 treatment extracted the greatest amount of phosphorus from the soil followed by peroxide (H_2O_2), Drainz and enzyme treatments. Increasing contact time increased amounts of total phosphorus in the H_2SO_4 and enzyme treatments. Problems associated with the fate of released phosphorus from these systems needs to be investigated further.

PHOSPHATE RELEASE IN LABORATORY SOIL COLUMNS

T. J. Bicki
W. R. Wright

The objective of this soil column study was to determine the magnitude of phosphorus release from phosphorus enriched soil treated with various rejuvenation products. Rejuvenation products are routinely applied to septic systems in an attempt to restore soil permeability after biological clogging has occurred.

PROJECT ACCOMPLISHMENTS

Soil columns were constructed from a bulk soil sample collected from the base of a seepage pit (cesspool). The seepage pit was constructed in outwash materials and had been in continuous use for approximately 35 years. Previous research by Wright, Galgowski and Kelly (OWRT No. A-705 R.I.) indicated that high concentrations of phosphorus were found in the soil at the base of seepage pits.

The bulk soil was air dried and ground to pass a 10 mesh sieve. The gravels (10 mesh) were discarded and the finer fraction was analyzed for total phosphorus using a perchloric acid digestion method outlined by Sommers and Nelson (1972). Total phosphorus content of the bulk sample was 934 ppm.

Columns were constructed of 6.25 cm diameter PVC pipe which was fitted with glass wool and rubber stoppers. The rubber stoppers were fitted with Tygon tubing and a clamp to permit sampling after 24 hour and 168 hour contact times with the various treatments. The soil columns were packed to a density of 1.2 g/cc.

Six replicate columns were constructed for each of 5 treatments. The treatments consisted of 100 ml solutions of 50% H_2SO_4, 16% H_2O_2, 1% Drainz, 1% enzyme and distilled H_2O. The concentrations of the various treatments were selected to represent the concentration of commercial application rates. The distilled water treatment served as a control.

The various treatments were applied and the solutions were withdrawn after 24 hours of contact time. A subsample was withdrawn and the remaining solution was reintroduced into the column. Total phosphorus content of the leachate after 24 hours of contact time is reported in Table 1.

The H_2SO_4 treatment extracted the greatest amount of phosphorus from the phosphorus enriched soil, followed by the peroxide, Drainz, and enzyme treatments respectively. Phosphorus concentration of the distilled water was negligible.

Total phosphorus concentrations for the various treatments after 168 hours of contact time are given in Table 2. The results follow a similar trend found with the 24 hour contact time. The H_2SO_4 treatment extracted the greatest amount of phosphorus followed by decreasing phosphorus content in the H_2O_2, Drainz and enzyme treatments.

Increasing the contact time from 24 hours to 168 hours resulted in significant increases in total phosphorus content in both the H_2SO_4 and enzyme leachates. The results suggest that 24 hours was insufficient time for the H_2SO_4 and enzyme to react completely with the soil.

No significant increase in total phosphorus content was found in the leachate by increasing the contact times of the H_2O_2 and Drainz treatments. The H_2O_2 appeared to be rapidly consumed upon introduction to the columns. Increasing the contact time did little to increase phosphorus content.

The data obtained from this study indicates that large quantities of phosphorus are extracted from phosphorus enriched soils treated with various rejuvenation products. The fate of this extracted phosphorus in the soil system has yet to be determined. The phosphorus may be readsorbed by the underlying soil material or may be released to groundwater.

Additional studies are needed to determine the ability of the soil to adsorb phosphorus from these rejuvenation leachates charged with phosphorus.

CITATIONS

Sommers, L.E. and D.W. Nelson. 1972. Determination of total phosphorus in soils: A rapid perchloric acid digestion procedure. Soil Sci. Soc. Am. Proc. 36:902-904.

Wright, W.R., Galgowski, C.E. and W.E. Kelly. Phosphate movement from on-site sewerage disposal systems. OWRT Project No. A-075-RI.

TABLE 1

Concentrations of Total Phosphorus in leachates for various treatments after 24 hours of contact time.

	H_2SO_4 ppm	H_2O_2 ppm	Drainz ppm	Enzyme ppm	H_2O ppm
	297	137	26	11	-
	263	107	33	17	-
	307	93	51	8	5
	281	101	37	--	-
	244	161	61	27	-
	351	128	40	5	-
Mean	291	121	41	14	-

TABLE 2

Concentrations of Total Phosphorus in leachates for various treatments after 168 hours of contact time.

	H_2SO_4 ppm	H_2O_2 ppm	Drainz ppm	Enzyme ppm	H_2O ppm
	371	159	29	53	-
	408	109	41	27	-
	446	112	62	32	-
	309	117	41	22	-
	389	153	61	29	-
	422	136	57	19	-
Mean	391	131	49	30	-

UV-OZONE PROCESS FOR THE CONCURRENT DECOMPOSITION OF HALOGENATED ALKANES AND ALKANES AND THE DISINFECTION OF WATER

UNIVERSITY OF RHODE ISLAND
1892

Rhode Island
Water Resources Center

Technical Completion Report

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Calvin P.C. Poon, and Bruno M. Vittimberga

Dept. of Civil and Environmental Engineering/Dept. of Chemistry

Submitted to
Office of Water Policy
United States Department of the Interior
Washington, D.C. 20243

The work on which this report is based was supported in part by funds provided by the United States Department of the Interior as authorized under the Water Research and Development Act of 1978.

Rhode Island Water Resources Center
University of Rhode Island
Kingston, R.I. 02881

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Final Report
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UV-Ozone Process for the Concurrent Decomposition of Halogenated Alkanes and Alkanes and the Disinfection of Water.

Calvin P.C. Poon
Dept. of Civil and Environmental Engineering

Bruno M. Vittimberga
Dept. of Chemistry

INTRODUCTION

Many organic chemical species found in water supply systems are toxic. Among these species are trihalomethanes, trichloroethylene and its related chemicals. All have been linked to animal cancers, and epidemiological data suggest that they may contribute to cancer in humans. Trihalomethanes (THM) can form in drinking water from the chemical interaction between chlorine, used as a disinfectant, and organic substances that occur naturally in drinking water sources. Unprotected watersheds with a "surface system" of wetlands and shallow reservoirs contain more organics and demand more chlorine for disinfection. The chances of having THMs in drinking water from these sources are higher than those from better protected watersheds. The case in point is the finding of unusually high concentrations of total trihalomethane (TTHM) in the Bristol County water system in Rhode Island. Several samples, according to EPA's analysis in November 1977 (ref. 1) showed slightly above to more than 3 times the EPA proposed standards of 100 ppb for TTHM for public water supplies. Like other places having similar problems in their water systems, Bristol County has an unprotected watershed with shallow reservoirs.

One of the major provisions of the National Safe Drinking Water Act of 1974 is the initiation of research on health, economic and technological problems related to drinking water supplies. In partial response to these needs, a new technology of water treatment enabling the destruction of these organic substances and providing disinfection at the same time is investigated in this research.

The major forms of THM found in water supply systems in the United States are chloroform ($CHCl_3$), bromodichloromethane (CHB_rCl_2), dibromochloromethane ($CHB_{r2}Cl$) and bromoform (CHB_{r3}), with $CHCl_3$ usually amounting to more than 85 percent and CHB_rCl_2 12 percent of the TTHM. In most water systems deriving their water from protected watersheds, the THM concentration is usually very low. At the time of the EPA tests in 1974, the high concentration in the nation was recorded in Miami with 311 ppb. Later tests have shown up to 550 ppb in some water systems. Even these high concentrations are very low in water for any known method of treatment to be effective.

Ozonation is one means of removing trihalomethane, trichloroethylene, carbon tetrachloride and their related compounds from water. Recent studies at the University of Rhode Island show that despite high ozonation using 5 gram/hour application sparging for 5 minutes, only 60 percent of removal can be realized. Activated carbon adsorption also has severe limitations on the removal of these chemicals because their low concentrations in water are not significantly different from the equilibrium concentrations from isotherm studies. Ozonation has an advantage over activated carbon in that ozonation provides disinfection as well as the removal of these toxic organic compounds. The process therefore is more economically justifiable. However, the need exists for a significant improvement of the efficiency of organic removal by ozone. One possible means is to use an ultraviolet light-ozone (UV-ozone) process.

UV-ozone is the strongest phyical-chemical oxidation reaction effective with toxic and highly refractory organics. The ultraviolet light provides the bond-breaking energy to excite molecules and to produce free radicals which are highly reactive in the presence of ozone. Ozone alone produces substantially less radicals and oxidizes refractory organics only to intermediates according to Gould (ref. 2). The interpretation of the photochemistry of aqueous solutions of ozone, according to Ashmore (ref. 3) is in the following. At a longer wavelength (600 $m\mu$) the oxygen atom produced in the primary step ($O_3 + h\nu \longrightarrow O + O_2$) is in its ground electronic state or $O(^3P)$, and cannot react with water. However, at the two shorter wavelength (310 and 245 $m\mu$), a ^1O oxygen (excited or high energy state) atom may be produced (higher efficiency at 245 $m\mu$). This atom reacts with water to give two hydroxyl radicals (-29 kcal/mole) of which the main reaction in solution will be recombination ($O + H_2O \longrightarrow 2OH\cdot$ and $2OH\cdot \longrightarrow H_2O_2$). The hydroxyl radicals are possibly the active species primarily responsible for the oxidation of THMS with a possible chain reaction.

Many compounds may be economically oxidized using UV-ozone whose reaction rates would otherwise be too low to be processed in other systems. UV and ozone were applied for both sterilization and reduction of organic matter in a wastewater-reuse system (ref. 4). Successful removal of complexed cyanides from wastewater was also reported (ref. 5). In the absence of UV radiation, difficult compounds such as potassium ferricyanide, ethanol and acetic acid are essentially unoxidized by ozone; however, with UV radiation oxidation proceeds rapidly at room temperature (ref. 6).

Recent EPA sponsored studies (ref. 7) have shown that UV-ozone reduces the level of polychlorinated biphenyls (PCB) in industrial wastewaters to less than 0.01 μg/l, and in many cases to below detectable limits. Activated carbon adsorption can only reduce PCB levels to 0.1 μg/l. Consequently, UV-ozone has been specified by EPA as the best practicable control tchnology currently available for PCB (as well as for photoprocessing wastewater).

It can be stated in summary that UV-ozone is capable of oxidizing most refractory organic and inorganic compounds. Although UV is an effective reagent itself in water disinfection (the possibility of photoreactivation can be a drawback of UV disinfection), the purpose of utilizing UV in the UV-ozone process is to produce radicals which initiates propagation chains and causes the overall reaction to proceed much faster, enhancing the reaction with ozone 10^2 to 10^4 folds. This brings about three results as follow: (1) faster and more complete oxidation of refractory and toxic compounds by ozone; (2) more complete disinfection of water; and (3) very small size reactors are needed which compensates for the higher power cost in operation. The fact that both toxic compound oxidation and disinfection can be accomplished in one step instead of two separate processes is unique and should result in significant saving of capital as well as operational costs in water treatment.

OBJECTIVE OF STUDY

The objective of this study is to determine the effectiveness of the UV-ozone process for concurrent removal of THMs and coliform in water. By taking advantage of the rapid chain reactions of UV-ozone and organic compounds, a simple and compact treatment system can be developed. A laboratory scale column reactor is specifically designed and built for the study. Individual effects of ozone and UV radiation and their combination are determined. The resulting data are analyzed in terms of kinetic rate expressions. The kinetic rates are used to compare the relative effectiveness of the control variables such as UV intensity and ozone dosing rate.

EXPERIMENTAL PROCEDURES

A specially designed column reactor is built as described in Figure 1. The UV lamp has an output of 13.8 watts and an intensity of 15,800 $\mu w/cm^2$ on the surface of the quartz jacket. The liquid volume in the reactor is 1.3-liter. Thus the power input of the UV radiation is 10.6 w/l solution. The four diffusers allow either air or ozone into the reactor in the form of medium size gas bubbles. The rising bubbles provide the mixing of the solution which is critical for photolysis since photolysis is a diffusion control process. Air or ozone supplied is maintained at a steady rate of 0.4 l/min or 0.308 l/min-l solution. The rate is adequate and eliminates any mass transfer limitation in the photolytic reaction.

Stock solutions of THM species are prepared as follow: $CHCl_3$ 4.5 $\mu g/\mu l$, CHB_rCl_2 0.6 $\mu g/\mu l$, mixture $CHCl_3$ 2.6 μg + CHB_rCl_2 0.23 $\mu g/\mu l$. A reservoir holding two liters of distilled water was spiked with one or both of the standard solutions aforementioned. The mixture was then pumped into the reactor for experiment. Batch experiments are used throughout the study.

Four sets of experiments are conducted as follow:

UV radiation only

Ozone only

Air purging only

UV-ozone (oxyphotolysis)

The UV lamp and the ozonator are warmed up 30 minutes and 3 hours respectively before the experiment. An initial sample is taken directly from the reservoir to establish the THM concentration. Zero time and periodic samples are taken from the reactor during the experiment. Samples taken are refrigerated 24 to 48 hours prior to extraction and gas chromatograph (GC) analysis. Refrigeration is found necessary for all UV exposed samples because sample temperature rises above the boiling point of the extraction solvent, pentane at 36.1°C. Extraction vessels are 40-ml in volume. THM extraction follows the liquid/liquid extraction procedure outlined in the Federal Register (Ref. 8). $CHCl_3$ and CHB_rCl_2 are analyzed with a Perkin-Elmer Sigma 3B gas chromatograph equipped with an electron capture detector. A steel column instead of a glass column is used for the GC.

Ozone, when used in the experiment, is analyzed for its initial and final concentrations in solution following Standard Methods (Ref. 9). Ozone input rate expressed in mg/min-1 is determined by measuring the ozone trapped in a potassium iodide solution over a given period of time.

For disinfection study, the distilled water is spiked with a primary effluent from a local sewage treatment plant. Coliform analysis is according to Standard Methods (Ref. 9).

RESULTS

Regardless of which method of treatment is used in this study, all data indicate a straight line obtained from a plot of the logarithmic concentration ratio ($\ln c/c_0$) versus time. This indicates a first order removal kinetic for the concentrations of $CHCl_3$ and CHB_rCl_2 used in this study. The concentrations used are 199 to 312 ppb for $CHCl_3$ and 15.3 to 48.6 ppb for CHB_rCl_2, simulating their respective concentrations found in drinking water supplies in the United States. When all control variables are held constant, i.e., UV power input I = 10.6 w/l solution; air or ozone flow rate = 0.308 l/min-l solution; ozone input rate = 8.8 ± 0.2 mg/min-l; the removal kinetic equation for any treatment is represented by $-dc/dt = k.c$ or $k = -\ln(c/c_0)/t$. The slope of the plot, or k, represents the removal rate with a unit of time^{-1}. Four plots, one each representing the typical results of a treatment method, are presented in Figures 2, 3, 4, and 5.

The results of the experiments including time of treatment, residual THM concentration, residual ozone concentration, and the calculated values of removal rate k, percentage of removal, are summarized in Tables 1 through 4.

Disinfection is conducted only for a few selected experiments using UV-ozone treatment. The sole objective for this portion of the study is to see if coliform can be killed effectively at the UV-ozone dose successful in THM removal. The result is recorded in Table 5.

DISCUSSION

Ozone appears to be effective in the removal of $CHCl_3$ and CHB_rCl_2, individually or as a mixture. Ozone input at 7.7 to 10 mg/min-l is adequate with sufficient dissolved ozone remained in the solution (0.9 to 3.9 mg/l) after 50 to 60-minute treatment. Both the percent removal and removal rate are higher for $CHCl_3$ than CHB_rCl_2. Table 1 shows the average of 95.4 percent removal and 0.053 min^{-1} removal rate for $CHCl_3$ versus 87.2 percent removal and 0.042 min^{-1} removal rate for CHB_rCl_2.

Table 1, Ozone Treatment of chloroform
and Bromodichloromethane
(0.308 l O_3/min-l solution, Temp. 22-25°C)

Chemical Compound	Time of Reaction	Initial Conc.	Final Conc.	Percent Removal	Removed Rate	O_3 Input	Residual O_3
	min.	ppb	ppb	%	min^{-1}	mg/min-1	mg/l
$CHCl_3$	60	170	8	95.3	0.049	7.7	1.9
	60	178	6	96.6	0.054	9.2	1.7
	50	316	18	94.3	0.056	8.1	1.9
				$\bar{x}$ = 95.4	$\bar{x}$ = 0.053		
					s = 0.0036		
CHB_rCl_2	60	28.8	3	89.6	0.044	8.3	1.8
	60	25.4	2.9	88.6	0.043	8.4	2.5
	60	48.6	8.1	83.3	0.039	9.8	0.9
				$\bar{x}$ = 87.2	$\bar{x}$ = 0.042		
					s = 0.0026		
Mixture	60	224 ($CHCl_3$)	12	94.6	0.050	10	1.6
		20.3 (CHB_rCl_2	3	85.2	0.038		
	60	256 ($CHCl_3$)	9	96.5	0.057	9.9	3.9
		18.8 (CHB_rCl_2)	2.5	86.7	0.040		

Table 2. Air Purging of Chloroform and Bromodichloroform
(0.308 l air/min-l solution, Temp. 23-26°C)

Chemical Compound	Time of Reaction	Initial Conc.	Final Conc.	Percent Removal	Removed Rate
	min.	ppb	ppb	%	min^{-1}
$CHCl_3$	120	299	2	99.3	0.053
	90	199	2	99.0	0.053
	90	203	2	99.0	0.065
				$\bar{x}$ = 99.1	$\bar{x}$ = 0.057
					s = 0.0069
CHB_rCl_2	90	42.8	1.1	97	0.040
	90	43.3	1.9	96	0.036
	90	30.0	1.0	97	0.040
	90	28.8	1.1	96	0.035
				$\bar{x}$ = 96.5	$\bar{x}$ = 0.038
					s = 0.0026
Mixture	105	238 ($CHCl_3$)	1.0	99.6	0.053
		20.5 (CHB_rCl_3)	1.0	97.0	0.040
	105	236 ($CHCl_3$)	1.0	99.6	0.059
		23.9 (CHB_rCl_3)	1.0	96.0	0.036
	90	237 ($CHCl_3$)	3.3	98.6	0.055
		21.1 (CHB_rCl_2)	1.0	95.0	0.041

Table 3. UV Radiation Treatment of Chloroform
and Bromodichloroform
(10.6-watt/l, Temp initial 27-30°C)
final 39-46°C

Chemical Compound	Time of Reaction Min.	Initial Conc. PPb	Final Conc. PPb	Percent Removal %	Removal Rate Min^{-1}
$CHCl_3$	150	292	211	27.8	0.0020
	150	312	209	33.0	0.0025
	300	290	111	25(150 min)	0.0015
	300	305	112	26(150 min)	0.0018
	150	200	136	32	0.0023
	150	176	136	23	0.0015
				$\bar{x}$ = 27.8	$\bar{x}$ = 0.0019
					s = 0.0004
CHB_rCl_2	80	42	1.0	97.6	0.045
	80	46	1.0	97.8	0.050
	80	36	1.5	95.8	0.041
	80	44	1.1	97.5	0.046
	80	28	1.0	96.4	0.053
	70	30.2	1.0	96.7	0.054
				$\bar{x}$ = 97.0	$\bar{x}$ = 0.048
					s = 0.005
Mixture	150	227 ($CHCl_3$)	183	19.4	0.0014
		22.9 (CHB_rCl_2)	1.0	95.6	0.043

Table 4. UV-Ozone Treatment of Chloroform
and Bromodichloroform
(10.6-Watt/l and 0.308 l O_3/min-1)
(Temp. initial 26-30°C, final 28-34°C)

Chemical Compound	Time of Reaction Min.	Initial Conc. PPb	Final Conc. PPb	Percent Removal %	Removal Rate $Min.^{-1}$	O_3 Input mg/min-1	Residual O_3 mg/l
$CHCl_3$	60	298	3	99.0	0.075	10.0	0
$CHBrCl_2$	60	20	1.0	95.0	0.096	9.5	0.1
Mixture	30	197 ($CHCl_3$)	16	91.9	0.082	---	0.5
		18 ($CHBrCl_2$)	1	94.4	0.102		
	60	228 ($CHCl_3$)	2	99.1	0.081	12.3	0.3
		15.3 ($CHBrCl_2$)	1	93.5	0.094		

Table 5. UV-Ozone Kill of Coliform
(10.6-Watt/l or 0.308 l O_3/min.-l)
(Temp. initial 26-30°C, final 28-34°C)

Exposure Time Min.	Initial Coliform Concentration MPN/100 ml	Final Coliform Concentration MPN/100 ml	Other Chemicals in Solution
60	180	0	$CHCl_3$
60	220	0	CHB_rCl_2
60	49	0	$CHCl_3$ CHB_rCl_2
30	170	0	$CHCl_3$ CHB_rCl_2

In a mixture, each chemical compound is removed at a rate independent of the other, i.e., $CHCl_3$ is removed faster and has a higher percentage removal than CHB_rCl_2 by the same amount as in experiments with solutions containing only a single compound.

It was observed in all experiments of CHB_rCl_2 removal by ozonation that there was an initial 10 to 15 minutes of lag period during which time the removal was extremely slow. This period as shown in Figure 2 was excluded from the calculation of the removal rate, K. While the mechanism and the pathway of reactions in ozonation was not investigated in this study, the fact that the lag period was never observed in the $CHCl_3$ treatment indicates possible different reactions involved, at least in the beginning, for the breakdown of the two compounds. When ozone gas is introduced into the column reactor, part of it dissolves into solution to provide a possible oxidation process while the remaining escapes from the reactor, stripping some $CHCl_3$ and/or CHB_rCl_2 from the solution. Consequently chemical oxidation and physical purging of the two THM species are expected although the relative amount of removal by either process is not known. Nevertheless the overall removal is high and ozonation is considered a successful process for $CHCl_3$ and CHB_rCl_2 removal.

By comparison, the result of the air purging experiments is as promising as those of the ozone treatment. Chloroform can be removed at a slightly faster rate and CHB_rCl_2 at a slightly slower rate when the air flow rate is at 0.308 l/min.-l of solution. This flow rate is identical to the ozone gas flow rate used in ozone experiments. Since much less air dissolves into water than ozone does in the column reactor, air stripping is expected to be more efficient than stripping with ozone. However the ozone treatment process provides oxidation in addition to the physical stripping of the chemical compounds. The oxidation removal of CHB_rCl_2 more than makes up the decrease in removal due to stripping. The fact that air stripping alone removes $CHCl_3$ and CHB_rCl_2 at a rate comparable to the ozone treatment process clearly indicates that air stripping is a much more cost-effective process.

Ultraviolet radiation is proven to be ineffective for $CHCl_3$ removal. With a power input of 10.6-watt/l and an intensity of 15,800 uw/cm^2, only 19.4 percent to 27.8 percent removal is obtained after 150 minutes of exposure, leaving 111 to 209 ppb $CHCl_3$ in the solution, a concentration exceeding the limit of the drinking water quality standards. The removal rate is 0.0019 $min.^{-1}$. At this rate, it would take 20 hours of exposure time to reduce 300 ppb $CHCl_3$ down to 30 ppb. This low photolysis is not unexpected since $CHCl_3$ does not appreciably absorb radiation in the UV region.

Although CHB_rCl_2 is similar to $CHCl_3$ in its chemical structure, it behaves significantly different in that CHB_rCl_2 absorbs UV radiation strongly. This leads to a high rate of photolysis at 0.048 $min.^{-1}$ with the same power input of 10.6 w/l and UV intensity of 15,800 $\mu w/cm^2$. Ninety-seven percent removal is obtained in 80 minutes of exposure time. In a solution with a mixture of both $CHCl_3$ and CHB_rCl_2, each breaks down independantly at its own rate. This finding is similar to that in the ozone treatment process.

In the UV-ozone process, ozone oxidation of $CHCl_3$ and CHB_rCl_2 is not expected to take place since ozone is breaking down quickly into O_2 and O in the presence of UV. The oxygen atom combines with a water molecule to form H_2O_2. UV radiation then converts H_2O_2 into hydroxyl radicals.

$$O_3 + H_2O + h\nu \longrightarrow O_2 + H_2O_2$$

$$H_2O_2 + h\nu \longrightarrow 2OH^{\cdot}$$

Hydroxyl radicals are possibly the active species primarily responsible for the oxidation of $CHCl_3$ and CHB_rCl_2 with a possible chain reaction. Table 4 shows very low ozone residue concentration in the solution exposed to UV, indicating a rapid breakdown of ozone in the solution by UV. The removal of $CHCl_3$ or CHB_rCl_2 by ozone oxidation, if there is any, is therefore minimal. On the other hand the hydroxyl radicals are much more effective in oxidizing both $CHCl_3$ and CHB_rCl_2. By comparing the results shown in Tables 1, 3 and 4, it is seen that UV-ozone removes $CHCl_3$ at a rate of 0.075 min.$^{-1}$, which is 42-percent high than 0.053 min.$^{-1}$ for ozone treatment and 39 times as fast as 0.0019 min.$^{-1}$ for UV treatment. Similarily, UV-ozone removes CHB_rCl_2 at a rate of 0.096 min.$^{-1}$ which is a 2.3 times the rate of 0.042 min.$^{-1}$ for ozone treatment and 2.0 times the rate of 0.048 min.$^{-1}$ for UV treatment. This rate increase is particularly important for $CHCl_3$ treatment where UV radiation alone is ineffective.

In this study, the $CHCl_3$ concentration is much higher than the CHB_rCl_2 concentration, mimicking their respective concentrations found in various water supply systems. The ratio of the rates of the chain terminationreactions to propagation reactions is smaller when the chain carrier find it easier to locate the substrate $CHCl_3$. This explains why the increase of the rate of removal by UV-ozone over that by photolysis alone is much more for $CHCl_3$ than for CHB_rCl_2, a finding which is in agreement with the chain reaction hypothesis according to Glaze (ref. 10).

The power input and ozone dose rate in the UV-ozone process effective in the removal of $CHCl_3$ and CHB_rCl_2 are also effective in coliform kill. Table 5 shows complete kill of coliform with 30 minutes of exposure time. There is no doubt that a UV-ozone system designed for successful removal of THM species will be successful in coliform kill, resulting in a drinking water meeting both the TTHM concentration and coliform concentration standards.

CONCLUSION

Two major species of TTHM, $CHCl_3$ and CHB_rCl_2, which often constitute more than 95 percent of TTHM in drinking water supplies can be removed by air purging, ozonation, UV radiation, and UV-ozone. UV radiation alone removes $CHCl_3$ only at a very slow rate because the chemical does not appreciably absorb UV radiation. Both air purging and ozonation are moderately effective and remove TTHM at comparable rates. UV-ozone is the most effective process attested to by its fastest removal rate of 0.096 $min.^{-1}$ for CHB_rCl_2 (2.3 times the rate of removal by ozonation and 2.0 times the rate by UV radiation) and 0.075 min^{-1} for $CHCl_3$ (42 percent higher than the rate of removal by ozonation and 39 times the rate of removal by UV radiation). The increase of the removal rate by UV-ozone over that by photolysis alone is much more significant for $CHCl_3$ than CHB_rCl_2. Since a much higher $CHCl_3$ concentration is used in the study, this can be explained by a chain reaction hypothesis involving the active hydroxyl radicals which require higher THM concentrations to propagate the reactions.

UV-ozone process is also found to be very effective in coliform kill. The process therefore can be used for concurrent THM destruction and coliform kill to meet the drinking water quality standards.

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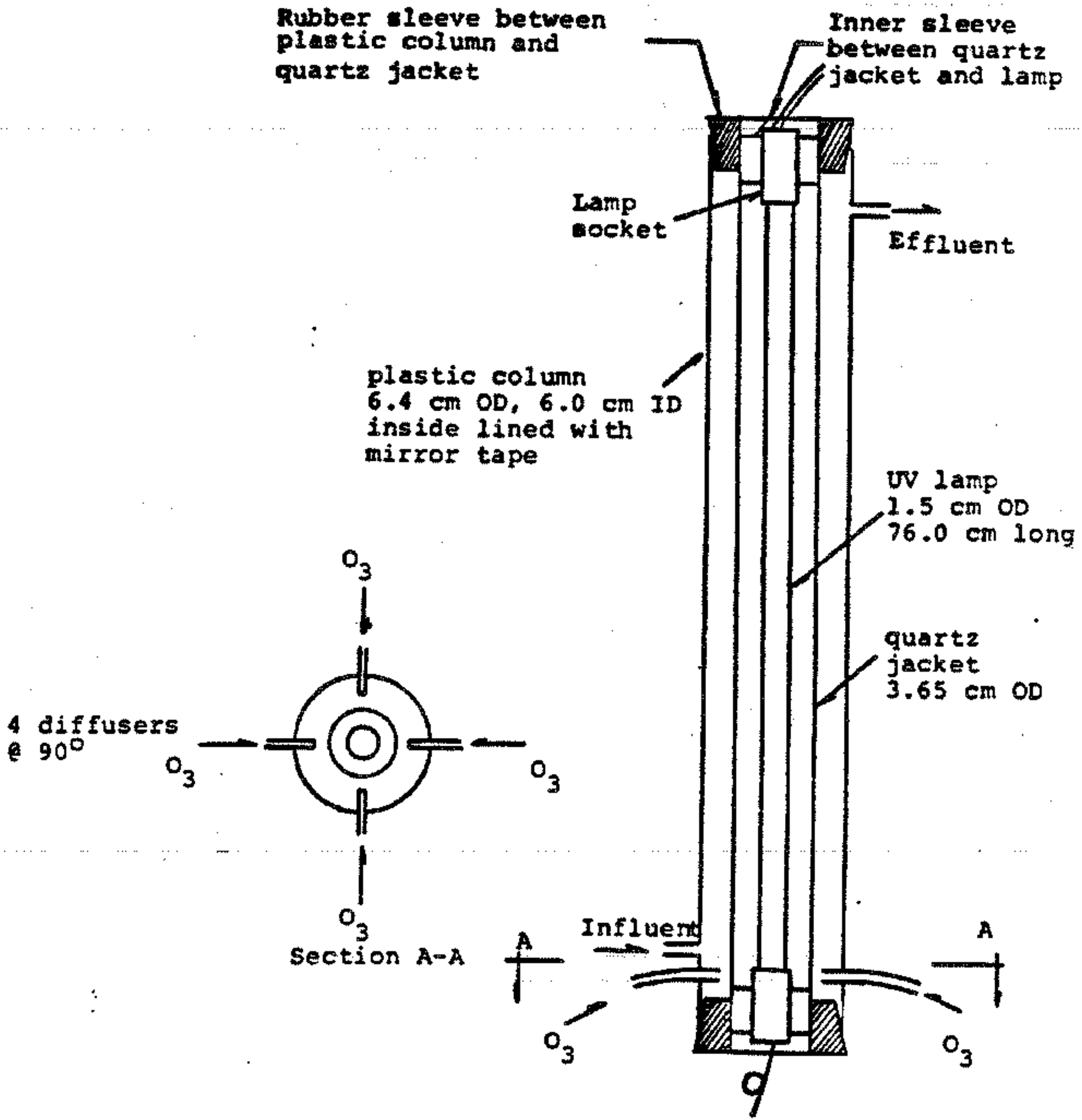

Section A-A

Cut-away view of column UV reactor

Figure 1

PHOTOCHEMICAL COLUMN REACTOR

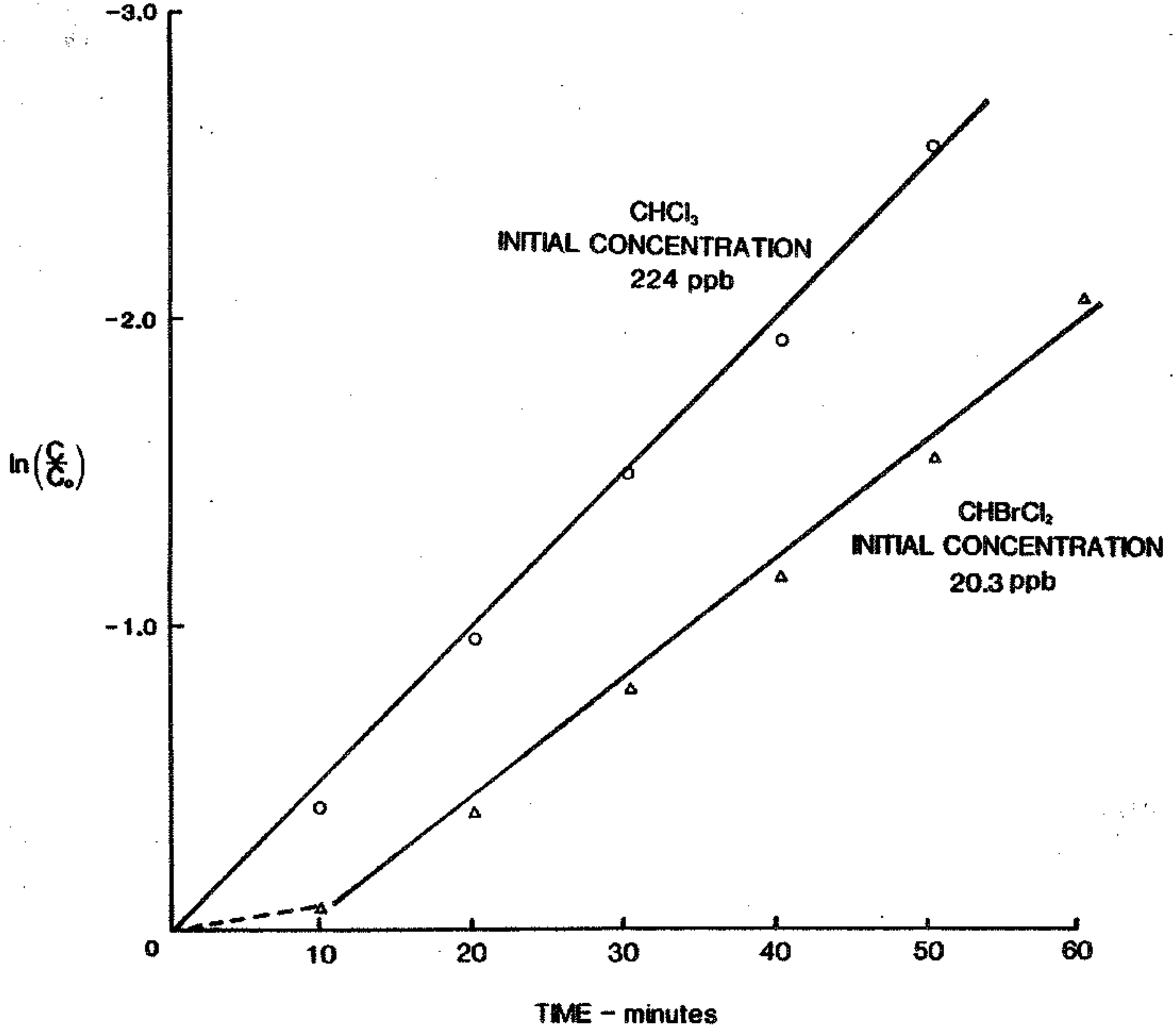

FIGURE 2– REMOVAL OF $CHCl_3$ AND $CHBrCl_2$ BY OZONATION

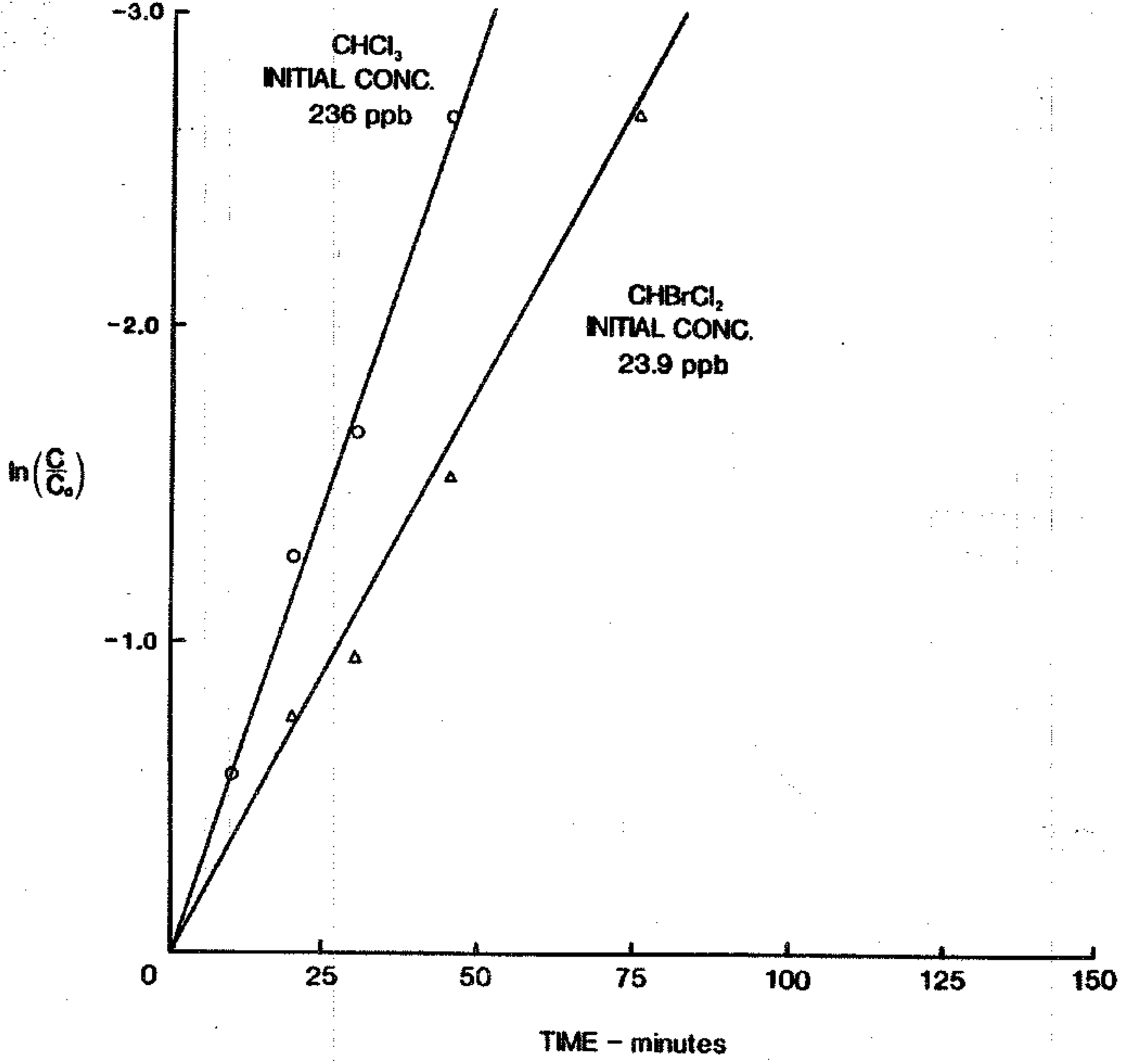

FIGURE 3– REMOVAL OF $CHCl_3$ AND $CHBrCl_2$ BY AIR PURGING

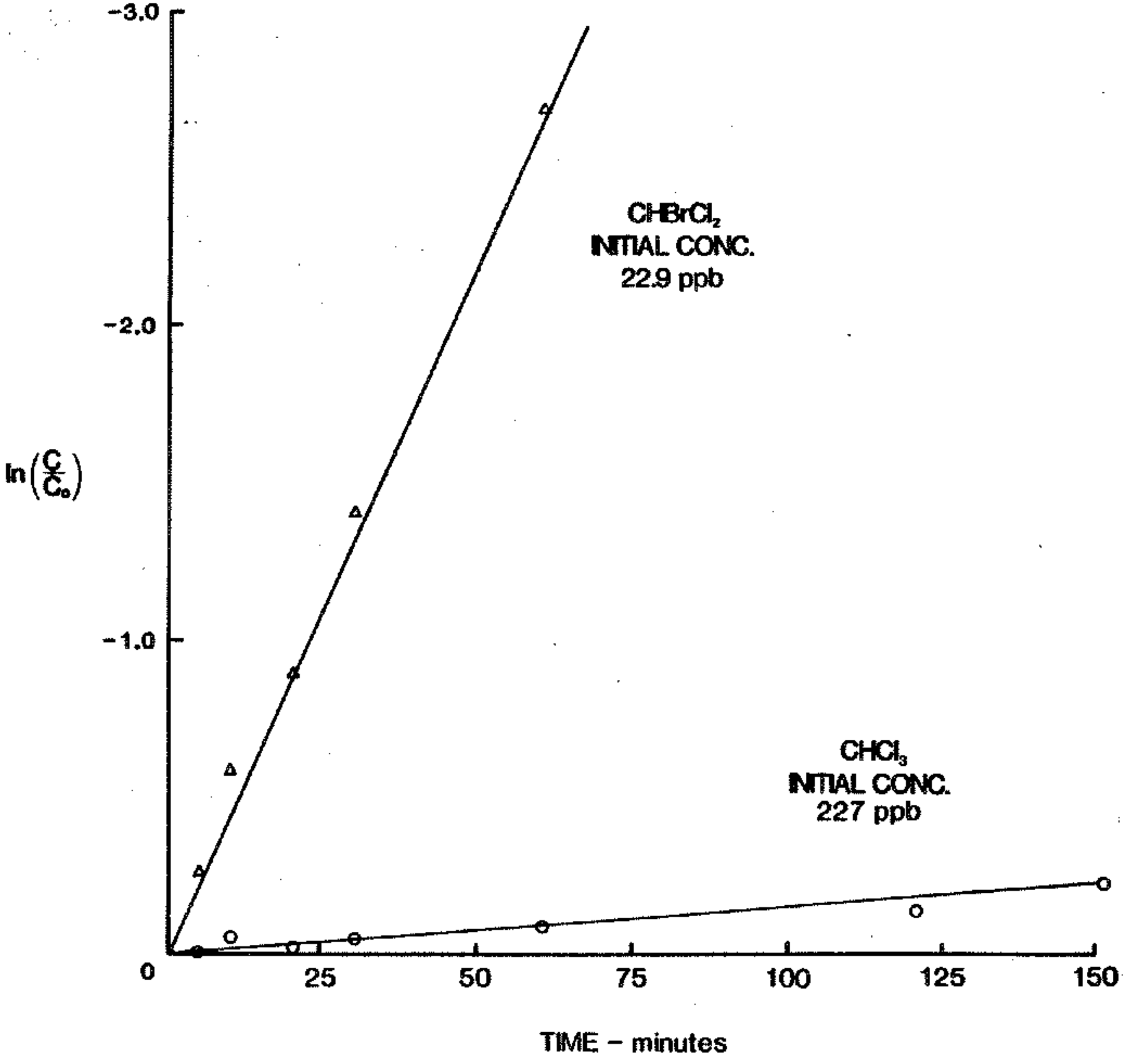

FIGURE 4– REMOVAL OF $CHCl_3$ AND $CHBrCl_2$ BY UV RADIATION

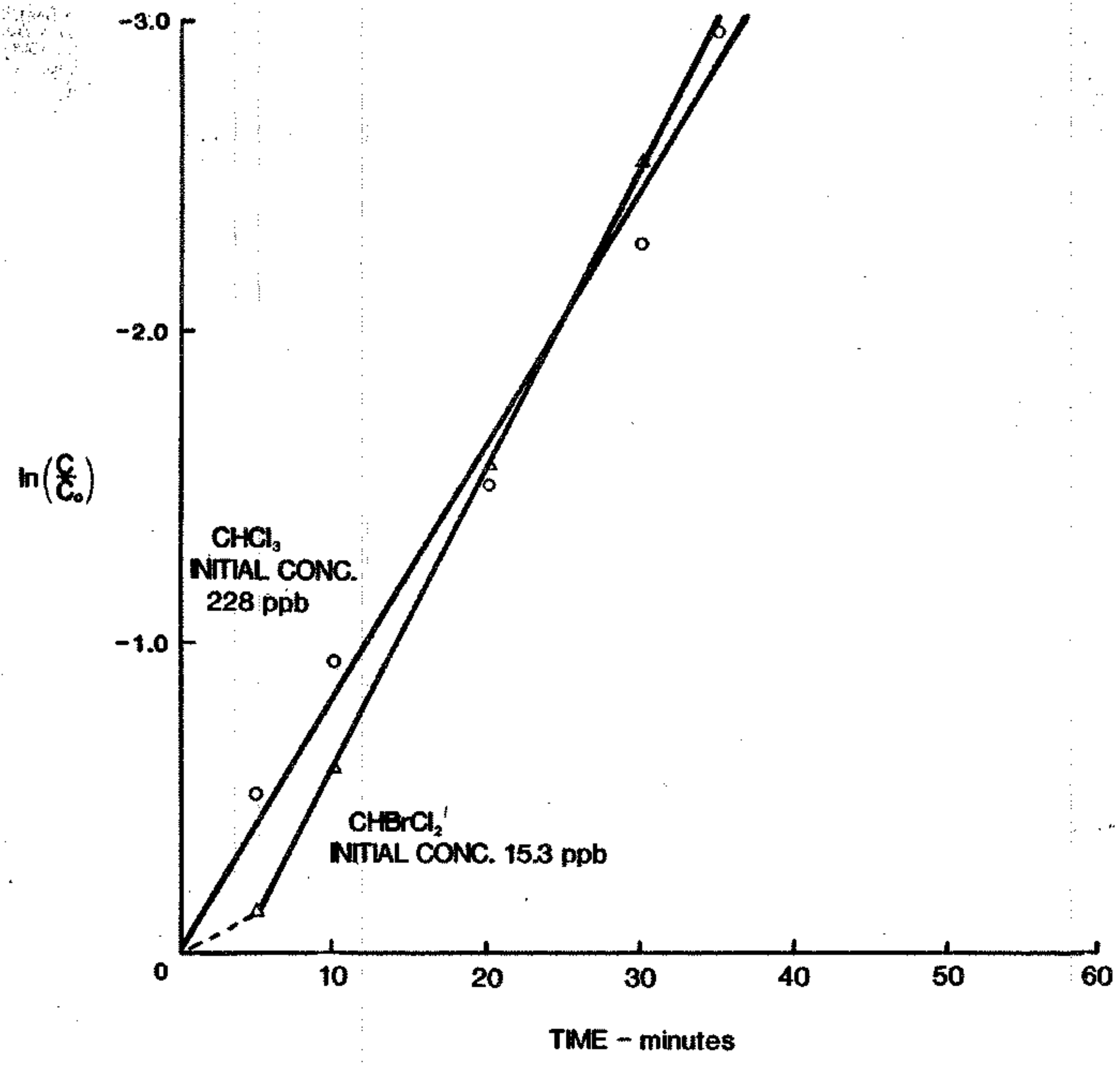

FIGURE 5– REMOVAL OF $CHCl_3$ AND $CHBrCl_2$ BY UV–OZONE

HYDROLOGIC IMPLICATIONS OF COAL MINING IN THE NARRAGANSETT BASIN, RHODE ISLAND

by

Daniel W. Urish
University of Rhode Island

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FOREWORD

This study is a part of a larger University of Rhode Island team effort to develop a State program for the regulation of environmental impact of coal mining in Rhode Island. The study was coordinated by the University of Rhode Island Energy Center in conjunction with the Rhode Island Department of Environmental Management. Funding support was provided by the U.S. Office of Surface Mining under OSM/DEM Grant No. 539928. Major assistance during the course of this study was provided to the Providence Office of the U.S. Geological Survey and the many city and town water supply agencies. Technical dissemination of this document is provided by the Rhode Island Water Resources Center at the University of Rhode Island.

HYDROLOGIC IMPLICATIONS OF COAL MINING
IN THE NARRAGANSETT BASIN, RHODE ISLAND

ABSTRACT

Geologic exploration of the Narragansett Basin has resulted in estimates of 17 million tons of anthracite coal in the Portsmouth, Rhode Island area alone. Additionally coal seams have been found in several other parts of the Basin. The hydrologic implications of coal mining are of great importance because of the high density of population in the coal mining regions. While most of the area is serviced by public water supply systems not likely to be affected by coal mining, smaller surface and ground water sources are highly vulnerable and could be adversely affected.

Hydrologic implications of mining can include disruption of drainage patterns, lowering of the ground water table, diminishing of stream flow, degradation of water quality and inducement of salt water intrusion. Beause of the potential irreparable harm that can be done, careful planning by state and municipal agencies is essential in advance of any mining operations. The collection of base line data prior to mining operations, and monitoring during and after mining is critical to avoiding adverse environmental impact.

Mining operations have a potential for direct degradation of surface water. Suspended sediment from coal processing and surface erosion must be controlled. Acid mine drainage is possible, but not likely because of the lack of framboidal pyrite in the Narragansett Basin rocks; however, site specific investigation and predictions should be made.

In the coastal regions of the Narragansett Basin, lowering of the water table by mine dewatering could cause salt water intrusion with severe consequences to wells in the affected area. Since salt water

bodies exist within a few miles of any prospective mining operations, Rhode Island coal mining regulations should include specific provisions to guard against ground water contamination by salt water intrusion.

HYDROLOGIC IMPLICATIONS OF COAL MINING IN THE NARRAGANSETT BASIN, RHODE ISLAND

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HYDROLOGIC IMPLICATIONS OF COAL MINING IN THE NARRAGANSETT BASIN, RHODE ISLAND

INTRODUCTION

PURPOSE

The purpose of this report is to evaluate the hydrologic implications of coal mining in the Rhode Island portion of the Narragansett Basin. The scope includes a general discussion of the current hydrology and water use in the Basin as well as the implications of coal mining activity.

SIGNIFICANCE

Geologic exploration and evaluation of the Pennsylvanian sedimentary rocks of the 900 square mile Narragansett Basin (Fig. 1) has produced resource estimates of 17.08 million tons of anthracite material in the eastern and western part of the Portsmouth, Rhode Island area (Shehan et al., 1981). In addition, test holes have indicated coal seams in the Barrington area of Rhode Island (Frimpter and Maevsky, 1979). According to Shehan et al. (1981) the incompetency of the roof and floor rock would tend to preclude underground mining methods; however surface mining, such as the open pit method would be feasible. The significant implications of such mining to the hydrology of a region are:

A. disruption of surface water levels and drainage

B. disruption of groundwater levels and flow patterns

C. depletion or reduction of groundwater

D. inducement of salt water intrusion

E. degradation of water quality

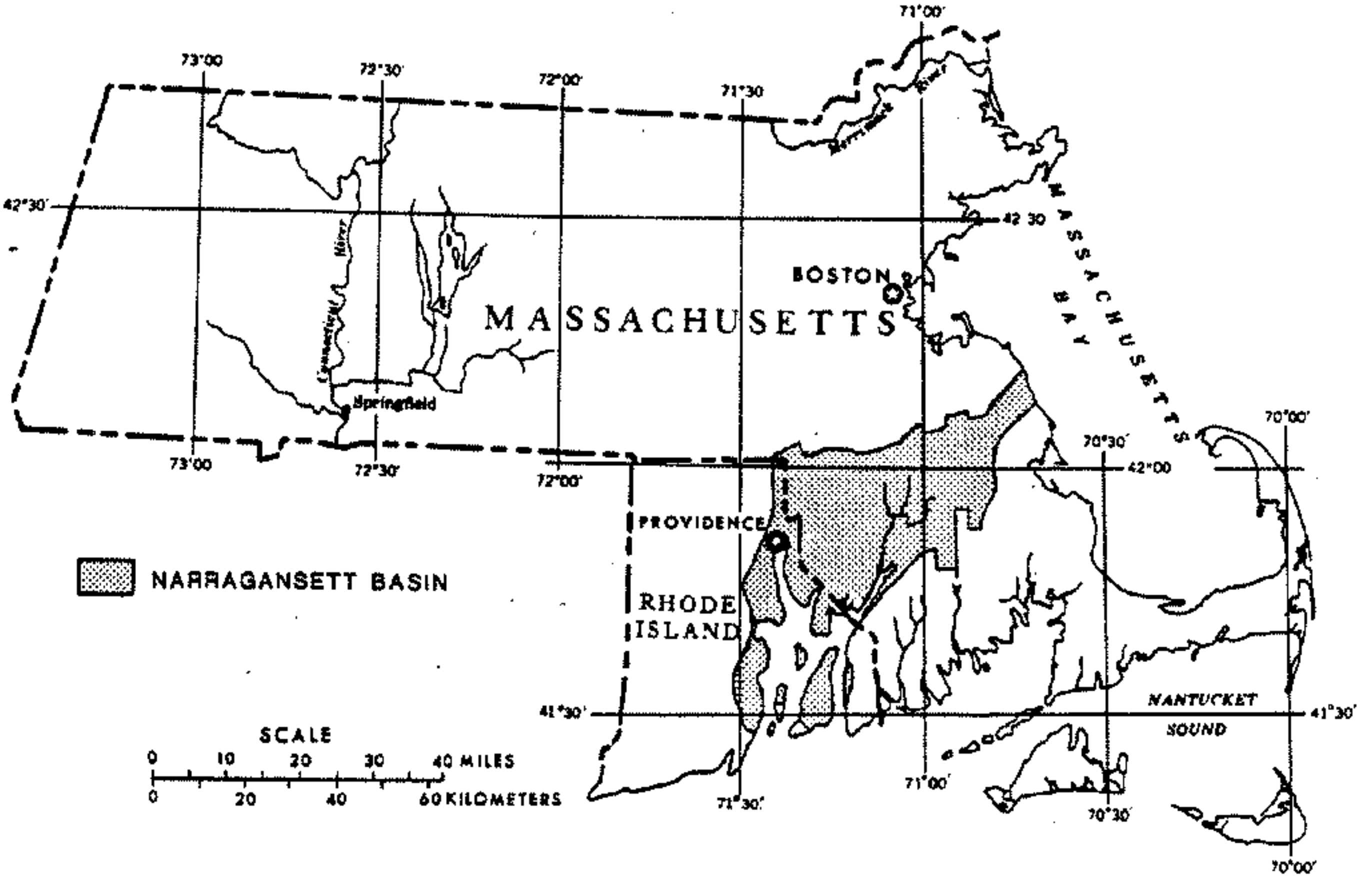


FIGURE 1. Location map of Narragansett Basin (from Frimpter and Maevsky, 1979)

PRESENTATION

This report discusses the hydrologic implications of coal mining in three main divisions. First the natural and existing conditions in the Narragansett Basin are presented, including the interrelation of surface and ground water as a part of the hydrologic cycle, and a description of existing water supply systems is included. Secondly the possible effects of mining on levels of surface water and groundwater, the potential for salt water intrusion and the degradation of water quality mine acid water and suspended sediment from mining excavations are considered. Lastly a review is made of applicable regulations and water law, and mine control recommendations are made.

NARRAGANSETT BAY HYDROLOGY

CLIMATE

Average annual precipitation in the Narragansett Basin, based on the period 1940-1956 is 42.7 inches (Lang, 1961). The average annual precipitation tends to be lower in the basin than in the rest of Rhode Island as shown in Figure 2. At all eight stations located in the Basin, rainfall is fairly uniformly distributed throughout the year. November is normally the wettest month having a mean precipitation of 4.83 inches, and June is the driest month, having 2.56 inches. There is however, great variability evidenced in the record for indcidual months and years. As an example, June 1982, normally the driest month, had a record 14.35 inches of rainfall; the minimum is 0.04 for the Kingston station. Mean annual precipitation has ranged from 30.69 inches in 1965 to 72.22 inches in 1898 at Kingston, a station with 93 years of record.

The mean annual air temperature is slightly above 50°F, the regions nearest the water being somewhat moderated as compared to inland stations. The coldest month normally occurs in February with a mean temperature of about 29°F in the Upper Narragansett Bay region and the hottest in July with a mean of about 73°F. Extremes of record at Providence (T.F. Green Airport) range from -17°F to 102°F.

Water is lost to the atmosphere by evapotranspiration, a term combining evaporation from land and water surfaces, and the transpiration of plants. Evapotranspiration is largely controlled by air temperature. During the winter or the nongrowing season when temperatures are low, evapotranspiration is very little. But as air temperature rises and the growing season starts, evapotranspiration increases rapidly, reaching a maximum in July or early August. Water loss by evapotranspiration in a

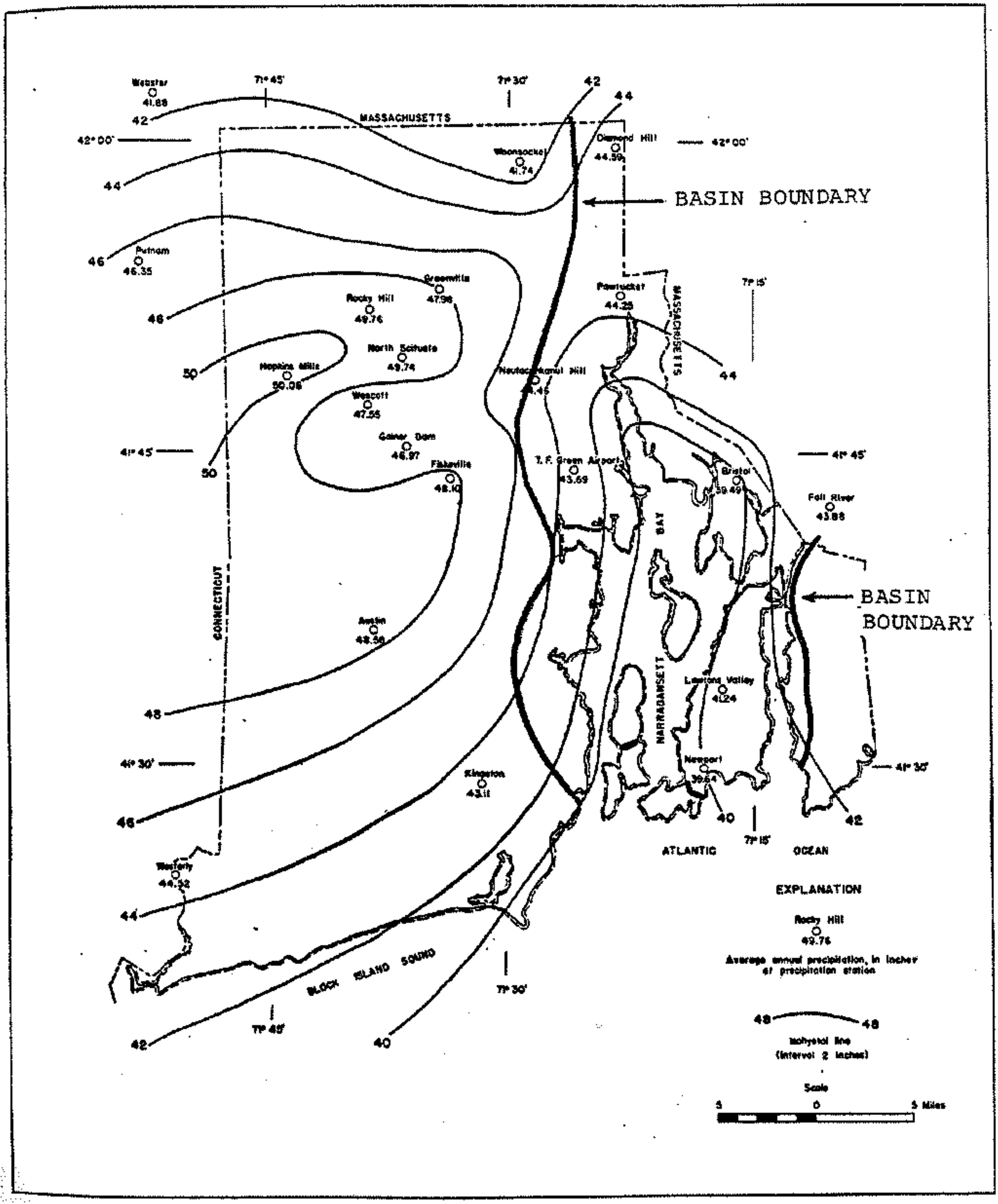


FIGURE 2. Average annual precipitation in Rhode Island (after Lang, 1961)

drainage basin is the difference between the precipitation over the basin and the runoff from the basin, including changes in surface and underground water storage for a given period. In humid regions a good estimate of annual evapotranspiration can be obtained by relation to average annual air temperature (Langbein et al., 1949). For the Narragansett Basin the evapotranspiration thus obtained is 24 inches.

HYDROLOGIC CYCLE

Precipitation, evapotranspiration, groundwater and surface water are all interrelated in a complex dynamic system termed the hydrologic cycle. The hydrologic cycle is the circulation of water from the sea, through the atmosphere, and back to the sea by various overland and subterranean routes. This cycle is illustrated in Figure 3 for a coastal area. In evaluating the impact on any of the components on the hydrologic cycle, the interrelation of all others must be considered.

The interrelation can be illustrated by examination of the effect on ground water recharge during a drought year, that is a year in which precipitation is 15% below normal. For the Narragansett basin this would be 36.3 inches of precipitation. Evapotranspiration would continue at about 24 inches, leaving only 12.3 inches for surface runoff and groundwater recharge as compared to a normal 18.7 inches. The most significant effect is likely to be on the groundwater levels, depending on the particular pattern of the drought. Additional stresses such as dewatering of mine excavations may greatly aggrevate the effect on wells and diminished streamflow.

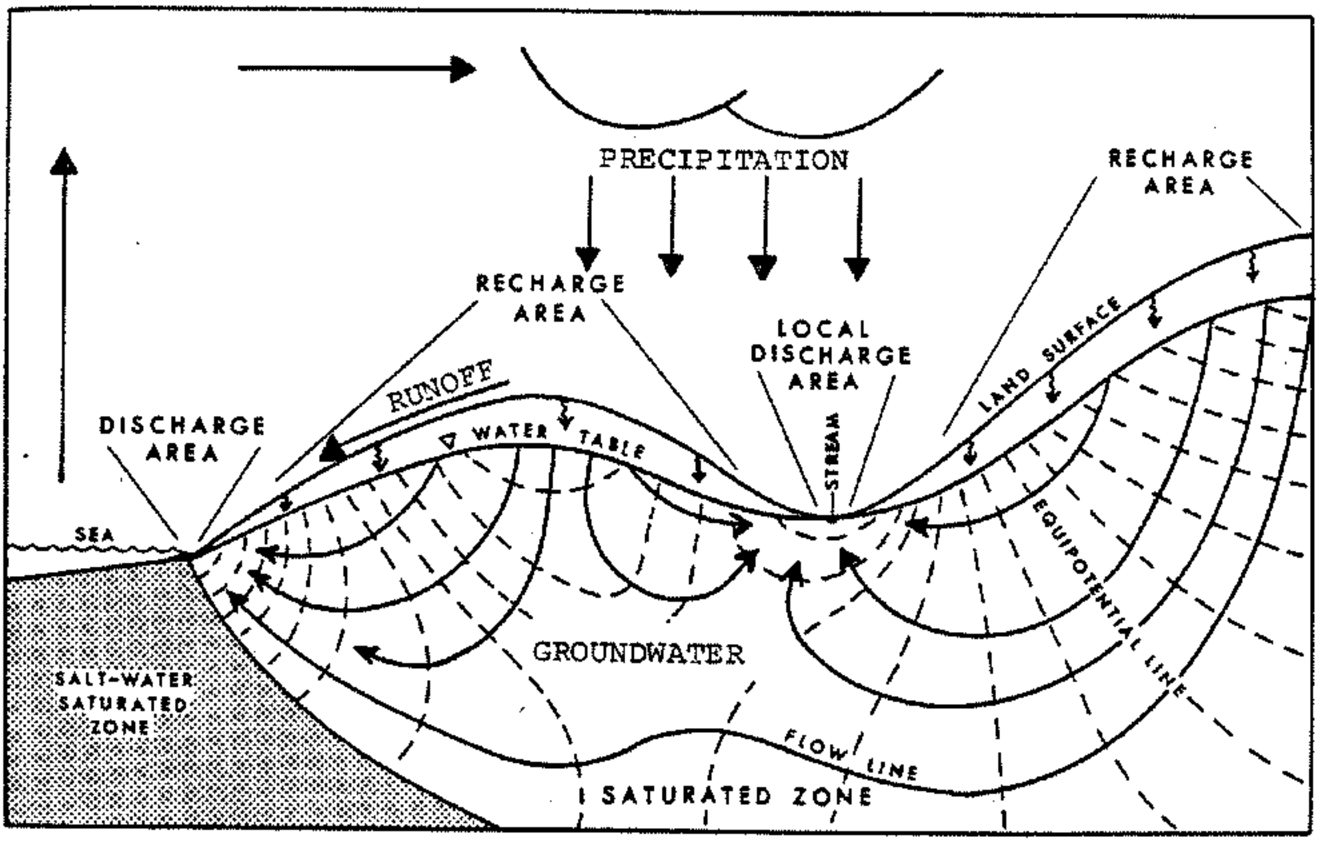


FIGURE 3. Hydrologic cycle and groundwater circulation (from Frimpter and Maevsky, 1979)

SURFACE WATER

An inventory of Rhode Island Lakes and Ponds (WRB, 1974) lists 357 fresh water impoundments. Of this an estimated 15 to 20% lie within the Narragansett Basin. Most are relatively small, less than 50 acres in surface area. Many are an essential part of public water supply systems as will be discussed later. In general these water bodies are visible manifestations of the water table in the area, and are connected hydraulically to the groundwater. Therefore any effect on groundwater levels or quality may be important to ponds and lakes in the area and vice versa.

Innumerable streams flowing into the Bay drain the Narragansett Basin. The largest of these are in the upper Basin area and include the Providence River formed by the confluence of the Woonasquatucket and Mohassuck Rivers, Blackstone River, Ten Mile River, Barrington River, Warren River, Kickamuit River, and Pawtuxet River. In the south Bay the most significant streams are Hunt-Potowomut River, Annaquatucket River and Narrow River. About three-fourths of the land area of the State, almost 800 square miles, is tributary to Narragansett Bay. Many of the streams of the State have their headwaters in the northwest uplands, where they occupy narrow, steep sloping valleys. In the lowlands, these streams generally are sluggish and meandering; and in the vicinity of the bay or ocean, they form fairly wide tidal estuaries.

Most of the coastal rivers are tidal to some extent bringing salt water in the lower parts of the stream channel well up into the land interior. Even though a groundwater location may be miles away from the bay coastline, if it is on a tidal river, salt water intrusion is a strong possibility. The position of salt water depends both on the depth of the channel and the freshwater outflow, hence generally moves up and down the length of a natural stream seasonally.

Most streams in Rhode Island are considered effluent streams, that is streams which are lower than the surrounding water table and collect groundwater outflow. In late summer when precipitation runoff is greatly reduced the primary flow of these streams is contributed by groundwater. The quality of the water during low flow periods is directly indicative of ground water quality.

Lowering of the water table, such as by pumping, in proximity to a stream may reverse the gradient and induce infiltration of stream water into the ground. These can have consequences of groundwater contamination if the stream water is of poor quality as well as reduced stream flow. Thus in conducting subsurface operations near a stream it should be assumed that stream and groundwater are hydraulically connected.

GROUNDWATER

In consideration of the effects mining may have in the Narragansett Basin, the groundwater implications are potentially of greatest significance because of the large number of wells in the basin.

The following is taken from Lang (1961):

> "The water-bearing formations that comprise the underground reservoirs of an area are called "aquifers." They differ greatly in thickness and extent. Two important factors, among others, govern the amount and availability of water in an aquifer. One is the porosity of the aquifer, that is the ratio of pore space to the total volume of the aquifer, expressed as a percentage. The porosity determines how much water the formation can hold. The other factor is the permeability of the aquifer, which determines how freely water can move through

it. Permeability and porosity thus are not synonymous. For example, clays that make up a large part of the till aquifers in Rhode Island are highly porous and can hold a great deal of water, but the pore spaces in the clay are so small that the water in them is locked into place by molecular forces. Hence wells drilled into clayey deposits may yield water at relatively low rates. The ratio of the volume of water that saturated material will yield to the total volume is known as the specific yield and is stated as a percentage. The beds of sand and gravel in the outwash are the most permeable aquifers of the state.

The openings in the unconsolidated rocks are known as "original or primary openings," because they were formed as the grains of material that compose their walls were deposited. "Secondary openings," on the other hand, are those which were formed after the rocks were deposited, by stresses that accumulated until the rocks were ruptured. Open joints or fractures in consolidated rocks are examples of this type. Joints and fractures commonly occur in sets, in which the individual joints are more or less parallel. In many places two or more sets of joints intersect each other. They are generally most numerous near the surface, becoming fewer in number and narrower in width with increasing depth. Where joints are numerous and open they not only allow relatively free movement of groundwater, but also permit the storage of moderate quantities of water.

Openings may occur also along bedding planes in sedimentary rocks. In the rocks of Carboniferous Age of the Narragansett Basin the water tends to be concentrated in and transmitted along the bedding planes. Bedding planes probably do not exist as actual cavities visible to the eye, but rather as narrow openings along planes of parting. Wells that intersect bedding planes draw part of their water at such horizons."

The specific characteristics of aquifers in the Narragansett Basin are summarized in Table 1. It is to be noted that well yields may vary from as little as 1 gallon per minute (gpm) in rock to 1300 gpm in glacial outwash. Glacial outwash, because of its productivity, is by far the most important water bearing material in the Narragansett Basin. Plate 1 shows the areal distribution of glacial outwash in the Narragansett Basin and the location of major wells. Also shown on Plate 1 is the theoretical radius of influence for the well assuming a table aquifer receiving a recharge of 10 inches/year. It is emphasized that this is theoretical and intended only to give an indication of the relative magnitude of effect from pumping at maximum yield <u>not</u> to show actual limits of influence.

Groundwater occurs in the Narragansett Basin in three general categories of geologic material: glacial outwash, glacial till and bedrock. The approximate distribution of till and outwash is shown in Figure 4. The bedrock in the Narragansett Basin is sedimentary rock. The hydrologic characteristics of each of these geologic materials is described in detail in Appendix A.

TABLE 1 HYDRAULIC CONDUCTIVITY, WELL YIELD AND TRANSMISSIBILITY OF AQUIFERS IN THE NARRAGANSETT BASIN

LOCATION (QUAD)	TYPE OF MATERIAL	HYDRAULIC CONDUCTIVITY (FT/DAY) OR WELL YIELD (gpm)	AQUIFER THICKNESS (FT)	TRANSMISSIBILITY (AVERAGE) (FT^2/DAY)	REFERENCE
Bristol	O	780 ft./day	60 (ave.)	46,500	Bierschenk, 1954
E. Greenwich	O	130-530 ft./day	0-215	35,790	Allen, 1956
E. Providence	O	300-1300 gpm	0-130		Allen & Gorman, 1959
	T	2-3 gpm	0-55		
	R	5-20 gpm	-		
Fall River	O	100-35 gpm	0-370		Allen & Ryan, 1960
	T	2-3 gpm	20-60		
	R	2-500 gpm	158 ave.		
Narragansett Pier	O	20-300 gpm	0-190		Hahn, 1959
	T/O	25-400 gpm	0-98		
	R	7 gpm (ave.)	173 (ave.)		
Newport	T	12 gpm	0-75		Schiner & Gonthier, 1965
	R	1-55 gpm	14-1300		
Providence	O	214-441 ft./day	29-90	6150-40,100	Biershenk, 1959
Prudence Is.	O	129 gpm	0-25		Schiner & Gonthier, 1965
Tiverton	R	1-75 gpm	12-478		Schiner & Gonthier, 1965
Wickford	O	30-800 gpm	0-135		Johnson & Marks, 1959
	T	3-4 gpm	0-41		
	R	6-10 gpm	140 ave.		
Wickford	G	468 ft./day	20-120	1340-40,000	Rosenshein, Gonthier & Allen, 1968
	S&G	200 ft./day			
	S	107 ft./day			
	FS	54 ft./day			

<u>Key to Type Material</u>

O - outwash
T - till
R - rock
G - gravel
S - sand
FS - fine sand

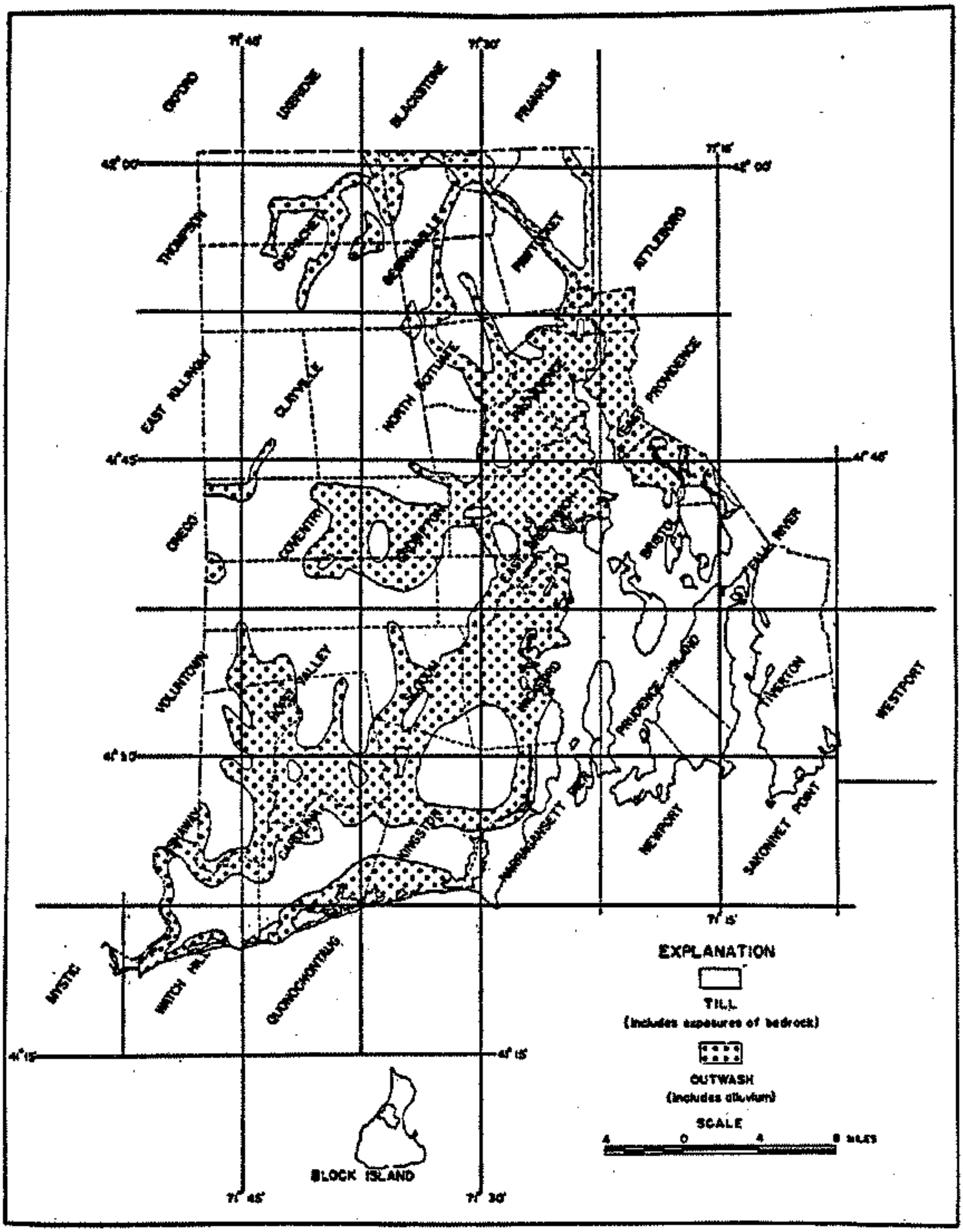


FIGURE 4. Approximate areal distribution of till and outwash deposits in Rhode Island (from Allen, 1953)

WATER SUPPLY IN THE NARRAGANSETT BASIN

WATER SYSTEM COVERAGE

There are twenty one Rhode Island cities and town lying wholly or in part in the Narragansett Basin. The total population in the Narragansett Basin is estimated at 494,000, based on 1980 U.S. Census figures. Most of the developed area in the Basin has public water service. However, there are notable exceptions, such as Jamestown, where one fourth of the population (1000 persons) is dependent on private wells. The areas served by public water systems based on the status as of 1980 are identified on Plate 2. A summary of the Narragansett Basin water supply systems is provided in Table 2.

SOURCES

The source of water for public water supply systems falls in three categories: water from surface reservoirs, groundwater from wells, or transfer water from other systems. A very large amount of transfer water used in the basin, probably about 60% of the total, comes from the Scituate Reservoir Complex, located approximately 6 miles to the west of the Basin. The remainder of the water comes from small reservoirs in or near the areas served, or from large capacity wells. The location of these sources is shown in detail on Plate 3. Table 3 provides a detailed listing of Narragansett Basin surface public water supply locations, and Table 4 is a detailed listing of public water supply wells. The information has been gleaned from a wide variety of references as noted, and verified to the extent possible by direct query to the water system managers.

While coverage of the Narragansett Basin by public water supply systems is fairly complete, it should be recognized that many private and

TABLE 2 NARRAGANSETT BASIN WATER SUPPLY SYSTEMS

SYSTEM NAME	WRB No.	LOCATION SERVED QUADRANGLE	SUPPLY TYPE[2]	SOURCE LOCATION	PERSONS SERVED[1]	QUANTITY (1980-MGD)[1]
Bristol Cnty Water Co.	2	Bristol Fall River	SW GW	Warren Barrington	47,000	4.04
Cumberland Water Dept.	3	Franklin Pawtucket	SW GW	Warren Barrington	18,300	2.12
E. Providence Water Division	4	E.Providence	TW	Providence	50,980	6.10
Jamestown Water Co.	8	Wickford Prudence Is Narra. Pier Newport	SW	Jamestown	3,500	0.19
Kent County Water Author.	9	E. Greenwich	GW GW TW	E. Green. W. Warwick Providence	88,000	8.46
Lincoln Water Dept.	11	Pawtucket	GW TW	Lincoln Providence	15,000	2.62
Narragansett Water Dept.	12	Narragansett Wickford	TW	Narra.	6,300	0.84
Newport Dept of Water	13	Newport Prudence Is	SW SW	Middletown Portsmouth	60,000	6.37
N. Kingstonwn Water Dept.	14	Wickford E. Greenwich	GW	N. Kingst.	20,000	2.39
N. Tiverton Dist. Water	15	Fall River	TW	Fall River	2,200	0.31
Pawtucket Water System	17	Pawtucket	SW GW	Pawtucket Pawtucket	106,000	13.30
Portsmouth Water & Fire District	18	Prudence Is Tiverton	TW	Newport Tiverton	12,100	0.38 0.69
Providence Water Supply Bd	19	Providence	SW	Scituate	450,000	63.58

TABLE 2 NARRAGANSETT BASIN WATER SUPPLY SYSTEMS (Continued)

SYSTEM NAME	WRB No.	LOCATION SERVED QUADRANGLE	SUPPLY TYPE[2]	SOURCE LOCATION	PERSONS SERVED[1]	QUANTITY (1980-MGD)[1]
Prudence Utilities Corp.		Prudence Is	GW	Prudence Is		
S. Kingstown Bd of Water Commissioners	21	Narra. Pier	GW	So. Kingst.	3,000	0.24
Stonebridge Dist. Water	22	Tiverton Fall River	SW	Tiverton	7,000	0.83
Wakefield Water Co.	23	Narra. Pier	GW	S. Kingst.	15,000	2.07
Warwick Water Dept.	24	E. Greenwich	TW	Providence	78,500	7.24

Notes: 1. Figures are for total system, including Narragansett Basin Use

2. SW - surface water; GW - ground water; TW - transfer water from another water system

TABLE 3 NARRAGANSETT BASIN SURFACE PUBLIC WATER SUPPLIES

SYSTEM	RESERVOIR NAME	LOCATION			AVERAGE DEPTH (FT)	AREA		SYSTEM STORAGE CAPACITY (MG)	REFERENCE	NOTES
		QUADRANGLE	LATITUDE	LONGITUDE		SURFACE (ACRES)	BASIN (SQ. MI)			
Bristol County Water Company (4 Reservoirs in Palmer and Kickemuit Basins)	Anawan (Mass)	Somerset			4.9	126	32.6		1,6,6	ARTIFICIAL (1912)
	Shad Factory (Mass)	E. Prov.			2.4	50		460		ARTIFICIAL (1883)
	Swansea (Mass)	Somerset			6.1	77	4.9		6	ARTIFICIAL (1912)
	Warren (Kickamuit)	Bristol	41°44'00"	71°16'00"	2.1	50			2,3,6	ARTIFICIAL (1883)
Cumberland Water Company	Sneech Pond *	Pawtucket	42°10'00"	71°27'00"	12.0	55	2	215 (est.)	1,2,3	NATURAL
Jamestown Water Company (2 reservoirs)	Carr Pond (North)	Prudence Is.	41°31'50"	71°22'30"	-	26	0.3	50	1,4	ARTIFICIAL
	Watson Pond (South)	Wickford	41°30'50"	71°23'00"	-	6	0.7	8	1,4	ARTIFICIAL
Newport Dept. of Water (8 reservoirs)	Lawton Valley Res.	Prudence Is.	41°33'40"	71°16'40"	29.3	84	1.1	377	1,3,6	ARTIFICIAL (1941)
	Sisson Pd.	Prudence Is.	41°33'00"	71°16'40"	5.7	90	0.4	77	1,3,6	ARTIFICIAL (1900)
	St. Marys Pd.	Prudence Is.	41°33'00"	71°16'20"	8.9	117	0.8	307	1,3,6	ARTIFICIAL
	Green End Pd.	Newport	41°30'00"	71°17'40"	8.0	257	4.0	516	1,3,6	ARTIFICIAL
	Nelson Pd.	Newport	41°29'30"	71°16'00"	10.2	29	0.6	95	1,3,6	ARTIFICIAL
	Gardner Pd.	Newport	41°29'30"	71°15'30"	9.8	101	2.2	341	1,3,6	ARTIFICIAL
	Nonquit Pd.	Tiverton	41°33'30"	71°11'40"	5.0	178	6.0	400	1,2,3,6	ARTIFICIAL
	H. E. Watson Pd. *	Tiverton	41°32'20"	71°10'40"	13.0	375	3.7	1300	1,2,3,6	ARTIFICIAL
										ARTIFICIAL
Pawtucket Water System (2 reservoirs)	Diamond Hill Res. (Upper)	Pawtucket	42°00'00"	71°24'00"	17.3 +10?	257		2606 (est.)	1,2,3	ARTIFICIAL (1885)
	Arnold Mills Res. (Lower)	Pawtucket	42°59'00"	71°24'00"	14.8	240			1,2,3	ARTIFICIAL (1928)
Storebridge Fire Dist. Water Dept.	Stafford Pd. *	Tiverton Fall River	41°38'30"	71°09'40"	10.0 (26.0 mx)	476		1551 (est.)	2,3	NATURAL

NOTES:

A. *outside Narragansett Basin

B. REFERENCE KEY
1. GB 6 , Groundwater Resources of RI, Allen, 1953
2. 208 Study, Water Quality Managment Plan, SWP,1979
3. Task EIGHT, RI Lakes and Ponds, WR7, 1974
4. Jamestown, Water Supply Study, Hazen, 1982
5. GB7, Groundwater Resources of Bristol Quad, Bierschentz, 1954
6. User information

TABLE 4 NARRAGANSETT BASIN PUBLIC WATER SUPPLY WELLS

SYSTEM	WELL NUMBER	LOCATION LATITUDE	LOCATION LONGITUDE	AQUIFER MATERIAL	DEPTH (FT)	CAPACITY (GPM)	REFERENCE
Bristol County	BAR 111	41°43'30"	71°22'30"	G	83' to BR	694	1,2
Water Company	BAR 119	41°43'30"	71°23'00"	S,G	88' to BR	820	1,2
(3 wells)	BAR 178						
Cumberland	CUM 405	41°55'01"	71°24'35"	S	60'	390	4
Water Dept.	CUM 407	41°57'09"	71°23'03"	G	71'	425	4
(5 wells)	CUM 409	41°57'57"	71°27'51"	G	75'	1080	4
				G	118' to BR	2700	2
Kent County	WAR 33	41°41'00"	71°28'00"	S,G	118' to BR	2700	3
Water Authority	WAR 667						
(7 wells)	EGR 3	41°37'45"	71°28'10"	G	107' to BR	1500	3
	COV 405	41°40'30"	71°35'30"	S,G	79'	1000	5
	COV 448	41°39'50"	71°38'0"	S,G	87	391	5
	COV 461	Mishnock					
	COV 462	Mishnock					
Lincoln	LIN 335	41°53'15"	71°24'42"	G	107'(110' to BR)	1080	4
Water Dept.	LIN 342 (2)	41°54'07"	71°24'20"	G	136' to BR	1400	4
(8 wells)	LIN 383 (1)	41°55'15"	71°25'28"	G	62'	650 (NIU)	4,8
	LIN 417 (3)	41°58'05"	71°27'58"	S,G	55'		4
	LIN 418 (4)	41°54'08"	71°24'18"	S	142'	708	4
	LIN 419 (5)	41°58'07"	71°27'58"	S,G	54'	726	4
	LIN 420 (6)	41°55'14"	71°25'25"	G	46'	1000 (NIU)	4,8
	(10)	41°58'	71°27'	S,G	95'	800	8
	(11)	41°54'	71°23'	S,G	120'	1400	8
North Kingston	NOK 26	41°33'30"	71°28'40"	G	50'	1000	2,6
Water Dept.	NOK 1156	41°33'10"	71°29'00"				6
(7 wells)	NOK 1235	41°31'15"	71°27'01"	S,G	67'	1000	7
	NOK 1297						
	NOK 1298						
	NOK 1299			0	85'	950	7

TABLE 4 NARRAGANSETT BASIN PUBLIC WATER SUPPLY WELLS (Continued)

SYSTEM	WELL NUMBER	LOCATION LATITUDE	LOCATION LONGITUDE	AQUIFER MATERIAL	DEPTH (FT)	CAPACITY (GPM)	REFERENCE
North Tiverton	TIV 1				12.6	NIU	8
Fire District	TIV 47	41°38'00"	71°11'30"	S,G	27' to BR	NIU	2,8
(3 wells)	TIV 130	41°40'00"	71°11'00"	S,G	18' to BR	20 NIU	2,8
(use discontinued, 1965)							
Pawtucket							
Water Dept.							
(10 wells)	CUM 381	41°54'12"	71°23'12"	S,G	57'	726	4
	CUM 418	41°54'20"	71°23'04"	S,G	68' (69' to BR)	703	4
	CUM 440	41°54'36"	71°23'00"	G	81'	703	4
	CUM 441	41°54'37"	71°23'02"	S,G	57'	703	4
	CUM 340						
	CUM 420						
	CUM 423						
	CUM 424						
	CUM 427						
Prudence	POR 235	41°36'10"	71°19'30"	R	221' (13' to BR)	40	2
Utilities Corp.	POR 236	41°36'00"	71°19'30"	R	300' (16' to BR)	5	2
?(6 wells)	POR 237					Well Field	7
	POR 238	41°35'20"	71°19'30"	R	120' (20' to BR)	7	2
	POR 239	41°37'15"	71°19'30"	S,G	4'	275	2
	POR 240	41°37'20"	71°19'30"	S,G	24'	275	2
	POR 241	41°36'00"	71°19'30"	R	280' (23' to BR)	16	2

NOTES:

A. Code S - Sand
G - Gravel
U - Unconsolidated Sediment
R - Rock
NIU - Not in use
( ) - Level well number

B. Reference Key
1. (Bierschank, 1954)
2. (Allen, 1953)
3. (Allen, 1956)
4. (Johnson and Dickerman, 1974)
5. (Gonthier, 1966)
6. (Johnson and Marks, 1959)
7. USGS Files, Providence, R.I. Office
8. Water Agency Information

small industrial wells exist even in covered areas. These wells are frequently used for supplement supply. Therefore, any alternate use, or effect on, groundwater by mining activity must also take these wells into consideration.

CITY AND TOWN WATER SUPPLY PROFILES

The following is a brief description of water supply systems by towns. The information is taken principally from the 1977 Water Quality Management Plan for the Narragansett Bay Basin (Swp, 1977). Population figures are from the preliminary 1980 U.S. Census Report.

1. Town of Barrington (population 16,181)

Water supply is provided by the Bristol County Water Company from three wells located in the town.

2. Town of Bristol (population 20,165)

The northwest half of the town lies in the Basin. The Bristol County Water Company provides public water to most of the areas where concentrated development exists in the community. Sources are both groundwater and surface water.

3. City of Central Falls (population 16,901)

The entire City is served by a public water system supplied by the City of Pawtucket water system. Sources are groundwater and surface water.

4. City of Cranston (population 71,936)

The east half of the City lies within the Basin. With the exception of western Cranston, which has no water distribution system, water supply in this community is provided by the Kent County Water Authority and the City of Providence water system.

5. Town of Cumberland (population 27,009)

Only the eastern one third of the town lies within the Narragansett Basin. The town is served both by the Town of Cumberland Water Supply Department and by the City of Pawtucket Water Department.

6. Town of East Greenwich (population 10,208)

Only a small part of town in the northeast corner is within the Basin. Water supply is provided in the developed areas of the town east of South County Trail (Route R. I. 2) by the Kent County Water Authority.

7. City of East Providence (population 50,960)

The City is served by a municipal water system which is supplied by the City of Providence.

8. Town of Jamestown (population 4,028)

The public water system in this community serves only the central part of the town. The water supply sources are Carr Pond and Watson Pond.

9. Town of Little Compton (population 3,086)

Only a small part of town in the northwest corner is in the Basin. The town has no pulbic water distribution system. The population is served by private wells.

10. Town of Middletown (population 17,251)

The water distribution system in Middletown is supplied by the City of Newport water system from surface water sources.

11. Town of Narragansett (population 12,097)

Only the north one third of the town is in the Basin. The town has two water distribution systems. The Point Judith system which serves the southern portion of the town is supplied by the Wakefield Water Company. The North End system which serves the northwest portion of the town is supplied by the Town of North Kingstown Water Department. Gravel packed wells are the sources of supply for both of these systems.

12. City of Newport (population 29,266)

About two thirds of the city is in the basin. The Newport water system has reservoirs in Tiverton and Little Compton and several small ones on Aquidneck Island. Most of the City is served by the public water distribution system.

13. Town of North Kingstown (population 21,855)

The North Kingstown Water Department, which provides water to most of the town, has wells as the source of supply.

14. Town of North Providence (population 29,216

The town is supplied both by the Providence Water Supply Board System and by the City of Pawtucket Water Department.

15. City of Pawtucket (population 71,033)

The entire city is served by a public water supply system which obtains most of its water supply from surface water and a small amount from wells. The surface water supply is the Abbott Run watershed in Cumberland which, after impoundment in Diamond Hill and Arnold Mills Reservoirs, flows to Happy Hollow Pond through Abbot Run. The groundwater supplement is from wells located in Pawtucket and Cumberland.

16. Town of Portsmouth (population 14,256)

There are two water distribution systems which are owned and maintained by the Portsmouth Water and Fire District. The area north of Sprague Street to Common Fence Point is supplied by the Stone Bridge system in Tiverton, while the area south of Sprague Street to the town line obtains its supply from the Newport system.

17. City of Providence (population 156,519)

The entire city is served by a public water supply system. The source of supply is the Scituate Reservoir complex in the Town of Scituate.

18. Town of South Kingstown (population 20,411)

There are three water systems which serve this community. The Wakefield Water Company serves the Wakefield-Peace Dale area. The Kingston Fire District serves the Village of Kingston, and the South Kingstown Water Company serves the area south of Post Road (U.S. Route 1). Water supply for the three systems is from wells.

19. Town of Tiverton (population 13,484)

Only the western shoreline is within the Basin. There are two water systems which serve the Town of Tiverton: the North Tiverton Fire District which purchases its water from the City of Fall River, and the Stone Bridge Fire District which obtains its supply from Stafford Pond. The northwest portion of the town is the only area which is presently served by the two systems.

20. Town of Warren (population 10,620)

The Bristol County Water Company provides water to this community. Several of the reservoirs which supply the system are located in adjacent Bristol County, Massachusetts.

21. City of Warwick (population 87,064)

The City's water system is the largest in the state that does not have its own sources of supply. It serves most of the built-up areas of the city and obtains its water from the Providence Water Supply System. The Greenwood and Potowomut areas are served by the Kent County Water Authority.

MINE DRAINAGE EFFECT ON WATER LEVEL

SURFACE WATER

Pumping from mining excavations must be disposed of either into a detention basin or surface stream; in either case the normal progress of the hydrologic cycle is disrupted and at least a temporary abnormal incidence of surface water may occur. Under other hydrogeologic situations, namely where the water table is near the surface, wetlands, streams and ponds may disappear as a result of mine dewatering. Low permeability barriers such as clay-filled trenches or grouted bedrock can be considered in some cases to reduce infiltration into mine excavations. The possibilities of effect must be determined based on 1) geohydrologic nature of the subsurface material, 2) proximity of water table to ground surface, and 3) mine dewatering plan in discharge quantity and location.

A most important consideration related to surface water change is quality. Changes in quality of the original water body may be caused by the addition of poor quality mine drainage water or by the reduction of natural flow which can reduce the ability to dilute contaminant input into the strem or pond. An impact analysis of this effect must be site specific, involving the aquisition of baseline data of existing flow and water quality for at least one full year before mining operations occur. The nature of impaired water quality from mine drainage will be discussed later in this report.

Additional effects may be caused by modifications to the surface of the mining region; the ability of the ground surface to hold or transmit water may be greatly changed. Removal of vegetation cover generally will results in a less permeable ground surface with greater ponding and runoff. Also, inversion of topography may cause ponding and reduced surface runoff. Review of detailed plans for the proposed mining area modification can allow assessment of this possibility.

Additionally, surface mining and subsequent area restoration may greatly alter the hydrologic character of material in the vadose zone immediately below the surface. As a result, the infiltration of precipitation downward may either be increased or decreased with consequences on both surface and groundwater levels. W.K. Summers (1981) offers a means of quantifying the impact of mining on groundwater recharge. The following is taken from the abstract of a presentation made at the Symposium on Surface Mining Hydrology at Lexington, Kentucky in 1981.

> "...To measure the impact of surface mining on ground-water recharge, hydrogeologists must quantify both the pre-mining and post-mining recharge rates.
>
> To quantify recharge rates at specific sites requires (1) the installation of suites of piezometers and tensiometers to determine the magnitude and direction of the hydraulic gradient and (2) <u>in-situ</u> measurements of soil-moisture content and hydraulic conductivity.
>
> Because rates vary seasonally, measurements for a period of time (at least one year) before mining are necessary to determine the range and variation in the rate. If the flow through the partialy saturated zone from the land surface to the water table follows fractures, recharge may occur at much faster rates than would be predicted for flow through the interstitial spaces of clastic rocks and soils. So, sufficient measurements to determine the mode of flow must be made.

> In pristine areas, natural recharge may be the only consideration and measurements to determine the area and extent of the natural recharge phenomena may be sufficient. But, if the area has many water wells that are pumping to their capacity, regional gradients may be reversed and, locally, recharge may be induced in discharge areas. So, the rates observed may be changing for reasons other than mining and these changes must be quantified before mining if the effects of mining alone are to be characterized."

GROUND WATER

Pits, drafts and headings created as a part of the mining operation frequently incise into water bearing strata. This is particularly true in the Narragansett Basin where the land surface elevations are low and relatively near the bay. The encounter with groundwater may be under water table or artesian conditions. Extraction of water from the mining excavation will result in a depression of the water table or piezometric surface. This lowering of the water table may create problems for wells both in unconsolidated sediments as well as in rock. Frequently the fractured and faulted coal beds become conduits for groundwater movement and storage. Wells in coal seams may have higher yield than in the roof or floor rock of mines.

The following information is taken primarily from the excellent discussion on potential coal mining impacts by Frimpter and Maevsky (1979).

> "Dewatering of bedrock for mining requires only the removal of water from storage in secondary porosity (joints and fractures) in the bedrock and removal of water from storage in

primary porosity in overlying unconsolidated deposits hydraulically connected with the bedrock. The specific yield of a rock is the ratio of volume of water that will drain by gravity from water-saturated rock to the volume of the rock. Because primary pores of the conglomerate and sandstone of the Rhode Island Formation in the Narragansett Basin are very poorly interconnected and because secondary pores (joints and fractures) make up only a small percentage of total rock volume, specific yield of the upper 300 feet of bedrock is estimated to be less than 0.5 percent. The degree of rock fracture and therefore specific yield is greatest near the top of the bedrock and decreases rapidly to a negligible amount between 300 and 400 feet.

Unconsolidated sand and gravel deposits of glacial origin in New England commonly have specific yields of about 20 percent and therfore may store large quantities of water. For example, a 1-mile-long section of a 1-mile-wide valley filled to an average depth of 30 feet with water-saturated sand and gravel constitutes a ground-water reservoir that contains 1.1 billion gallons of water. The aquifer mapped by Williams (1968) between Lake Mirimichi and Greenwood (Bungay) Lake in Mansfield and Foxborough is about this size but is also in contact with the lakes and additional water-saturated sand and gravel both to the north and to the south. Mansfield withdraws an average of 1 Mgal/day from wells in this ground-water reservoir, and Attleboro has a pumping capacity of 2.75 Mgal/day at its diversion station on the Wading River in Mansfield (Williams and Willey, 1967). Base flow in the Wading River at this station is partly dependent on ground-water discharge from the 1.1 billion gallon ground-water reservoir and releases from Lake Mirimichi. Mines close to the ground-water reservoirs such as this would have a large potential for ground-water inflow. However, there commonly is a layer of till separating rock from sand and gravel, so inflow to rock would depend on the thickness and permeability of the till and the hydraulic gradient induced by dewatering.

Sustained high rates of ground-water seepage to mines are not expected unless the mines are in proximity to large bodies of surface water or water-saturated glaciofluvial deposits. Avoidance of infiltration from water-saturated glaciofluvial deposits to minimize mine seepage and pumping costs would also lessen chances of interference with public-supply wells tapping glaciofluvial deposits. However, interference with domestic water-supply wells tapping bedrock should be expected near underground or deep-pit operations. Historical and hydrologic evidence indicate that mining operations could cause local dewatering of the bedrock aquifer and resultant failure of domestic water-supply wells. Public water-supply service might be extended into areas where mining might have this effect."

The following historic note of relevant interest is also contained in the Frimpter and Maevsky (1979) report.

"Water problems were encountered in the early prospecting and mining efforts in the last century in the Mansfield, Massachusetts, area. During dewatering of the 84-foot Skinner mine shaft wwest of Tremont Street in Mansfield, home wells went dry. On August 24, 1923, the Mansfield News reported: "The first attempt to pump out the water was successful although continuous pumping is necessary to keep the shaft dry." On August 31, the News reported: "Following a lengthy hearing at the Selectmen's meeting last night, given to several residents of Tremont St., West Mansfield, whose supply of water has dwindled to nothing on account of the continuous pumping at the coal mine, the Board voted to call a town meeting on September 17 to take action on the matter..." And, on September 31, "A debate of an hour at the special town meeting Monday evening resulted in the Selectmen and town manager being empowered to furnish relief for any resident who has no supply of water. Albert H. Bagloe said that the wells were only dry when the mine was being pumped."

> "Harry B. Chase (oral commun., 1976) reported that an early attempt to develop the Hardon mine north of School Street in Mansfield ended in 1838 because of water, difficulty of mining steeply inclined seams, and national depression. Mr. Chase also reported that in 1917-18 mining operations at the Hardon mine failed because of inability to pump out the shaft; that in 1920 two to five pumps ran continuously to drain the mine; and that in 1922-23 a 25-horsepower electric pump failed to pump the shaft dry."

Once the mining plan and site condition are known, predictions of probable inflow into mining excavations and lowering of the water table can be made. McWhorter (1981) presents practical closed form formulas by which inflows and drawdowns can be calculated for several selected situations. Cases covered are 1) flow to an advancing pit, 2) effect of pit elongation, 3) effect of leakage on extent of affected piezometric surface and 4) drainage of alluvium or fault zone by adjacent pit.

A good engineering treatment of the ground water and geotechnical problems involved in tunneling and open excavations is given by Freeze and Cherry (1979). Concepts are discussed and predictive equations given.

SALT WATER INTRUSION

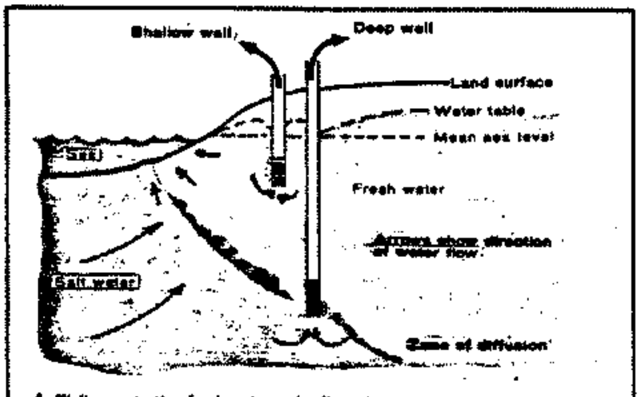
CONCEPT

Coastal land masses in proximity to salt water such as Narragansett Bay commonly develop a groundwater feature of particular importance in mining operations. Fresh groundwater flowing to discharge at the shoreline of the bay overrides deeper salty groundwater and must maintain a hydrostatic balance with the underlying salty groundwater. The fresh water of lesser density than salt water tends to float on the salt water. The thickness of the fresh groundwater body becomes less as the shoreline is approached, finally tapering to no thickness as it exits into the salt water of the open bay. This relationship is commonly termed the Ghyben-Herzberg relation (Todd, 1959). When usual values of 1.00 and 1.025 are taken for fresh water and sea water density respectively are assumed it is found that on a theoretical basis for every foot the fresh water stands above mean sea level there are approximately forty feet of fresh water to the underlying salt water interface. A very complete discussion of this phenomenon is provided by Bear (1979).

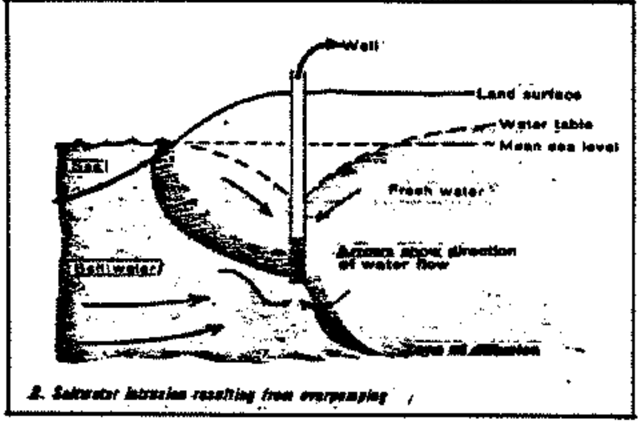
In practice there are important differences between theory and reality. First, the interface is not sharp, but a transition zone which may greater reduce the fresh water thickness. Secondly the water levels and the position of the interface are highly dynamic, fluctuating daily with the tide and seasonally with the amount of fresh water recharge into the ground. Finally the actually position and integrity of the fresh water body is dependent on the amount and nature of voids in the subsurface material; this is particularly important in rock where large fissures in direct communication with the sea can allow salt water to intrude much more rapidly than in unconsolidated sands where subsurface flow must take a slower more tortuous path. In contrast however, tight bedrock may form an impevious boundary protecting against salt water intrusion into a aquifer. The relationship between fresh water and the underlying salt water during pumping is illustrated in Figure 5. As indicated, deeper wells are the first to show the effects of salt water intrusion. Any well, however, can be affected when the fresh water level at that well is lowered below mean sea level. This is important since mine dewatering would be continued regardless of whether the water pumped was fresh or salt. This then could adversely affect supply wells in the area by reducing the fresh water thickness to less than the depth of the well.

CURRENT PROBLEMS

According to Frimpter (1973) salt water encroachment from Narragansett Bay and associated lagoons, coves and estuaries is a threat to groundwater quality under normal conditions. Under conditions of extensive dewatering from mining excavation the potential for salt water encroachment is much greater, particularly due to the likelihood of reversing normal groundwater gradients. Frimpter (1973) notes that public supply wells in Barrington, less than half a mile from Narragansett Bay, yielded water with a chloride content of 15 mg/l (milligrams per liter) in 1952. Since then, chloride content has increased. One of the wells has yielded water with a chloride concentration of 460 mg/l in 1966. The danger of salt-water encroachment was recognized (Allen, 1953) long before the increase in chloride content. Pumping of wells in the aquifer reverses the natural hydrologic gradient between the wells and Narragansett Bay, causing landward



A. Wells penetrating fresh water and salty water



B. Saltwater intrusion resulting from overpumping

Figure 5 Relationship between salt water and fresh water in a coastal aquifer during pumping (from Mazzaferro et al, 1979) encroachment of a salt-water wedge in the lower part of the aquifer. At the well, salt water is withdrawn with fresh water. Unless pumping rates are carefully controlled, the chloride content will continue to increase, particularly during dry summers. Chloride concentration in these and similarly situated wells can be expected to fluctuate seasonally. Because the salt/fresh-water interface migrates during periods of fresh-water recharge (in the spring), less salt water will mix with the fresh water in the well; and during periods of no recharge (in the summer), more salt water will mix with it. During short-term recharge periods, chloride content diminishes, but salt-water encroachment is increasing on an annual basis.

The Barrington region is worthy of further examination since early monitoring (Biershank, 1954) did not show a salt water intrusion problem though it was recognized that the water table gradient reversal could induce salt water encroachment. Figure 6 is a map of the Barrington area showing the elevations of static water levels in wells during the period July-September 1949. Also identified on Figure 6 are the traces of two cross sections A-A' and B-B' which are shown in detail in Figures 7 and 8 respectively. From Figure 6 it is apparent that the water table in Barrington reached a maximum of only 10 feet above sea level. Drawdown in wells would in most cases exceed this thus reducing the head available to counter salt water intrusion to less than sea level.

Wells or excavations that tap outwash deposits near tidal waters or that pump large quantities of water for a prolonged period of time may induce salt-water encroachment if the water table is drawn below sea level resulting in a hydraulic gradient favorable to such intrusion. The only known area in Barrington where such a gradient occurred according

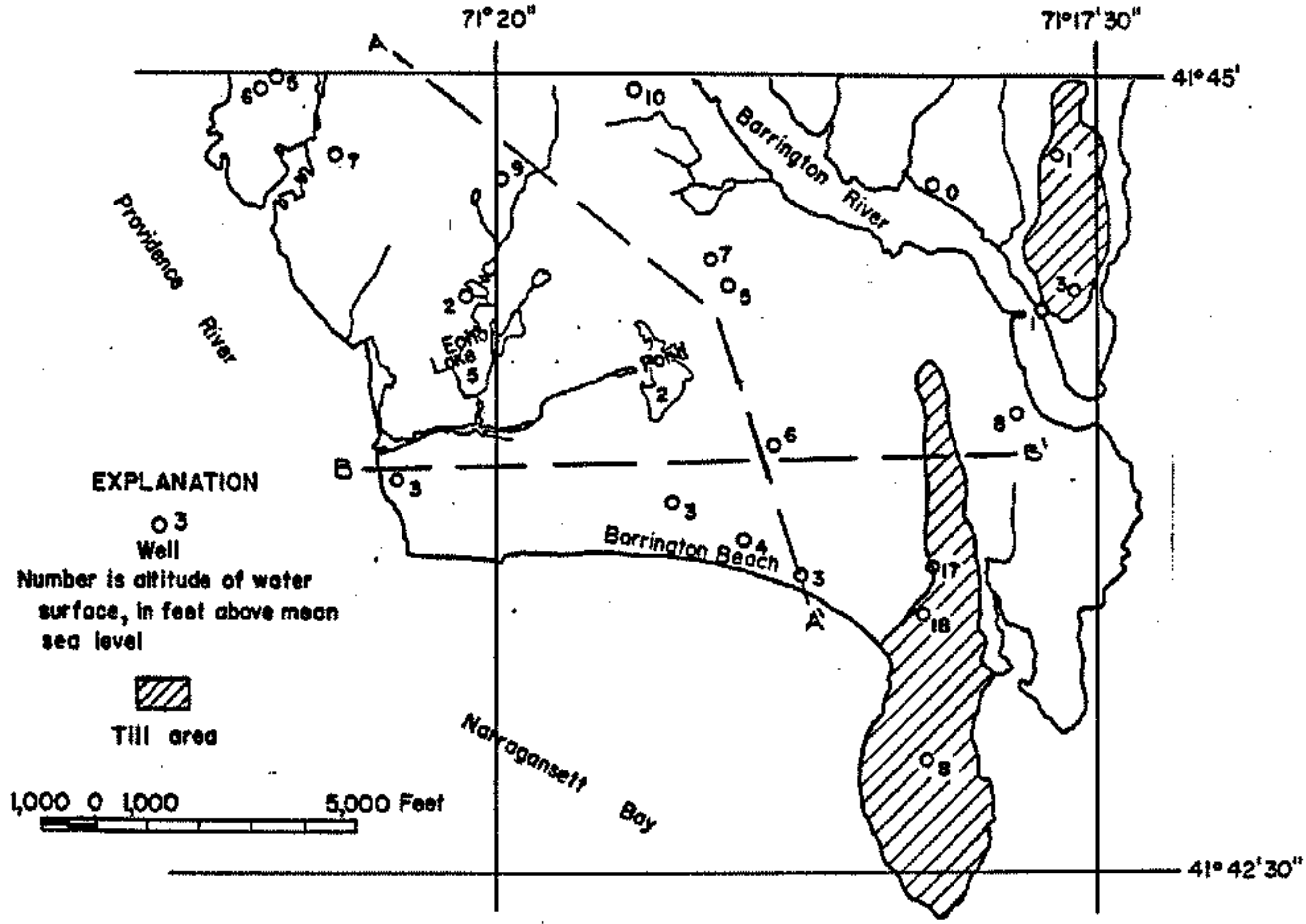


FIGURE 6 Map of Barrington, Rhode Island showing altitude of static water levels in water table wells as of July-September 1949 and locations of hydrogeologic cross sections (after Bierschenk, 1954)

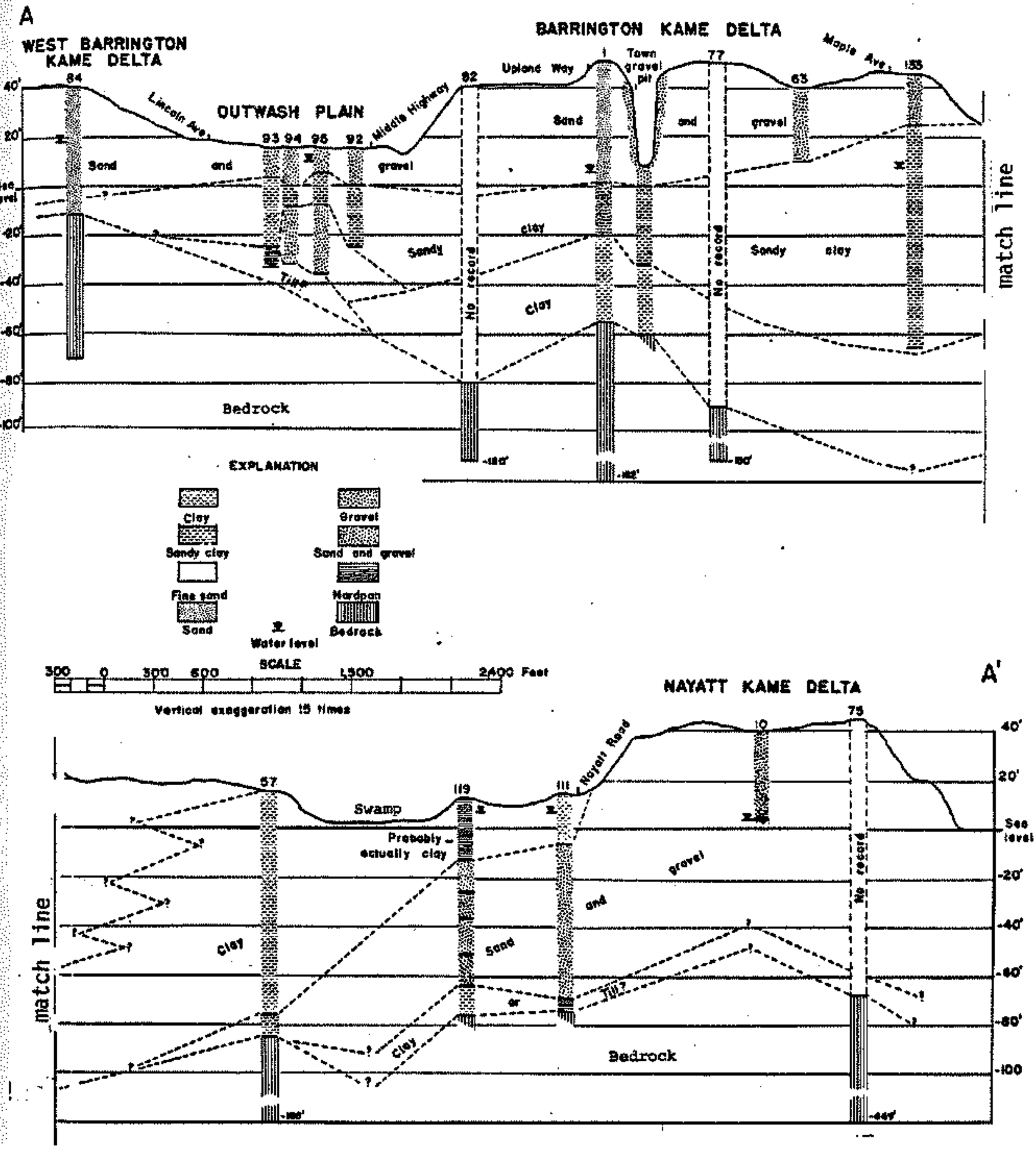


FIGURE 7 Hydrogeologic cross section A - A' at Barrington, Rhode Island (from Bierschenk, 1954)

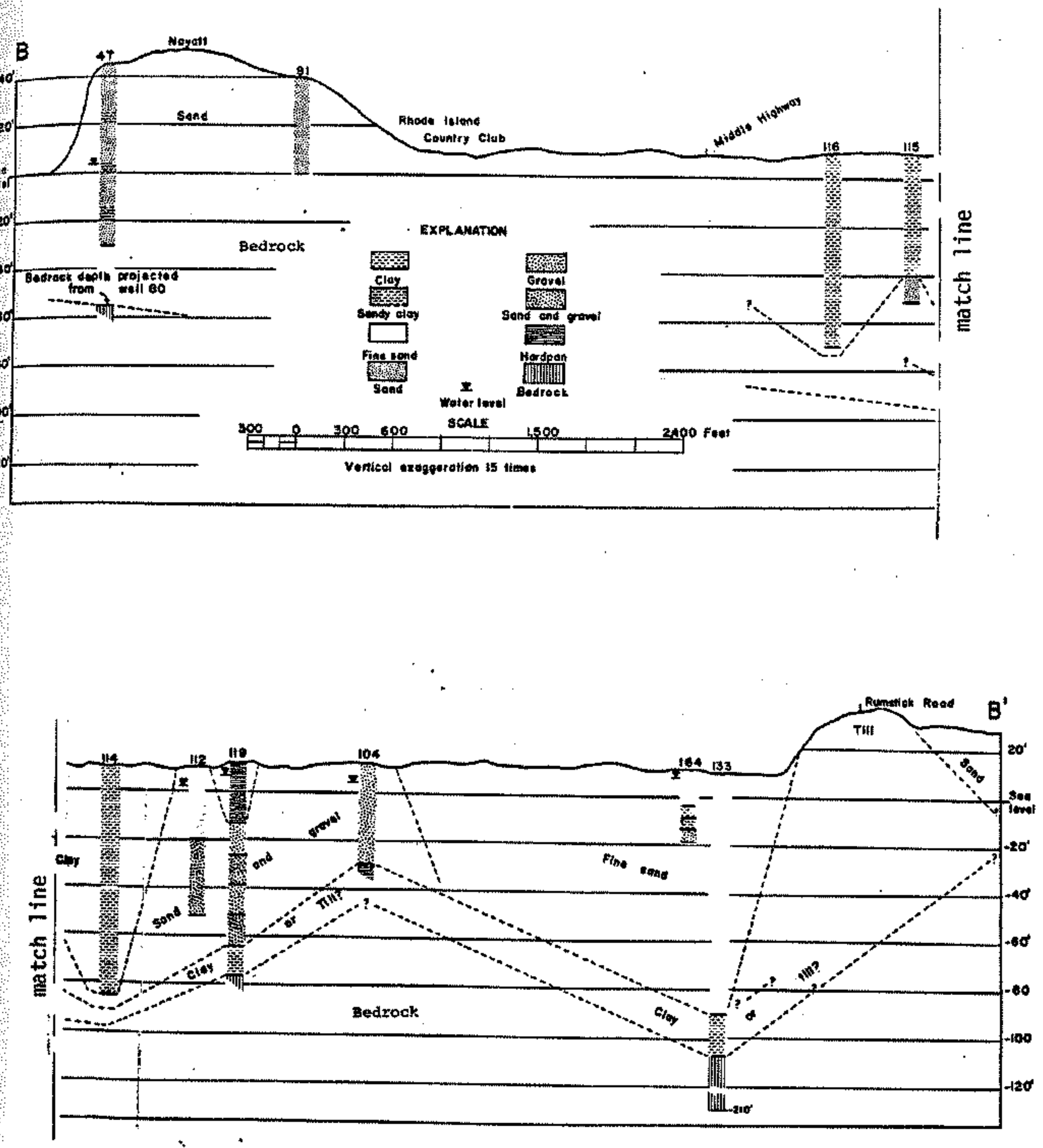


FIGURE 8 Hydrogeologic cross section B-B' at Barrington, Rhode Island (from Bierschenk, 1954)

to Biershank (1954) was at the well field of the Bristol County Water Co. However, data at that time did not show any sea-water contamination of the outwash deposit from which water is pumped. In both wells Bar. 111 and 119, which are about 2,000 feet from Narragansett Bay, the concentration of chloride was 12 parts per million (ppm) in 1950. It was 15 ppm in June 1952 when the wells were first put into operation, and it was 10 to 15 ppm, respectively. In 1966, however the concentration was 460 mg/l, in October 1953. In well Bar. 10, about 600 feet from the bay, the chloride concentration was 20 ppm in December 1953. The fresh-water head in observation well Bar. 10, between the supply wells and the bay, ranged from a maximum of about 7 feet to a minimum of something less than 2 feet above sea level. During the period of the Biershank (1954) study there appeared to be a fluctuating positive head of water with a hydraulic gradient from well Bar. 10 toward the sea that prevents landward migration of sea water. It is also possible that a body of impermeable lacustrine clay lies underneath the Nayatt kame delta and extends beneath Narragansett Bay. If so, it may have acted at least as a temporary barrier to landward movement of sea water. It is evident that sea water intrusion is a long term event responding to changes in the hydrologic system slowly, in a time frame which may be measured in years.

The outwash deposits in Warren underlie an irregularly shaped area in the northeastern part of the quadrangle. They range in thickness from a few inches at the rock outcrops east of the Warren Reservoir to a reported maximum of 90 feet at well Wan. 66 southeast of the outcrops. In addition to the fine grained character of most of the outwash in Warren, three other features are significant. The first is that nearly everywhere the saturated portion is not over 30 feet thick. Except where the outwash rests against the higher hills, the bedrock surface ranges from a few feet above to about 30 feet below sea level. Accordingly, there is no deep-lying body of saturated materials to draw upon, as there is in Barrington. Second, the outwash bodies are narrow and, generally not more than about half a mile from salty, tidal water. Third, there is no known evidence of any strata or zones impermeable enough either to confine water under artesian pressure or to prevent the downward or lateral movement of water from the land surface, or from the bay. Because of the generally fine grained nature of the deposits, their thinness, and probable continuity with salty bay water, the outwash deposits of Warren are vulnerable to salt water intrusion.

The outwash deposits in the towns of Bristol, Portsmouth, and Warwick are in small thin bodies of irregular areal extent, generally bordering the till-mantled bedrock hills. They probably consist of stratified gravel, sand, and silt, and perhaps clay. On the west side of the principal land area of Bristol, the outwash deposits are 10 feet thick or less and on the east side, at wells Bri. 19 and 133, they are 20 and 30 feet thick, respectively, and consist of gravel, sand, and silt. Data are not available on the thickness of the outwash on Patience and Prudence Islands in Portsmouth (southwestern portion of the quadrangle), but the deposits are probably not more than 30 feet thick. The groundwater in these areas is presumed to be generally unconfined. The water table is at altitudes of 1 to 40 feet above sea level, and at most places not more than 10 feet below land surface. The deposits are thin and are all in close proximity to Narragansett Bay, hence dewatering in mine excavations would probably draw in sea water.

The following is taken from Biershank (1954):

" Many rock wells situated near Narragansett Bay can encounter or draw in sea water through the fractures. On

Popasquash Neck, in Bristol well Bri. 10 intersected a fresh-water-bearing fracture at a depth of 70 feet. However, at a depth of 140 feet it encountered a salt-water "vein." Thus the water supply was contaminated. On the same property, well Bri. 11 encountered at a depth of 60 feet fresh water which rose to about sea level. The well yielded 7 gpm of fresh water. Just east of Bristol Harbor, well Bri. 25, drilled to a depth of 203 feet, yields brackish water. This well, which reportedly had a static water level approximately at sea level when drilled in 1933 and which originally yielded fresh water, is pumped for 24 hours per day at a rate of about 40 gpm and thus, more than likely, has drawn in the sea water. On the east shore of Warren River, abandoned wells Wan. 35, 74, and 76, ranging in depth from 500 to 530 feet, yielded brackish water when drilled. However, nearby wells Wan. 31, 32, 33, and 38, ranging in depth from 50 to 104 feet supply fresh water."

TEST RESULTS

The potential salt water intrusion effect of mining operations on groundwater in the Narragansett Basin was evaluated by Frimpter and Maevsky (1979), using test hole observations. The U.S. geological survey measured water levels monthly in 13 cased holes penetrating the Rhode Island Formation in Rhode Island and Massachusetts. In addition continuous records of water level fluctuations was obtained on six test holes for periods ranging from about a week to 2 months. Complete well logs are available for these test holes. Water level fluctuations and salinity determinations enabled estimates to be made of the salt water intrusion potential at the test sites. Well records and location sketches are contained in Appendix B.

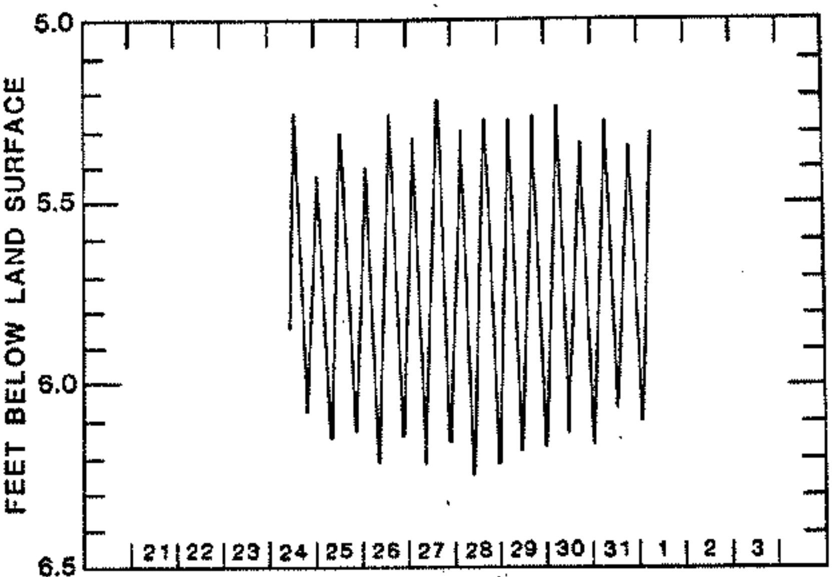
A measure of the relationship of groundwater to tidal influenced water bodies can be obtained by observing the water level response in a well to tidal fluctuation. This should be done in any area where it is proposed to undertake pumping and dewatering. This was accomplished for two of the Rhode Island test holes, Bristol 23 and 64.

Water-level recorders placed on Bristol 23 and 64 showed (Fig. 9) that water levels in these holes fluctuated diurnally in response to tides in Narragansett Bay, as did water levels in a mine pit in Bristol (Conrad Beauregard, Bristol resident, oral commun., 1977). Bristol 23 had a range of about 1 foot, whereas Bristol 64 had a range of 1.5 feet. Typical tidal characteristics for the region are shown in Figure 10.

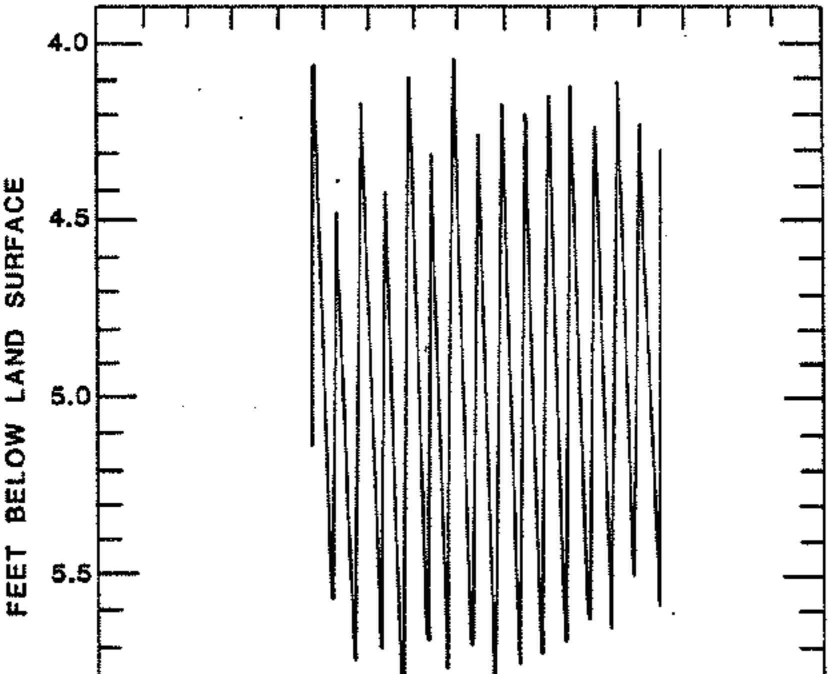
Because the tidal range in Narragansett Bay at Bristol during this period was 5.4 feet, the tidal efficiency of these test holes is 18 and 28 percent, respectively. Fluid-conductance logs of these test holes indicate they contain saltwater. Pumping for 5 hours did not yield freshwater. These data and a specific capacity of 0.25 to 0.39 gallons per minute per foot of drawdown for test holes 7 and 23 strongly suggest that mine shafts, tunnels, or pits would encounter high inflow or seepage rates at this location.

Additional indications of the potential salt water intrusion problem were in evidence during test pumping of test hole Bristol 23. A graphic record of the pump test is shown in Figure 11. The following pertinent comments are taken from Frimpter and Maevsky (1979).

> "During the pumping of Bristol 23 (Fig. 11), water color gradually changed from black to gray. At about 180 minutes, it turned black again and yield increased as a result of the unplugging of a water-bearing fracture in coal or carbonaceous shale. Water from Bristol 7 and 23 remained salty throughout



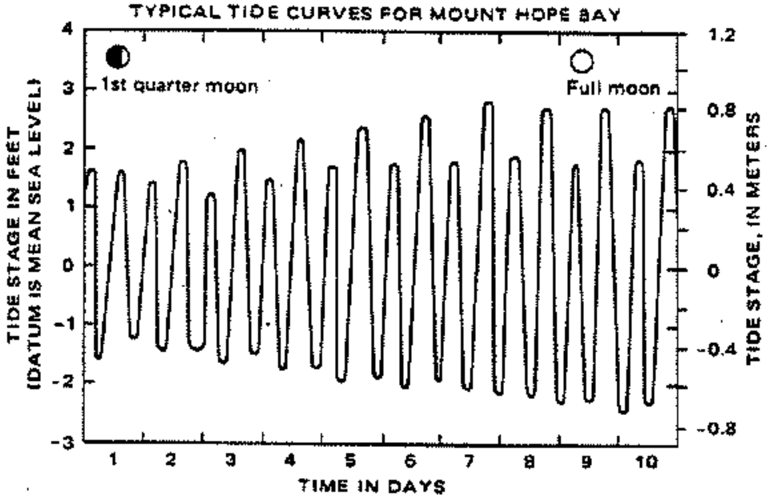
WATER LEVEL IN BRISTOL 23, FROM RECORDER CHART, AUG.24-SEPT.1,1977, TIDAL EFFICIENCY 18 PERCENT



WATER LEVEL IN BRISTOL 64, FROM RECORDER CHART, AUG.24-SEPT.1,1977, TIDAL EFFICIENCY 28 PERCENT

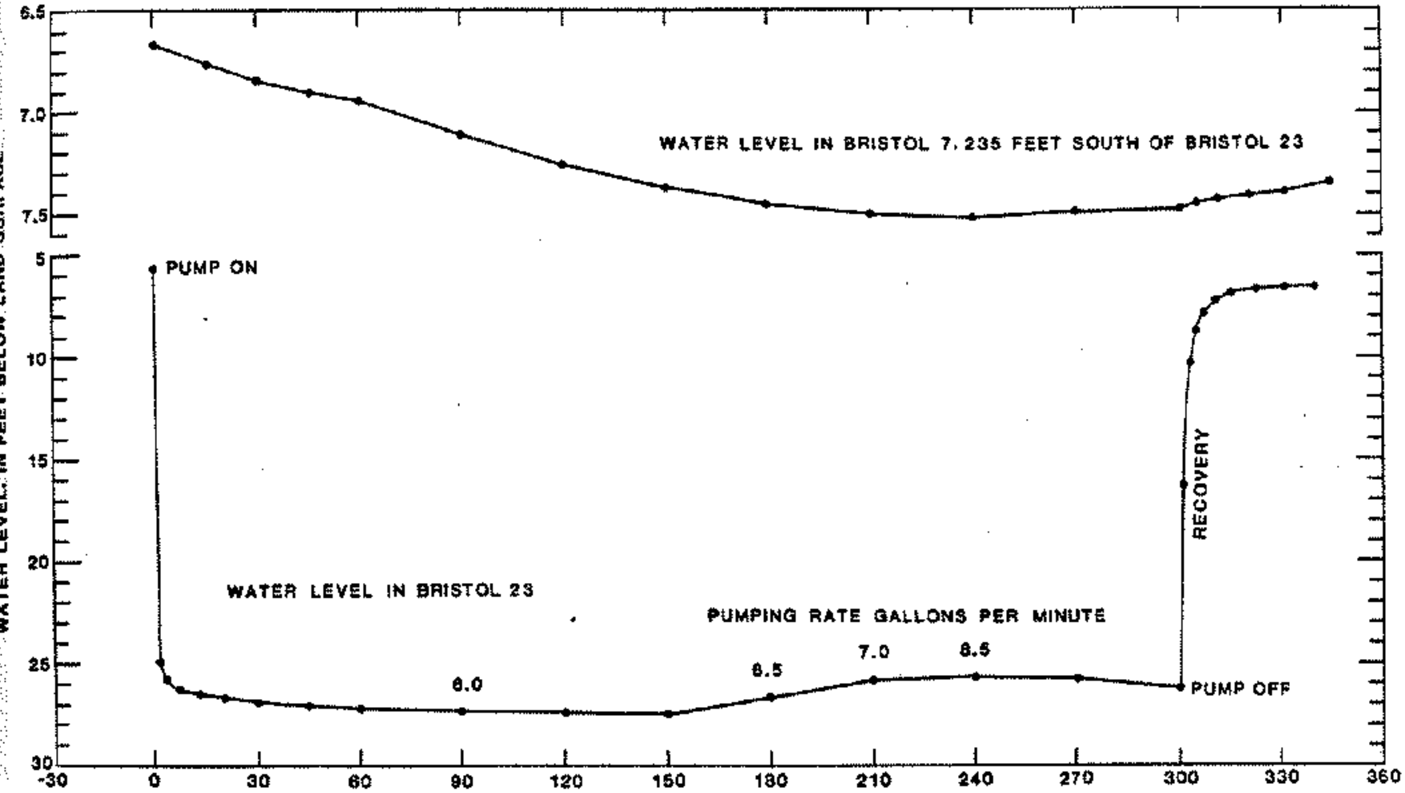
Figure 9 Tidal water level fluctuations of groundwater in wells at Bristol, Rhode Island (from Frimpter and Maevsky, 1979)

TIDAL CHARACTERISTICS



ALONG THE COAST THERE ARE TWO HIGH TIDES AND TWO LOW TIDES EACH LUNAR DAY (24 HOURS AND 50 MINUTES). *The difference between high and low tide is greater than average at times of new or full moon and less than average at times of first or third quarter moons*

Figure 10 Tidal characteristics for Mount Hope Bay, Rhode Island (from Willey, 1978)



ELAPSED TIME, IN MINUTES. JULY 13, 1977

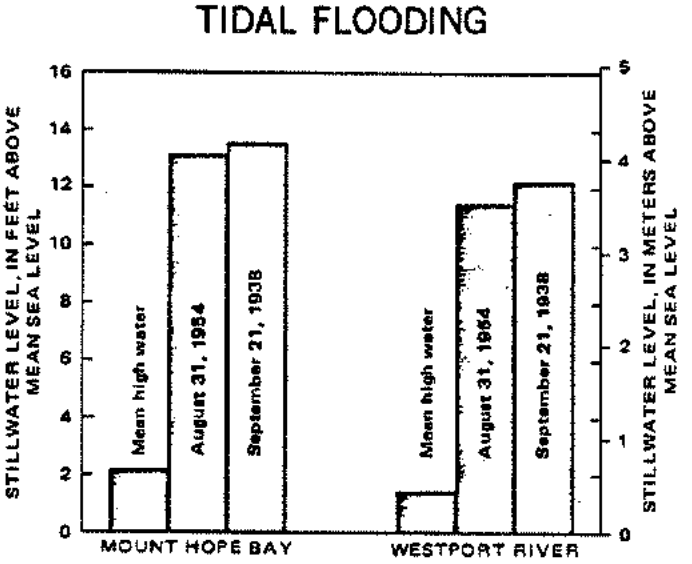
Figure 11 Drawdown from pumping test of test hole Bristol 23
(from Frimpter and Maevsky, 1979)

pumping and remained at 15°C - warmer than the 11°-12°C common for shallow ground water in southeastern New England. The rapid and nearly complete recovery of water levels in Bristol 7 and 23 suggest little depletion of water in storage. The water level in Bristol 7 declined 0.8 foot during pumping of Bristol 23, owing to low tide in Narragansett Bay 220 feet to the west."

MINING IMPLICATIONS

The foregoing tests strongly suggest that the test holes, located generally in the area of potential coal mining operations, are in hydrologic contact with Narragansett Bay and that mining would facilitate saltwater seepage. Whether or not this is of any real significance requires site specific evaluation of the planned mining operation vis a vis use of groundwater in the area.

In the location and construction of mine facilities and excavations consideration must also be given to the possibility of surface flooding from salt water. Protective berms to prevent flooding from 1938 hurricane levels should be required. The bay water rose during this event by almost 14 feet above mean sea level. Tidal flooding potential is shown graphically in Figure 12.



UNPROTECTED, LOW-LYING COASTAL AREAS ARE SUBJECT TO TIDAL FLOODING FROM HURRICANE SURGES. – *From 1635 to 1974 tidal levels along the coast have exceeded those of September 21, 1938, and August 31, 1954, only on August 3, 1638, and August 15, 1635 (U.S. Army Corps of Engineers, 1965; and Paulsen, 1940)*

Figure 12 Tidal flooding at Mount Hope Bay, Rhode Island
(from Willey, 1978)

WATER QUALITY

Acid Mine Drainage

Acid mine drainage is an extremely acidic, iron sulfate rich drainage that forms under natural conditions when certain coal seams are exposed to air and water. When coal is mined, the iron disulfides, occurring either as marcasite or pyrite, which are commonly associated with the coal and overlying strata, are exposed to the atmosphere and oxidize in the presence of humidity and oxygen to form soluble hydrous iron sulfates. Subsequent contact dissolves these compounds which chemically react to produce a highly acidic drainage with attendant high concentrations of iron and sulfate. Althougth this process is generally accepted as the mechanism by which acid mine drainage is formed, the exact chemical reactions are not fully understood (Carruccio et al., 1977).

Chemical reactions explaining the oxidation of the iron disulfide and the generation of acidity are given by the following equations:

$$FeS_{2(s)} + 7/2\ O_2 + H_2O = Fe^{++} + 2SO_4^{=} + 2H^+ \tag{1}$$

$$Fe^{++} + 1/4O_2 + H^+ = Fe^{+++} + 1/2H_2O \tag{2}$$

$$Fe^{+++} + 3H_2O = Fe(OH)_{3(s)} + 3H^+ \tag{3}$$

$$FeS_{2(s)} + 14Fe^{+++} + 8H_2O = 15Fe^{++} + 2SO_4^{=} + 16H^+ \tag{4}$$

(Singer and Stumm, 1968)

On the surface of a weathered coal mine face, yellow and white crusts commonly occur along certain horizons within the strata. These white and yellow salts are the oxidation products of the pyrite and are the crystallized products of equation 1. Some of the products have been identified as melanterite (white crystals of ferrous sulfate), copiapite (yellow crystals of ferric sulfate), halotrichite (white crystals of iron or magnesium sulfate), and alumogenite (white crystals of aluminum sulfate) (Lorenz, 1962).

The ferrous iron generated in the reaction described in equation 1 can be further oxidized to the ferric state in accordance with equation 3 and generate additional amounts of sulfuric acid. It has been estimated by Stumm and Lee (1960) that a large part of the acidity generated in acid mine drainage production arises from the oxidation of ferrous iron to ferric iron. The ferrous and ferric hydroxides associated with the chemical reaction in equation 3 impart the red and yelleow-orange color that is characteristic of acid mine drainage. The precipitated iron hydroxide is the "yellow boy" that is commonly observed in streams and coal mine areas.

The sulfuric acid causes the water to be highly corrosive. These chemical qualities make the water unsuitable for drinking and for almost any other use. They form a hostile environment for normal stream life, especially fish, and commonly cause the formation of an orange slime of iron hydroxides and iron-metabolizing bacteria (Frimpter and Maevsky, 1979). The following is taken from a study done by Caruccio et al. (1979) for the Environmental Protection Agency:

> "Sulfur in coal can occur as organic sulfur, pyritic sulfur or sulfate sulfur. Organic sulfur is that component which is incorporated in the plant structure and is organically bound within the coal. In general, the organic component is not chemically reactive. Sulfate sulfur usually represents the water soluble weathering products of the disulfides and in most cases constitutes a very small percentage of the total sulfur measured in a section. Pyritic sulfur is that sulfur which is found in the disulfide phase usually as either marcasite or pyrite.

"Studies by Mansfield and Spackman (1965) have shown that variations in the total sulfur contents of coal samples collected from the bituminous coal field of western Pennsylvania reflect variations in pyritic sulfur contents. In their study the organic sulfur content of a particular coal seam remained relatively constant from the top to the bottom of the seam. Although the values of organic sulfur varied from 0.5 to 2% between seams, variations in total sulfur content expressed variations in pyritic sulfur content within each seam."

"In comparing two areas in central Pennsylvania, Caruccio (1968) showed that the occurrence of acid mine drainage produced in the strip mine areas could not be related to the sulfur content of the coals and overlying strata. The two areas in Pennsylvania, one containing strip mines that produced acid, while the other containing mines with non-acid drainages, had strata with total sulfur contents which varied and overlapped and whose values were apparently similar. Microscopic examination of polished samples of coal and rock strata collected from the non-acid producing area showed them to contain abundant amounts of pyrite as well as total sulfur percentages that were similar to the samples from the acid producing area."

"In a combination of studies, selected samples of coal and rock were placed in leaching chambers and periodically flushed with distilled water. The quality of the leachate collected from each sample was analyzed and the degree of acidity produced by each sample ascertained. Representative splits of the samples used in the leaching chambers were analyzed for sulfur contents and equal portions cast in polished pellets for microscopic examination. Caruccio (1968, 1969) found that the pyrite morphology was significantly different between the samples that produced acid and those that did not, even though the total sulfur contents were similar."

"In addition, there was a significant variation in the pyrite morphology betewen samples from the two areas of study. In samples from the non-acid producing area the pyrite commonly had a massive form and appeared to be secondary in origin. Most of the grains were greater than 400 microns and commonly had a morphology that suggested that the pyrite had replaced plant structures and occupied joints in the coal. In samples from the acid producing area, however, a major portion of the pyrite occurred as clusters of spheres measuring approximately 25 microns in diameter. Each of the spheres was an agglomeration of minute crystals of pyrite approximately 0.25 microns in diameter that collectively had globular morphology. Gray, Shapiro and Coe (1963) called attention to this type of pyrite occurring in the Pittsburgh seam of Pennsylvania, which is called framboidal pyrite."

"In terms of reactivity, Caruccio showed that framboidal pyrite is much more reactive and less stable than the massive secondary pyrite (1969, 1973). Samples containing framboidal pyrite when left in the lab were noted to readily decompose to produce the salt crusts that appear on the surface of the coals and which are products of the oxidation process. On the other hand, coarse grained particles of pyrite were noted to remain

> shiny and brassy for indefinite periods of time and did not show appreciable signs of weathering. Subsequent studies by Caruccio (1970) showed that the percentage of framboidal pyrite within samples of similar permeabilities, multiplied by the total pyrite content of that sample, can be used as a measure of the acid producing potential of that particular sample. In this manner, samples could have high amounts of pyritic sulfur, but if occurring as massive coarse grained secondary types will tend to remain stable and not produce acid. In contrast, if framboidal pyrite were to be present, then it is expected to readily decompose and produce acid. On this premise, and in view of the natural limits of alkalinity imposed by the carbonate-bicarbonate geochemical reactions, the occurrence of acid mine drainage can be directly related to the occurrence of framboidal pyrite within a coal seam and associated strata."

According to Frimpter and Maevsky (1979) pyrite is reported to occur in minor quantities disseminated throughout the rocks of the Narragansett Basin, but visual inspection and chemical analyses of coal samples show low sulfur-bearing mineral contents. Framboidal pyrite occurs as clusters of spheres of iron disulfide about 0.25 microns in diameter. Euhedral crystals and coarse grained crystals of the type reported in the Narragansett Basin, however, do not decompose rapidly enough to produce severe acid mine drainage. The occurrence of framboidal pyrite has been correlated with paleodepositional environments and shown to be high in marine-influenced back-barrier and lower delta-plain deposits and poor in upper delta-plain and alluvial-plain deposits (Caruccio and Ferm, 1974). Because the Naragansett Basin sediments are alluvial-plain deposits and have been metamorphosed and the coal is anthracite, little if any framboidal pyrite is expected to be present, and severe acid mine drainage problems would not be likely (Frimpter and Maevsky, 1979).

Methodology to predict the occurrence of acid drainage has been developed using simulated weathering tests on core samples (Caruccio and Geidel, 1981). The procedures are additionally described by Caruccio et al., 1981). It would be appropriate to apply these procedures and develop predictions for acid drainage in the most likely coal producing regions of the Narragansett Basin. The results would relate directly to the requirement for control or treatment of mine drainage.

SUSPENDED SEDIMENT

Suspended sediment is a potential problem in waters originating in, or passing through, coal mining regions. In general the sediment may originate from two sources: 1) coal processing with water to remove fine material from the coal and 2) surface soil erosion from stripped or exposed land surfaces. In either case the sediment can be a serious problem unless controlled.

Total suspended and settlable solids are primary causes of turbidity (cloudiness). Turbid water affects aquatic life by reducing photosynthesis are primary causes of turbidity. They also serve as a transport mechanism for nutrients, pesticides, and other toxic substances, which are readily adsorbed onto clay particles. Suspended solids are of special importance for drinking water, because suspended matter can reduce the effectiveness of disinfection by creating areas where bacteria do not come into contact with the disinfectant.

Fish and fish food populations are affected by suspended and settleable solids in the following ways (Statewide Planning, 1979).

- fish may be killed directly, or their growth rate or disease resistance may be reduced;
- fish spawning and development of fish eggs and larvae may be impaired;
- natural movements and migrations of fish may be modified;
- bottom-dwelling organisms may be smothered;
- settled organic materials may remove dissolved oxygen from overlying waters.

The extent to which coal processing produces sediment is an operational aspect which can be controlled by regulating the coal mining and processing procedures. Solutions may range from performing the washing operation at a location where the discharge is of no consequence to a contained wash water recycle operation. The latter is by far the best solution, since it is difficult to find an environment even in a coastal area where tubidity would not have some adverse effect.

With regard to erosion and sedimentation in general, proper control requires both short term and long term measures. Generally the most critical period is during the initial construction and development phase when large areas of surface are laid bare. Restoration of the affected land areas should be dilberate programs and accomplished as rapidly as possible.

The State 208 study (Statewide Planning, 1979) provides the following pertinent discussion:

> "The state's role in regulating erosion and sedimentation impacts from construction generally is limited to grant administration and assisting local governments. The major state legislation dealing with soil and erosion control is Chapter 2-4 of the <u>General Laws</u> of Rhode Island. This statute

creates a state Soil Conservation Committee (SCC) to offer assistance to the soil conservation districts, also established under the act. The SCC's powers are limited generally to offering assistance to the directors of the conservation districts, disseminating information throughout the state concerning the activities and programs of the conservation districts, providing technical assistance to the Department of Environmental Management, and establishing uniform accounting and auditing procedures to be used by the conservation districts. The state conservation districts play a more direct role by assisting local communities in developing conservation programs, conducting surveys of renewable natural resources, preparing long-range conservation programs, and acquiring and purchasing land for conservation purposes. Neither the Soil Conservation Committee nor the district commissions have any direct regulatory authority, although the commissions may carry out preventive and control measures for the conservation of renewable natural resources on lands owned or controlled by the state, in cooperation with the state agency having jurisdiction over the area; or on other lands with the consent of the occupier of the land.

There are several other state statutes, however, that could potentially be used to control the impacts of erosion and sedimentation near high-quality water bodies. Chapter 46-14 of the General Laws, for example, prohibits any person from discharging any sewage, drainage, refuse, or other noxious material tending to pollute or corrupt any drinking water source. Erosion and sedimentation could be deemed a pollution source for purposes of this act, and the Department of Health could require erosion and sedimentation control devices near drinking water sources. The fine under this act for a violation, however, is only $20 per day, and is not a strong deterrent to a polluter and applies only to pollution of drinking water.

A second act which could be used to increase the state's control over erosion and sedimentation is the state's water pollution control act. Chapter 46-12 of the General Laws prohibits any person from causing pollution of the state's waters through the discharge of sewage. Sewage is defined quite broadly under this legislation and includes any substance which may be "injurious to public health or comfort, or which would injuriously affect the natural and healthy propagation, growth, or development of any fish or shellfish, ...or which would defile (the) waters." Although the act has been used primarily to regulate point sources of pollution, the procedures of this law could be used to regulate the erosion and sedimentation impacts from construction sites.

The major drawback in the existing regulatory framework, however, is its lack of comprehensiveness. There is no single regulatory program responsible for controlling the erosion and sedimentation impacts of construction, and only a limited number of communities have developed local controls. Existing state legislation is inadequate to implement the best management practices (discussed below) for control of erosion and sedimentation.

BEST MANAGEMENT PRACTICES FOR CONTROLLING EROSION AND SEDIMENTATION FROM CONSTRUCTION SITES

Erosion and runoff of sediments can be controlled effectively and economically by proper planning of land-disturbing activities. Proper planning serves the following purposes:

- the time and area of exposure of disturbed ground surfaces to the energy of rainfall and runoff water are minimized;
- the angles for graded slopes and fills are limited to an angle no greater than that which can be retained by vegetative cover or other acceptable erosion control device or structure;
- the lengths as well as the angles of graded slopes are minimized to reduce the erosive velocity of runoff water.

In addition, the appropriate combination of best management practices (BMP's) for erosion and sedimentation control should be used at the site in accordance with the following procedures:

<u>Ground Cover</u> - A ground cover (such as mulches, grass, etc.) sufficient to restrain erosion should be applied on that portion of the disturbed area where further active construction is not being undertaken.

<u>Reduce Runoff Velocity</u> - All areas subject to erosion should be treated so that the velocity of runoff water is effectively reduced below tht necessary to erode the materials. In addition to using natural vegetation and

mulches as flow impediments, mechanical measures (such as retaining walls, ditches, etc.) may also be applied.

Diversion of Runoff - Runoff from upper watershed areas which would contribute to erosion at the construction site should be diverted from disturbed areas by dikes, ditches, downdrains, etc.

Runoff Detention - Structures should be provided where needed to collect and detain runoff and trap sediment that would otherwise be transported from the site. Such structures include filter berms, straw bale barriers, nd sediment detention basins.

Protection of Downstream Channels - Where increases in stormwater runoff velocity and volume are expected to result from facilities constructed, provision should be made for permanent protection of downstream channels from the erosive effects of increased flows. Stormwater flows should be managed to decrease the time and volume of runoff concentration by increasing infiltration on site, and by conserving natural drainage ways and providing wide, meandering vegetated channels with gentle gradients and side slopes. Naturally vegetated buffer strips along stream banks should be preserved to promote infiltration of runoff water. As recommended in the 208 water-related land use plan, the width of this buffer strip should be at least 100 feet.

Source Controls - Erosion and sedimentation control measures that prevent transportation of sediments from a site area will also deter movement of solid wastes and other pollutants, such as oils, metals,and pesticides that are adsorbed to soil particles. However, sediment controls will not prevent the passage of pollutants carried in solution. Adequate control of dissolved pollutants (such as nitrates, chlorides, metals, etc.) is therefore, dependent on proper application of materials and "good housekeeping" practices. These involve conservative use of fertilizers and pesticides, with special attention to applying them only to points of need, minimizing the quantities applied and prohibiting application in periods of weather extremes such as freezing conditions which render the ground impermeable and ensure runoff of materials. Washing facilities for equipment should be located and concentrated at specific points where draining waters can be collected in impervious holding ponds. Washing of finished surfaces to remove excess concrete or other chemical residues should be undertaken only after holding ponds have been rovided to catch drainage waters. Waste quantities of paints, oils, and greases and other liquid and solid waste materials should be collected and transported to proper off-site disposal areas.

The particular measures which should be required for control of non-point source pollution from construction ites will depend on specific site characteristics, including topography, soil characteristics, vegetative cover, and climate. For a more complete description of erosion and sediment control options, see Recommendations for Erosion and Sediment Control During Land Use Change, The Southern New England Chapter, Soil Conservation Society of America, January, 1978 (available from the 208 office, Rhode Island Statewide Planning Program, 265 Melrose Street, Providence, Rhode Island 02906); or Nonpoint Source Control Guidance: construction Activities, U.S. Environmental Protection Agency, Office of Water Planning & Standards, Washington, D.C. 20460, December, 1976. Technical specifications for determing erosion potential and applying particular vegetative or structural control measures are provided in Rhode Island: Erosion and Sediment Control Handbook, U.S. Soil conservation Service, West Warwick, Rhode Island 1972."

REGULATIONS AND WATER LAW

Responsibilities

The prevention of water pollution traditionally involves all three levels of government. The federal government has served as the major source of treatment facility grants and technical assistance, and it has provided additional enforcement authority. State water pollution control agencies generally have been responsible for establishing basic regulatory and enforcement programs, water quality planning, surveillance of ground and surface waters, and administration of state aid for treatment facilities. Local governments have been principally responsible for installing and operating pollution control facilities and regulating land use.

More recently, and of direct relevance to mining control, the Office of Surface Mining (OSM) was created in 1977 after 5 years of discussions between the coal industry, environmental groups and many other interested parties. The primary purpose of the OSM was to write and administer the rules and regulations of a new federal law called Surface Mining Control and Reclamation Act, Public Law 95-87 (SMCRA). SMCRA was the first national legislation to attempt to control surface mining. In form, it is comparable to other environmental acts, such as the Clean Air Act. In approach, however, SMCRA is unique.

Unlike other environmental acts, SMCRA details specifically the goals of reclamation and precisely describes how those goals are to be met. Other environmental regulations set performance standards that industry can meet, usually using best available technology.

Among the purposes of the SMCRA is the provision of "a means for development of the data and analyses necessary to establish effective and reasonable regulation of surface mining operations for other (than coal) minerals."

An important regulatory objective is the preservation of the hydrologic balance. Permits for mining will not be issued unless the effect of mining on the hydrologic balance is ascertained and mining operations are planned in a manner that minimizes adverse consequences. Detailed regulations have been promulgated to insure that the hydrologic balance is not adversely affected during mining operations and to insure that reclamation of the mined area is carried out in a manner that restores the hydrologic balance.

The United State Environmental Protection Agency (EPA) is the major federal agency responsible for implementing environmental programs, including water pollution. Enactment of the Federal Water Pollution Control Act Amendments of 1972 signalled a long-range commitment on the part of the federal government to clean up and maintain the purity of the nation's waters. This act, which was amended in 1977, provides for the abatement of water pollution and the prevention of new pollution. First, water quality standards are established by the state; then the standards are to be attained by limiting the pollution discharged into water by individual sources. The amount of pollution is regulated under the National Pollutant Discharge Elimination System (NPDES). The NPDES system requires a permit for all point discharges to surface water. A permit generally contains conditions designed to assure compliance with water quality standards and effluent limitations. The level of treatment required by a permit depends on the type and amount of pollutants permitted to be discharged (Statewide Planning, 1979).

Among programs the Environmental Protection Agency currently is administering are those mandated by the Safe Drinking Water Act, the Clean Air act, and the National Environmental Policy Acts.

A. The Safe Drinking Water Act delegates the regulation of the quality of drinking water supplied to the EPA and the states. The major provisions which relate to the safety of drinking water and coordinated water supply-wastewater treatment planning include adoption of national interim primary standards, proposed state underground injection control program regulations for designation of sole source aquifiers, proposed regulations for organic chemicals, and research on water quality problems.

B. Under the Clean Air Act, the EPA set national ambient air quality standards, new source performance standards for new plants, and emission limits for existing stationary sources. Sludge, a by-product of most air quality control technology, must be disposed of carefully to avoid pollution of water.

C. The National Environmental Policy Act requires that all federal agencies prepare an Environmental Impact Statement for all major projects before commencing construction or operation. The impact of the proposed project on the environment including water supplied must be assessed and, if necessary, mitigating measures identified.

The State of Rhode Island has a number of departments, agencies, and boards concerned with planning, regulation, administration, and enforcement functions. The Department of Environmental Management (DEM) is the major state agency which has responsibility for water quality mamagement. Two divisions of DEM, Water Resources and Land Resources, are responsible for controlling pollution from both point and nonpoint sources of pollution. The various programs administered by these divisions form the basic framework for the state's water quality management program. The major programs administered by DEM that address point sources of pollution are construction grant funding for wastewater treatment facilities, water quality monitoring, and review of EPA discharge permits. DEM establishes water quality standards and monitors wastewater discharges (effluent) and instream (ambient) water quality. The results of the ambient monitoring program provide a basis for determining progress toward the attainment of water quality goals and standards. Effluent monitoring also is particularly important in establishing effluent load allocations, abatement programs, and compliance dates for wastewater discharge permits (Statewide Planning, 1979).

Although DEM is the primary state water quality management agency, several other offices also have responsibilities in this area. The Water Resources Board, consisting of nine (9) members representing both the public and state agences, is charged with the development of public drinking water supplies. The Department of Health is primarily responsible for protecting drinking water supplies from contamination, and it tests water supply sources. The Coastal Resources Management Council (CRMC) has extensive authority over activities within or affecting the state's coastal region, including the protection of coastal wetlands from pollution. The CRMC adopted a coastal zone management plan in March, 1978 to protect the state's coastal region. It will implement the plan through its permit and regulatory powers. The Rhode Island Statewide Planning Program is the central planning agency for state government, and it is responsible for developing plans in several functional areas, such as land use and water quality management. Finally the Solid Waste Management Corporation is responsible for developing strategies for resource recovery as an alternative solution to the state's solid waste management problems (Statewide Planning, 1979).

At the local level land use controls are the principal means available to regulate potential pollution causing activity. The relationship between land use regulations and water quality has been specifically recognized under the Federal Clean Water Act. Local governments in the Rhode Island 208 area receive the authority to regulate land use through the state's zoning and subdivision enabling acts, which delegate these powers exclusively to cities and town. At the present time, all 39 Rhode Island cities and towns have adopted zoning ordinances, and all but two urbanized communities have subdivision regulations. Blackstone and Millville (Massachusetts) also have adopted zoning and subdivision ordinances (Statewide Planning, 1979).

While zoning is an issue periferal to the study of hydrologic implications, the two are frequently related through anticipated impact. It should be noted that any development relative to mining would be in the industrial category. The vast majority of land in the Narragansett Basin is zoned as open space or residential (Statewide Planning, 1978); a small amount is industrial. This combined with a general high residential density in much of the Basin will necessitate early agreements with both the state and the municipalities involved by the prospective miner before any detailed planning effort takes place. A good initial reference is the State Housing Plan Report Number 24 (Statewide Planning).

Existing Regulations

The following discussion of the several federal, state, and local programs affecting the use of land for mining activity in Rhode Island is taken directly from the Rhode Island 208 study (Statewide Planning, 1979).

A. "Federal Programs

The relationship between land use and water quality is specifically recognized under Section 208 of the Federal Clean Water Act, which requires that the 208 plan establish a program to "regulate the location, modification and construction of any facilities... which may result in any discharge." This section also focuses on the institution of land use controls to minimize pollution from nonpoint sources, such as agriculture and construction.

The Safe Drinking Water Act of 1974 provides that federal funds be limited in areas where aquifers are in danger of contamination. The 208 land use recommendations are a means of helping to ensure that such contamination does not occur.

The Coastal Zone Management Act of 1972 provides for the development of management plans to protect the nation's coastal waters, shorelands, and inland waters which have a direct and significant impact on coastal waters. There are several relaionships between coastal zone management planning and water quality planning, undertaken through Section 208 of the act. Section 307 of the Coastal Zone Management Act specifically provides that programs developed pursuant to the Clean Water Act will be incorporated as the water quality component of coastal zone management programs. This provision attempts to achieve compatible planning between the two programs, and a memorandum of understanding has been entered into between Rhode Island's 208 planning program and the state's coastal resources management agency. All proposals for activity in the coastal zone are evaluated in terms of their impact on water quality, among other factors."

B. "State Programs

There are several state laws aimed at protecting wetlands and shoreline areas. These include controls over intertidal salt marshes, coastal wetlands, and freshwater wetlands.

Intertidal wetlands are protected under Chapter 11-46.1 of the General Laws. Any person who

> ...dumps or deposits mud, dirt, or rubbish upon, or who excavates or disturbs the ecology of intertidal salt marshes, or any part thereof, without first obtaining a permit from the Department of Environmental Management shall be fined for each offense five hundred dollars ($500).

A violator may be required to restore the marsh to its original conditon.

Coastal wetlands can also be protected under Sections 2-1-13 through 2-1-17 of the General Laws. The Department of Environmntal Management is authorized under these sections to "...designate coastal wetlands or parts thereof, the ecology of which shall not be disturbed and the use of which shall be restricted to those uses compatible with the public policy of this state as set forth in such order." The Department, in adopting such an order, must consider the value of the coastal wetlands to the public health, marine fisheries, wildlife, and the protection of life and property from flood, hurricane and other natural disasters. No city or town can permit "the use of such restricted coastal wetlands contrary to such order."

There have been, however, several difficulties in implementing the Coastal Wetlands Act. An owner of land, subject to an order designating a coastal wetland, can "recover compensation for damage in an action filed in superior court within two years from the date of recording such order." the money to be awarded for these damages is appropriated through a Recreational and Conservation Land Acquisition and Development Fund established in 1964, or it can be appropriated directly for the enforcement of the act. No special appropriations have been made, however, for the enforcement of the act, and the Recreation Fund has been inadequate to meet the potential cost of damages to owners. As a result, no order has as yet been issued under this act.

Freshwater wetlands, including marshes, swamps, bogs, and other types of wetland areas, are protected under the Fresh Water Wetlands Act of 1971, and the amendments to this act of 1974. The act prohibits the alteration of freshwater wetlands by excavation, drainage, fill and other activities without first obtaining a permit from the Department of Environmental Management and the approval of the local city or town council. A violator under this act may be required to restore the wetland to its previous condition, and he also is liable for a fine of up to $1000 for each violation.

The Fresh Water Wetlands Act differs from the Coastal Wetlands Act in several ways. Under the Fresh Water Wetlands Act, the Department of Environmental Management acts on individual permits, rather than issuing an order designating an area to be protected and the permitted uses. The 1974 amendments to the act also establish several criteria for the awarding of damages. The superior court may direct that compensation be paid if "...the proposed alteration would not essentially change the natural character of the land, would not be unsuited to the land in the natural state, and would not injure the rights of others." The Coastal Wetlands Act does not contain any similar criteria, and protection under this act could routinely involve the payment of funds.

The Fresh Water Wetlands Act, Sections 2-1-9 through 2-1-25, also defines floodplains as areas adjacent to a river or stream which are likely to be covered with floodwaters resulting from a 100-year frequency storm. These floodplains are considered wetlands under the act, along with any area of land within 50 feet of the edge of a bog, marsh, swamp or pond.

Recent controversy over the application of the Wetlands Act has resulted in several changes to the permit process. The thrust of these changes has attempted to provide an objective determination of the application of the Wetlands Act to a particular site, and a more open process for the granting or denial of wetland permits.

Chap. 46-23 of the General Laws established the Coastal Resources Management Council (CRMC) to plan and coordinate activities in the coastal areas. Several specific types of activities over which the CRMC has jurisdiction are set out in the act:

- power generating and desalination plants;
- chemical or petroleum processing, transfer, or storage;
- minerals extraction;
- shoreline protection facilities and physiographical features;
- intertidal salt marshes; and
- sewage treatment and disposal, and solid waste disposal facilities.

The CRMC has adopted a coastal management plan in accordance with the national legislation. The 208 plan, when completed, will be included as the water quality element of this coastal plan. A memorandum of understanding has been ntered into by the 208 project and the CRMC to ensure coordination of the two planning processes. The R.I. Coastal Resources Management Council has authority to regulate potentially polluting activities within coastal wetlands and contiguous land areas within 200 feet of these wetlands. The CRMC plan recognizes that sewage disposal and stormwater runoff occurring outside that 200-foot area can affect the quality of coastal waters, but coastal permits are required only for "major" activities which occur beyond the 200-foot boundary.

C. Local Program

Local governments traditionally have had the primary authority for regulating land use. This authority is granted to the cities and towns by the state zoning and subdivision enabling acts, which were adopted during the early 1920's. The acts set forth specific purposes for land use controls and describe the kinds of actions which can be taken.

Zoning - Zoning ordinances divide the land in a community into districts and specify the uses which are permitted in each. Every community in Rhode Island, as well as Blackstone and Millville, Massachusetts, have adopted zoning ordinances. A general zoning map for the 208 area is in the back of this report. In Rhode Island, most communities adopted their ordinances under the provisions of the general state zoning enabling act, although several communities, such as South Kingstown, have special acts. The power to adopt a zoning ordinance rests with the city or town council. In most communities, the ordinance is drafted by the planning board, usually with the assistance of a professional planner, and reviewed by the town solicitor before it is enacted. The building inspector usually is the enforcement officer; a permit will not be ussued for a structure not in conformance with the provisions of the zoning ordinance. The zoning board of review is authorized to grant variances from the requirements when "a literal enforcement of the provisions of the ordinance will result in unnecessary hardship..." and to grant special exceptions which are "in harmony with its general purpose" or are "reasonably necessary for full enjoyment of the property."

The zoning powers, as stated in the general enabling act, are as follows:

> ...to regulate and restrict the height, number of stories and size of buildings and other structures, the percentage of lot that may be occupied, the size of yards, courts and other open spaces, the density of population, the location and use of buildings, structures and land for trade, industry, residence or other purposes, and to prohibit or limit uses of land in areas deemed to be subject to seasonal or periodic flooding.
>
> For any and all of said purposes said city or town council may divide the municipality into districts of such number, shape, and area as it may deem best suited to carry out the purposes of this chapter; and within such districts it may regulate and restrict the erection, construction, reconstruction, alteration, repair or use of buildings, structures or land. All such regulations shall be uniform for each class or kind of buildings throughout each district but the regulations in one district may differ from those in other districts.

The Rhode Island Supreme Court has held that city and town ordinances cannot exceed the authority conferred by the enabling legislation. Because these acts were drafted in the 1920's, many of the more modern zoning techniques are not mentioned, and it is questionable whether communities have the power to use many of these newer tools.

The most persistent controversy with regard to zoning is the so-called "taken issue." The Fifth Amendment to the U.S. Constitution provides protection for property owners: "...nor shall private property be taken for public use, without just compensation." Courts have held that a municipality cannot zone property in such a way that the owner is "denied all economic use" of the land. It is often difficult to determine at what point zoning restrictions constitute such an unlawful taking.

The takings issue fundamentally is one of balancing the rights of society against the rights of individual landowners. Because there is no certain position on these matters, courts have applied the takings principle in view of their understanding of current conditions. In thousands of cases, courts have been asked to determine whether a particular restriction went too far to be sustainable without compensation. Decisions and rationales have been widely divergent, and as a result, there is considerable uncertainty about how far restrictive powers can go before expensive compensation must be paid."

The basis of regulatory control under the Surface Mining Control and Reclamation Act are contained in the following quote (Seltz-Patrash, 1980):

> "Under the Surface Mining Control and Reclamation Act (SMCRA), surface mining and reclamation proceed together. First vegetation and topsoil (6-12 in [253-305 mm] in the West) are removed and stockpiled. Next the overburden (100-150 ft/20.2-45.7 m thick) is removed and stored next to the pit in piles (spoil ridges). At this point, each mine site must have sedimentation ponds and run-off diversion ditches constructed.
>
> Next, rows (cuts) are dug up to 50 ft (15 m) thick, 1 mile (1.6 km) long and 15 to 200 ft (4.6 to 61 m) deep. The coal is drilled, blasted and removed. Each cut must be backfilled within 180 days after coal is removed, by law. Because the overburden expands when removed, the filled cuts have ridges which must be graded back to the original contour of the land. Finally topsoil is replaced and the land is seeded, mulched and the healing process begins.
>
> SMCRA is designed to protect the land during mining and ensure that it is returned to its pre-mining condition-and this includes soil composition, vegetation and wildlife habitats, land contour and groundwater and aquifer flow."

The following are key issues in regulatory control of mining operations:

A. Establishment of base line information areas proposed for mining must have their characteristics completely defined prior to commencement of mining operations to avoid subsequent controversy over restoration.

B. Detention and monitoring of water leaving the mine area is essential to ensure down stream water quality during operations. In this regard, diversion channels and sedimentation ponds are the heart of the operational regulatory scheme.

C. Groundwater quality control by adequate design of dewatering and monitoring systems. As with all other regulatory practices, it is very important that monitoring with shut down authority be accomplished by parties completely independent of the mine operator.

D. Post mining planning and restoration is essential to the future use of the mined area (Green, 1981). The land mined must be returned to other productive uses when mining is complete. But this can be done effectively only if a coherent plan is developed before mining operations start.

Proposed Mining Controls

In order to protect the public and the environment, certain hydrologic aspects must be included in mining controls. Such controls must be a part of the planning, operation and post-operation phases of mining. The main elements which should be included in any mining rules and regulations are:

Establishment of baseline data for determination of premining water quality and quantity.

Prior approval of mining schemes and detailed evaluation of probable environmental impact.

Design and establishment of monitor systems to ensure that adequate surveilance can be maintained.

Ensurance that operational controls are adequate to maintain hydrologic balance in the mining region.

Resealing of exploration holes to preclude cross flow contamination of groundwater.

Acceptable water quality of surface water and groundwater moving from the site. Quality considerations must include both dissolved and suspended loads.

Procedures for maintenance of water table levels in areas in proximity to mining operations.

Procedures for maintenance of stream flow in areas in proximity to mining operations.

Procedures for special protection of wetlands.

Provisions for restoration of region after mining has ceased.

All of the foregoing are adequately covered in Pennsylvania Bulletin, Volume 10, Number 51, (Department of Environmental Rules and Regulations Concerning Coal Mining). This document can be used as a model for Rhode Island mining regulations, with certain additions hereafter described.

A unique feature of the Narragansett Basin is the large amount of salt water shoreline included in the region. This necessitates special measures to avoid salt water intrusion problems. Provisions should be included in the Rhode Island mining regulations to:

1. establish baseline information on the location of the fresh water-salt water interface in the ground in coastal areas.
2. evaluate the effect of the preposed mining operations, especially dewatering, on the fresh water-salt water interface.
3. establish a coastal groundwater monitor systems to ensure protection for present and future groundwater users.

The following specific additions to adapt the Pennsylvania mining regulations to Rhode Island are recommended:

1. Sections 87.1,88.1 and 89.5, "Definitions."

   add (x) Coastal ground water - ground water in hydrologic balance with a salt water boundary.

2. Section 87.45a, "ground water information"
   Section 88.25a, "ground water"

   add (x) The position and limits of the fresh water - salt water interface in coastal areas.

   add (x) Water Table fluctuations on a seasonal and daily basis in coastal areas.

3. Section 88.305, "Hydrologic balance: ground water monitoring."
   Section 89.92, " Surface and ground water monitoring"

   add (x) Ground water monitoring in coastal ground water shall include multi-level sampling sufficient to describe movement and limits of the fresh water - salt water interface.

CONCLUSIONS

Most of the Narragansett Basin is served by public water supply not likely to be affected by mining activity; however, numerous active private and industrial wells are present which could be adversely affected by mining activity.

In the coastal region of the Narragansett Basin, lowering of the water table could cause salt water intrusion with severe consequences to wells in the affected area.

Any effect by mining on ground water levels or quality can be of great importance to ponds, lakes and streams because of the likelihood of hydraulic connections.

Because of the lack of framboidal pyrite in the Narragansett Basin rocks, severe acid mine drainage problems are not likely. However, investigation and acid drainage predictions should be made on a site specific basis.

Suspended sediment contamination of surface waters is a potential problem in waters originating in, or passing through, coal mining regions. Sediment from coal processing and surface erosion must be controlled.

Adequate control of mining operations and protection of Rhode Island citizens from adverse consequences while still permitting reasonable exploitation of coal resources will necessitate detailed involvement and careful planning by both state and municipal agencies.

It is essential that the prospective miner produce complete plans for both operational and post operational phases of mining prior to commencement of mining.

Collection of baseline data before operations begin, and continuous monitoring during and after mining is essential to assessing and controlling the environmental impact of mining.

As compared with other states, such as Pennsylvania, where comprehensive mining regulations exist and can be used as model, Rhode Island is unique in that salt water bodies exist within a few miles of any prospective mining operation. This requires that Rhode Island mining regulations include specific provisions to guard against ground water contamination by salt water intrusion.

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APPENDIX A

GROUNDWATER CHARACTERISTICS FOR WATER BEARING FORMATIONS OF THE NARRAGANSETT BASIN

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GROUNDWATER CHARACTERISTICS FOR WATER BEARING FORMATIONS OF THE NARRAGANSETT BASIN

SEDIMENTARY ROCKS

The following is taken from Lang (1961):

"The Carboniferous sedimentary rocks of Rhode Island also have a porosity of less than 1 percent, and the only openings capable of transmitting water are the secondary openings along joints, fractures, and bedding planes.

A summary of the yield of 418 wells tapping sedimentary rocks in Rhode Island indicates an average yield of 30.9 gallons per minute and a range in yield from less than 1 to 500 gallons per minute. Thus, the average yield from sedimentary rocks as a whole is almost three times as great as from the crystalline rocks. Three percent of ten wells yielded less than 1 gallon per minute. Forty-nine percent yielded from 1 to 10 gallons per minute, and 32 percent yielded from 11 to 50 gallons per minute. Only 16 percent yielded more than 50 gallons per minute. Small and large yields of wells, as in the crystalline rocks, were scattered throughout the State.

Depths of wells in Carboniferous strata range from 38 to 1,436 feet and average about 277 feet. Such wells are, on the average, more than 100 feet deeper than those tapping crystalline rocks. This greater average depth is due partly to topographic location. The sedimentary rocks are in the low-lying Narragansett and Woonsocket Basins covered in most places by 50 to 100 feet of overburden. Thus, wells in sedimentary rocks may also penetrate thick deposits of overburden.

Many wells have been drilled into the Carboniferous strata in Rhode Island. Most of them have produced enough water for domestic, farm, and small industrial use. As only 16 percent of 418 wells penetrating Carboniferous sedimentary rock had reported yields of more than 50 gallons per minute, they cannot be considered sources of large supplies of ground water for municipal and industrial use."

Biershenk (1959) provides the following observation of interest:

"In the summer of 1955 there was opportunity to examine closely the Pennsylvanian sedimentary rocks then exposed along the line of a sewer tunnel under construction in Pawtucket. The 8-foot tunnel passes beneath the large till-bedrock hill in the northeast corner of the quadrangle and lies beneath the line of test borings Paw. 310, 307, 305, 302 and others extending northeastward to Pleasant Street. The tunnel is 4,980 feet long and penetrates interbedded sediments, principally dark-gray sandy shale, shaly sandstone, and thin coaly beds of the Rhode Island formation. Locally, at the eastern end, red sandstone of the Wamsutta formation was penetrated. The bedding of the sedimentary rocks strikes roughly north and dips 35 to 50 degrees east. Two major joint systems are evident. The greater number of joints strike north and dip generally about 35 degrees or about 50 degrees west, although a few dip as much as 80 degrees west. Other joints strike north and dip roughly 60 to 80 degrees east. The spacing between joints usually ranges from a few feet to 10 feet and the width of opening ranges from that which was scarcely visible to a sixteenth of an inch. Water was observed to be percolating along both bedding planes and joints, presumably coming largely from the overlying unconsolidated glacial deposits."

GLACIAL TILL

The following is taken from Lang (1961):

"The till in Rhode Island is relatively impermeable and, like clay, yields water very slowly, te rate of yield depending upon the proportion of coarse material to fine material. The composition of till may vary considerably from place to place. Some observers report a great contrast in the character of the till in the town of Cumberland west and east of Diamond Hill Road. To the west the till is underlain by metamorphosed igneous and sedimentary rocks and has a somewhat sandy or stony character, whereas to the east the till overlies shales of Carboniferous age and is more clayey. More permeable lenses or local layers of stratified sand and gravel occur in till or immediately between the till and the underlying bedrock. Doubtless, many of the wells listed as penetrating till obtain most of their water from such permeable layers.

Till, in one form or another, generally yields sufficient water for household and farm use. Groundwater is usually obtained from the till by means of dug wells, which offer the advantage of a large storage area and comparatively inexpensive cost of construction. The water level in such shallow dug wells may reach low stages in late summer and early fall. Records show that many till wells become dry each year late in the summer. As a result, shallow dug wells are gradually being replaced by deeper drilled wells tapping bedrock.

In general, wells finished in till average about 20 feet in depth and yield less than 2 gallons per minute, unless layers of sand and gravel are penetrated. About half the water pumped from farm and household wells in the State is obtained from the till."

GLACIAL OUTWASH

The following is taken from Lang (1961):

"Outwash deposits are the most productive aquifers in Rhode Island because of the abundance of well-sorted coarse-graned particles. Such deposits yield water readily to drilled and driven wells. Depositional conditions during the Pleistocene epoch were varied and relatively complex. As a result the character, and consequently the permeability, of the outwash varies considerably within relatively short distances, in some cases abruptly changing from coarse-grained to fine-grained materials. The finer outwash deposits, clay and silt, are nearly imperrvious. Data for wells ending in outwash indicate a range in depth from 20 to more than 200 feet and a range in yield from to 3 to 2,700 gallons per minute.

The coarser stratified beds of sand and gravel are the most important potential sources of large supplies of ground water in the state. Unfortunately, only a relatively small part of the state is underlain by such beds. The principal areas in Rhode Island that are underlain by coarse stratified deposits include the valleys of the major streams, except in Newport County.

Where present streams flow directly over beds of coarse outwash, infiltration of river water can be induced by locating wells adjacent to the streams. In such locations, individual wells may yield as much as 2,000 gallons per minute, or even more. For example, a small area of outwash along the Hunt River in Warwick and East Greenwich yields several million gallons of water daily without causing a progressive decline in water levels. Also, the Kent County Water Authority well field, several hundred feet from the Hunt River, yields more than 1 million gallons daily without causing a decline of water levels. Less than one-quarter of a mile from the Kent County wells and also near the Hunt River, the supply wells for Quonset Point Naval Air Station also withdraw more than 1 million gallons per day without progressive lowering of water levels. Undoubtedly the yield from these well fields represents but a small part of the total capacity. In Rhode island, ground-water levels under natural conditions are usually above stream levels, and infiltration through stream beds into the ground occurs only for short periods at times of high streamflow. However, where groundwater levels are lowered below stream levels by pumping from wells, as is the case along the Hunt River, the water-table gradient is reversed and water flows from the river into the ground. Under such conditions streamflow is a major factor in ground-water recharge. Pumping may also result in more recharge during highwater stages by providing more storage space in the aquifer, even in areas where recharge is not induced during periods of lower streamflow."

APPENDIX B

WELL RECORDS FOR RHODE ISLAND TEST HOLES DRILLED IN 1976-77

FORM NO 9-1904-A

SITE NO.

#7

U.S. DEPT. OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION
GROUND WATER SITE INVENTORY
SITE SCHEDULE

Recorded by MAEVSKY

Date 11-11-76

Check One ✓ English ___ Metric Units

GENERAL SITE DATA (0)

Site Ident No 414324371164801

RG Number R-0

Transaction T- [✓ A] D M V (add, delete, modify, verified)

Site Type 2- C D H I M P T [✓ W] (collector, drain, unc hole, connector, multiple, pond, tunnel or shaft, well)

Data Reliability 3- [✓ C] U L M (field checked, unchecked, location not accurate, minimal data)

Reporting Agency 4- USGS

Project No. 5- MA27245

District 6- 25

State 7- 44

County (or town) 8- 001

Latitude 8- 414024 (deg min sec)

Longitude 10- 0711649 (deg min sec)

Lat-Long Accuracy 11- [✓ S] F T M (sec, 5 sec, 10 sec, Min)

Local Number 12- BRW 145

Land Net Loc. 13- (1/4 1/4 1/4 section, T township, R range, merid)

Location Map 14- BRISTOL

Scale 15- 24000

Altitude 16- 10

Method of Measurement 17- A L [✓ M] (altimeter, level, map)

Accuracy 18- 5

Topo Setting 19- D C E F H K L O P [✓ S] T U V W (depression, stream channel, dunes, flat, hilltop, sink, swamp, offshore, pediment, hillside, terrace, undulating, valley flat, upland draw)

Hydrologic Unit (OWDC) 20- 01090004

Date of First Construction/Completion 21- 08/30/1976 (month day year)

Use of Site 23- A D E G H O M P R S [✓ T] U W X Z

Use of Water 24- A B C D E F H I M N P R S T U Y [✓ Z] (air cond., bottling, commercial, dewater, power, fire, domestic, irrigation, medicinal, industrial, public supply, recreation, stock, institution, unused, desal, other)

Secondary Water Use 25-

Tertiary Use of Water 26-

Depth of Hole 27- 332

Depth of Well 28- 332

Source of Depth Data① 29- G

Water Level 30- 6.41

Date Measured 31- 11/09/1976 (month day year)

Source① 33- G

Method of Measurement 34- A C E G H L M R [✓ S] T V Z (airline, calibrated airline, estimated, pressure gage, calibrated pressure gage, geophysical logs, manometer, reported, steel tape, electric tape, calibrated electric tape, other)

Site Status 37- D F G H O P R S T V X Z (dry, flowing, nearby flowing, nearby recently flowing, obstruction, pumping, recently pumped, nearby pumping, nearby recently pumped, foreign substance, surface water effects, other)

Source of Geohydrologic Data① 36- G

Pump Used 35- (no)

Measuring Point 268- 0.20

Measuring Point Date 267- 11/09/1976 (month day year)

OWNER IDENTIFICATION (1)

R-158 T- [✓ A] D M (add, delete, modify)

Date of Ownership 159# / / (month day year)

Name: Last 161- BRISTOL

First 162- TOWN

Middle Initial 163-

OTHER SITE IDENTIFICATION NUMBERS (8)

R-189 T- [✓ A] D M (add, delete, modify)

Ident 190#

Assignor 191- NE DIST

New Card Starts H & T

Ident 190#

Assignor 191-

SITE VISIT DATA (8)

R-186 T- [✓ A] D M (add, delete, modify)

Date of Visit 187# 11/09/1976 (month day year)

Name of Person 188- MAEVSKY A.

FIELD WATER QUALITY MEASUREMENTS (1)

R-192 T- A D M (add, delete, modify)

Date 193# / / (month day year)

Geohydrologic Unit 195#

New Card Same H thru 195

Temperature 196# 00010

Degrees C 197-

Conductance 196# 00095

µmhos 197-

Other (STORET) Parameter 196#

Value 197-

Other (STORET) Parameter 196#

Value 197-

FOOT NOTES:

① Source of Data Codes:

S	D	O	A	R	L	G	Z
reporting agency	driller	owner	other gov't. agency	other reported	logs	geologist	other

#7

WELL CONSTRUCTION DATA (1)

R=65 • T= [✓ A] D M • add, delete, modify

Entry No 58# 0,0,1 •

Date of Construction Completion 66• 0,2/2,0/1,9,7,6 • month day year

Source of Data ① 3 •

Name of Contractor/Driller 62• S+H BROOKS •

Method of Construction 63• A B C D [✓ H] J P R T V W Z •
air rotary, bored or augered, cable tool, dug, hydraulic rotary, jetted, air percussion, reverse rotary, trenching, driven, drive wash, other

Finish 66• C F G H M P S T W [✓ X] Z •
porous concrete, gravel w. sand, gravel screen, horizontal gallery, open end, perforated or slotted, screen, sand point, walled, open hole, other

Type of Seal 67• B C G Z •
bentonite, clay, cement grout, other

Bottom of Seal 68• •

Method of Development 69• A B C J M P S Z •
air lift pump, bailed, compressed air, jetted, ..., pumped, surged, other

Number of Hours in Development 70• •

Special Treatment During Development 71• C D E F H M Z •
chemicals, dry ice, explosives, deflocculant, hydrofracturing, ..., other

DIMENSIONS OF THE HOLE CONSTRUCTED (2)

R=72 • T= [✓ A] D M • add, delete, modify

Construction Entry No 59# 1 •

New Card for Each Hole Segment Same R, T & Field 59

Top of Hole Segment Below LSD	Bottom of Hole Segment Below LSD	Diameter of Hole Segment
73# 0.0 •	74• 332. •	75• 3.0 •
73# •	74• •	75• •
73# •	74• •	75• •
73# •	74• •	75• •
73# •	74• •	75• •

CASING SCHEDULE (2)

R=76 • T= [✓ A] D M • add, delete, modify

Construction Entry No 59# 1 •

New Card for Each Casing With Same R, T & Field 59

Top of Casing Segment Below LSD	Bottom of Casing Segment Below LSD	Diameter of Casing Segment	Casing Material ⑤	Thickness of Casing
77# •	78• 46. •	79# 3.0 •	80• S •	81• 3.75 •
77# •	78• •	79# •	80• •	81• •
77# •	78• •	79# •	80• •	81• •
77# •	78• •	79# •	80• •	81• •
77# •	78• •	79# •	80• •	81• •

OPENINGS SCHEDULE (2)

R=82 • T= [✓ A] D M • add, delete, modify

Construction Entry No 59# 1 •

New Card for Each Open Section With Same R, T and Field 59

	(Openings Data)	(Openings Data)	(Openings Data)
Top of Section Below LSD	83# 46. •	83# •	83# •
Bottom of Section Below LSD	84• 332. •	84• •	84• •
Type of Openings ⑥	85• •	85• •	85• •
Type of Material ⑦	86• •	86• •	86• •
Diameter of Open Section	87• •	87• •	87• •
Width of Opening	88• •	88• •	88• •
Length of Opening	89• •	89• •	89• •

FOOTNOTES:

① Source of Data Codes:
[B D E A R L G Z]
reporting agency, driller, owner, other gov't, other reported, logs, etc. / geol., other

⑤ Casing Material Codes
[B C G I M P R S T U W Z]
brick, concrete, galv. iron, wrought iron, other metal, PVC or plastic, rock or stone, steel, tile, ..., wood, other

⑥ Type of Openings Codes
[F L M P R S T W X Z]
fracture, louvered, mesh, perforated or slotted, wire wound, screen, sand point, walled, open hole, other

⑦ Type of Material Codes for Open Sections
[B C G I M P R S T Z]
brass or bronze, concrete, galv. iron, wrought iron, other metal, PVC or plastic, ..., steel, tile, other

7

PRODUCTION DATA (1)

R= 134 146 ● (flowing, pumped) T= A D M (add, delete, modify) Entry No 147 # ● Date 148= / (month day) (year) ●

Discharge 150= ● Source of Data① 161= ●

Method of Measurement 152= B C E F M O P R T U V W Z ● (bailer, current meter, estimated, flume, totaling meter, orifice, pitot-tube meter, reported, trajectory, unknown, volumetric, weir, other)

Production Level 153= ● Static Level 154= ● Source of Data① 155= ● Specific Capacity 272= ●

Method of Measurement 156= A C E G H L M R S T V Z ● (airline, calibrated airline, estimated, pressure gage, calibrated pressure gage, geophysical logs, manometer, reported, steel tape, electric tape, calibrated electric tape, other) Pumping Period 157= ●

LIFT DATA (1)

R=42 ● T= A D M ● (add, delete, modify) Type of Lift 42 # A B C J P R S T U Z ● (air, bucket, centrifugal, jet, piston, rotary, submergible, turbine, unknown, other) Entry No 254 # ●

Pump Intake Setting 44= ● Type of Power 45= D E G H L N W Z ● (diesel, electric, gasoline, hand, LP gas, natural gas, windmill, other)

Date 31= / / ● (month day year) Horsepower 46= ●

MAJOR PUMP DATA (2)

R=47 ● T= A D M ● (add, delete, modify) Type of Lift 43# ● Lift Entry No 254 # ● Manufacturer of Pump 48= ●

Serial No of Pump 49= ● Name of Power Company 50= ●

Power Company Account No 51= ● Power Meter No 52= ● Pump Rating 53= ●

Person or Company Who Maintains the Pump 54= ● Additional Lift 255 = ● Rated Pump Capacity 268= ●

STANDBY POWER DATA (2) (See LIFT DATA for codes of fields 43 and 56 below)

R=55 ● T= A D M ● (add, delete, modify) Type of Lift 43# ● Type of Power 56= ● Horsepower 57= ● Lift Entry No 254 # ●

AVAILABLE LOG DATA (1)

R=198 ● T= [✓ A] D M ● (add, delete, modify)

New Card for Each Log Type Same R & T

Type of Log②	Begin Depth	End Depth	Source of Data①
199 # G ●	200= 0.0 ●	201= 332 ●	202= G ●
199 # ●	200= ●	201= ●	202= ●
199 # ●	200= ●	201= ●	202= ●
199 # ●	200= ●	201= ●	202= ●

WATER QUALITY DATA COLLECTION (1)

R=114 ● T= [✓ A] D M ● (add, delete, modify) Begin Year 115# 1,9,7,6 ● End Year 116= ● Source Agency 117= USGS ●

Frequency of Collection ③ 118= ● Network Site 257 = ● Type of Analyses④ 120= ●

WATER LEVEL DATA COLLECTION (1)

R=121 ● T= A D M ● (add, delete, modify) Begin Year 122# ● End Year 123= ● Source Agency 124= ●

Frequency of Collection ③ 125= ● Network Site 258= ●

WATER PUMPAGE/WITHDRAWAL DATA COLLECTION (1)

R=127 ● T= A D M ● (add, delete, modify) Begin Year 128# ● End Year 129= ● Source Agency 130= ●

Frequency of Collection ③ 131= ● Network Site 259= ● Method of Collection 133= C E M U Z ● (calculated, estimated, metered, unknown, other)

OTHER DATA AVAILABLE (1)

R=180 ● T= [✓ A] D M ● (add, delete, modify) Type of Data 181# CQAL ● Loc 182= C [✓ D] Z ● (cooperator, district, other) Format 261= [✓ F] M P Z ● (film, machine readable, published, other)

New Card Same R & T Type of Data 181# ● Loc 182= C D Z ● Format 261= F M P Z ●

FOOT NOTES:

① Source of Data Codes:

S	D	O	A	R	L	G	Z
reporting agency	driller	owner	other gov't	other reported	logs	geologist	other

② Type of Log Codes

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
time	collar	caliper	driller's	electrical	fluid conduct	geologist	magnetic	induction	gamma ray	dipmeter	laterlog	microlog	neutron	[illegible]	photo	[illegible]

S	T	U	V	Z
sonic	temp.	gamma gamma	fluid velocity	other

③ Frequency of Collection Codes

A	B	C	D	F	I	M	O	Q	S	W	Z
annual	bi-monthly	continuous	daily	semi monthly	intermittent	monthly	one time only	quarter annual	semi-annual	weekly	other

④ Type of Quality Analyses Codes

A	B	C	D	E	F	G	H	J	K	L	M	Z
physical	common chemical	trace elements	pesticides	nutrients	sanitary	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	other

#7

GEOHYDROLOGIC UNIT DESCRIPTIONS (8)

R=90 • | T= [✓ A] D M • (add, delete, modify) | Entry No 256 # 1 • | Depth to Top 91 = 0.0 • | Depth to Bottom 92 = 33.2 •

Unit Identifier 93 = 320SDMR • | Lithology 96 = SDMN • | Lithologic Modifier 97 = •

AQUIFER DATA (2)

R=94 • | T= A D M • (add, delete, modify) | Geohydrologic Unit Entry No 256 # •

Date 95 # / / • (month day year) | Water Level 129 = • | % Water Contributed 132 = •

GEOHYDROLOGIC UNIT DESCRIPTIONS (8)

R=90 • | T= A D M • (add, delete, modify) | Entry No 256 # • | Depth to Top 91 = • | Depth to Bottom 92 = •

Unit Identifier 93 = • | Lithology 96 = • | Lithologic Modifier 97 = •

AQUIFER DATA (2)

R=94 • | T= A D M • (add, delete, modify) | Geohydrologic Unit Entry No 256 # •

Date 95 # / / • (month day year) | Water Level 129 = • | % Water Contributed 132 = •

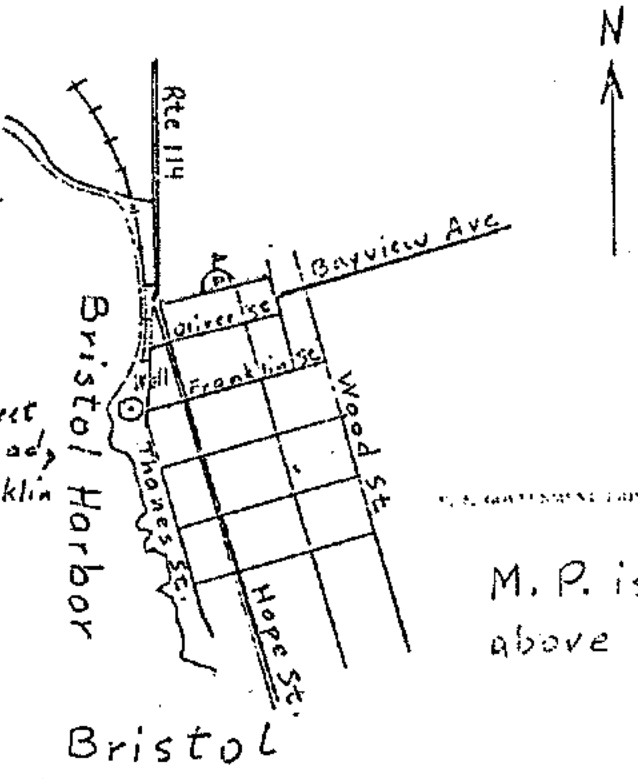
PERTINENT REMARKS

R=161 • | T= A • (add) | 185 = •

New Card Start R&T | 185 = •

185 = •

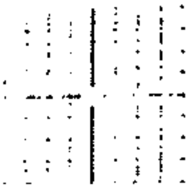
NOTES:



Well is 90 feet west from road, opposit Franklin St.

M. P. is 0.20 feet above LSD

Bristol



U.S. GOVERNMENT PRINTING OFFICE : 1975 O - 574-068

FORM NO 9-1904-A

SITE NO

#23

U.S. DEPT. OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION
GROUND WATER SITE INVENTORY
SITE SCHEDULE

Recorded by MAEVSKY

Date 11-11-76

Check One ✓ English ___ Metric Units

GENERAL SITE DATA (0)

Site Ident No 414026071164701

RG Number R-0

Transaction T- [✓ A] D N V (add, delete, modify, certified)

Site Type 2- C D N E M P T [✓ W] (collector, drain, sinkhole, excavation, multiple, pond, tunnel or shaft, well)

Data Reliability 3- [✓ C] U L M (field checked, unchecked, location not accurate, minimal data)

Reporting Agency 4- USGS

Project No. 5- MA77045

District 6- 25

State 7- 44

County (or town) 8- 001

Latitude 9- 414026 (deg min sec)

Longitude 10- 0711647 (deg min sec)

Lat-Long Accuracy 11- [✓ S] F T M (sec, 5 sec, 10 sec, Min)

Local Number 12- BRW 146

Land Net Loc. 13- 1/4 1/4 1/4 S (section) T (township) R (range) (merid)

Location Map 14- BRISTOL

Scale 15- 24000

Altitude 16- 10

Method of Measurement 17- A L [✓ M] (altimeter, level, map)

Accuracy 18- 5

Topo Setting 19- D C E F H K L B P [✓ S] T U V W (depression, stream channel, dunes, flat, hilltop, sink, swamp, offshore, pediment, hillside, terrace, undulating, valley flat, upland draw)

Hydrologic Unit (OWDC) 20- 01090004

Date of First Construction/Completion 21- 09/13/1976 (month day year)

Use of Site 23- A O E G H D M P R S [✓ T] U W X Z (anode, drain, geothermal, seismic, heat reservoir, observation, oil or gas, recharge, repressure, test, unused, withdrawal, waste, destroyed)

Use of Water 24- A B C D E F H I M N P R S T U Y [✓ Z] (air cond., bottling, commercial, dewater, power, fire, domestic, irrigation, medicinal, industrial, public supply, recreation, stock, institution, unused, desal, other)

Secondary Water Use 25-

Tertiary Use of Water 26-

Depth of Hole 27- 524

Depth of Well 28- 524

Source of Depth Data① 29- G

Water Level 30- 5.74

Date Measured 31- 11/09/1976 (month day year)

Source① 33- G

Method of Measurement 34- A C E G H L M R [✓ S] T V Z (airline, calibrated airline, estimated, pressure gage, calibrated pressure gage, geophysical logs, manometer, reported, steel tape, electric tape, calibrated electric tape, other)

Site Status 37- D F G H J P R S T V X Z (dry, flowing, nearby flowing, nearby recently flowing, obstruction, pumping, recently pumped, nearby pumping, nearby recently pumped, foreign substance, surface water effects, other)

Source of Geohydrologic Data① 36- G

Pump Used 35- (no)

Measuring Point 266- 1.20

Measuring Point Date 267- 11/09/1976 (month day year)

OWNER IDENTIFICATION (1)

R-158 T- [✓ A] D M (add, delete, modify)

Date of Ownership 159# / / (month day year)

Name: Last 161- BRISTOL

First 162- TOWN

Middle Initial 163-

OTHER SITE IDENTIFICATION NUMBERS (3)

R-189 T- [✓ A] D M (add, delete, modify)

Ident 190#

Assigner 191- WE DIST

New Card Same R & T

Ident 190#

Assigner 191-

SITE VISIT DATA (1)

R-186 T- [✓ A] D M (add, delete, modify)

Date of Visit 187# 11/09/1976 (month day year)

Name of Person 188- MAEVSKY A

FIELD WATER QUALITY MEASUREMENTS (1)

R-192 T- A D M (add, delete, modify)

Date 193# / / (month day year)

Geohydrologic Unit 195#

New Card Same R thru 195

Temperature 196# 0,0,0,1,0 Degrees C 197-

Conductance 196# 0,0,0,9,5 μ Mhos 197-

Other (STORET) Parameter 196# Value 197-

Other (STORET) Parameter 196# Value 197-

FOOT NOTES:

① Source of Data Codes:
S D G A R L G Z (reporting agency, driller, owner, other gov't, other reported, logs, geologist, other)

#23

WELL CONSTRUCTION DATA (8)

R-58 • T- [✓ A] D M • (add, delete, modify) Entry N. 59 # 001 • Date of Construction Completion 60- 09/13/1976 • (month day year) Source of Const. Data 64- Dr 3 •

Name of Contractor, Driller 63- S&H. BROOKS •

Method of Construction 65- A air rotary, B bored or augered, C cable-tool, D dug, [✓ H] hydraulic rotary, J jetted, P air percussion, R reverse rotary, T trenching, V driven, W drive-wash, Z other •

Finish 66- C porous concrete, F gravel w/ perf, G gravel w/ screen, H horizontal gallery, O open end, P perforated or slotted, S screen, T sand point, W walled, [✓ X] open hole, Z other •

Type of Seal 67- B bentonite, C clay, G cement grout, Z other •

Bottom of Seal 68- •

Method of Development 69- A air lift, B bailed, C compressed air, J jetted, N none, P pumped, S surged, Z other •

Number of Hours on Development 70- •

Special Treatment During Development 71- C chemicals, D dry ice, E explosives, F deflocculant, H hydrofracturing, M mechanical, Z other •

DIMENSIONS OF THE HOLE CONSTRUCTED (2)

R-72 • T- [✓ A] D M • (add, delete, modify) Construction Entry No. 59 # 1 •

New Card for Each Hole Segment Same R, T & Field 59

Top of Hole Segment Below LSD	Bottom of Hole Segment Below LSD	Diameter of Hole Segment
73 # 0.0	74- 524.	75- 3.0
73 #	74-	75-
73 #	74-	75-
73 #	74-	75-
73 #	74-	75-

CASING SCHEDULE (2)

R-76 • T- [✓ A] D M • (add, delete, modify) Construction Entry No 59 # 1 •

New Card for Each Casing With Same R, T & Field 59

Top of Casing Segment Below LSD	Bottom of Casing Segment Below LSD	Diameter of Casing Segment	Casing Material ⑤	Thickness of Casing
77 #	78- 30.	79 # 3.0	80- S	81- .375
77 #	78-	79 #	80-	81-
77 #	78-	79 #	80-	81-
77 #	78-	79 #	80-	81-
77 #	78-	79 #	80-	81-

OPENINGS SCHEDULE (2)

R-82 • T- [✓ A] D M • (add, delete, modify) Construction Entry No 59 # 1 •

New Card for Each Open Section With Same R, T and Field 59

	(Openings Data)	(Openings Data)	(Openings Data)
Top of Section Below LSD	83 # 30.	83 #	83 #
Bottom of Section Below LSD	84- 524.	84-	84-
Type of Openings ⑥	85-	85-	85-
Type of Material ⑦	86-	86-	86-
Diameter of Open Section	87-	87-	87-
Width of Opening	88-	88-	88-
Length of Opening	89-	89-	89-

FOOTNOTES:

① Source of Data Codes: [S O D A R L G Z] reporting agency, driller, owner, other gov't, other reported, logs, geologist, other

⑤ Casing Material Codes: [B C G I M P R S T U W Z] brass, concrete, galv. iron, wrought iron, other metal, PVC or plastic, rock or stone, steel, tile, coated steel, wood, other

⑥ Type of Opening Codes: [F L M P R S T W X Z] fracture, louvered shuttered, mesh, perforated or slotted, wire wound, screen (unknown), sand point, walled, open hole, other

⑦ Type of Material Codes for Open Sections: [B C G I M P R S T Z] brass or bronze, concrete, galv. iron, wrought iron, other metal, PVC or plastic, stainless steel, steel, tile, other

#23

PRODUCTION DATA (1)

R- 134 145 — flowing, pumped | T- A D M — add, delete, modify | Entry No 147# | Date 148- __/__/____ month day year

Discharge: 150- | Source of Data① 151-

Method of Measurement 152- B C E F M O P R T U V W Z — bailer, current meter, estimated, flume, totaling meter, orifice, pitot-tube meter, reported, trajectory, venturi, volumetric, weir, other

Production Level 153- | Static Level 154- | Source of Data① 155- | Specific Capacity 272-

Method of Measurement 156- A C E G H L M R S T V Z — airline, calibrated airline, estimated, pressure gage, calibrated pressure gage, geophysical logs, manometer, reported, steel tape, electric tape, calibrated electric tape, other | Pumping Period 157-

LIFT DATA (1)

R-42 | T- A D M — add, delete, modify | Type of Lift 43# A B C J P R S T U Z — air, bucket, centrifugal, jet, piston, rotary, submergible, turbine, unknown, other | Entry No 254#

Pump Intake Setting 44- | Type of Power 45- D E G H L N W Z — diesel, electric, gasoline, hand, LP gas, natural gas, windmill, other

Date 34- __/__/____ month day year | Horsepower 46-

MAJOR PUMP DATA (2)

R-47 | T- A D M — add, delete, modify | Type of Lift 43# | Lift Entry No 254# | Manufacturer of Pump 48-

Serial No of Pump 49- | Name of Power Company 50-

Power Company Account No 51- | Power Meter No 52- | Pump Rating 53-

Person or Company Who Maintains the Pump 54- | Additional Lift 255- | Rated Pump Capacity 268-

STAND BY POWER DATA (2) (See LIFT DATA for codes of fields 43 and 56 below)

R-55 | T- A D M — add, delete, modify | Type of Lift 43# | Type of Power 56- | Horsepower 57- | Lift Entry No 254#

AVAILABLE LOG DATA (1)

R-198 | T- [✓ A] D M — add, delete, modify

New Card for Each Log Type Same R & T

Type of Log②	Begin Depth	End Depth	Source of Data①
199# G	200- 0.0	201- 524	202- G
199#	200-	201-	202-
199#	200-	201-	202-
199#	200-	201-	202-

WATER QUALITY DATA COLLECTION (1)

R-114 | T- A D M — add, delete, modify | Begin Year 115# | End Year 116- | Source Agency 117-

Frequency of Collection③ 118- | Network Site 257- | Type of Analysis④ 120-

WATER LEVEL DATA COLLECTION (1)

R-121 | T- [✓ A] D M — add, delete, modify | Begin Year 122# 1976 | End Year 123- | Source Agency 124- USGS

Frequency of Collection③ 125- | Network Site 258-

WATER PUMPAGE/WITHDRAWAL DATA COLLECTION (1)

R-127 | T- A D M — add, delete, modify | Begin Year 128# | End Year 129- | Source Agency 130-

Frequency of Collection③ 131- | Network Site 259- | Method of Collection 133- C E M U Z — calculated, estimated, metered, unknown, other

OTHER DATA AVAILABLE (1)

R-180 | T- [✓ A] D M — add, delete, modify | Type of Data 181# COAL | Loc 182- C [✓ D] Z — computer, district, other | Format 261- [✓ F] M P Z — files, machine readable, published, other

New Card Same R & T | Type of Data 181# | Loc 182- C D Z | Format 261- F M P Z

FOOT NOTES:

① Source of Data Codes: S D O A R L G Z — reporting agency, driller, owner, other gov't, other reported, logs, geologist, other

② Type of Log Codes: A B C D E F G H I J K L M N Ø P Q — time, caliper, cement, driller's, electric, fluid conductivity, geologist, magnetic, induction, gamma ray, dipmeter, laterolog, microlog, neutron, [illegible], photo, radioactivity

S T U V Z — sonic, temp, gamma-gamma, fluid velocity, other

③ Frequency of Collection Codes: A B C D F I M Ø Q S W Z — annual, bi-monthly, continuous, daily, semi-monthly, intermittent, monthly, one time only, quarter, semi-annual, weekly, other

④ Type of Quality Analyses Codes: A B C D E F G H J K L M Z — physical, common chemical, trace elements, pesticides, nutrients, sanitary, [illegible], other

#23

GEOHYDROLOGIC UNIT DESCRIPTIONS (1)

R = 90 • T = [✓ A] D M • add, delete, modify Entry No 256 # 1 • Depth to Top 91 = 0.0 • Depth to Bottom 92 = 52.4 •

Unit Identifier 93 = • Lithology 94 = • Lithologic Modifier 97 = •

AQUIFER DATA (2)

R = 94 • T = A D M • add, delete, modify Geohydrologic Unit Entry No 256 # •

Date 95 # / / • month day year Water Level 126 = • % Water Contributed 132 = •

GEOHYDROLOGIC UNIT DESCRIPTIONS (1)

R = 90 • T = A D M • add, delete, modify Entry No 256 # • Depth to Top 91 = • Depth to Bottom 92 = •

Unit Identifier 93 = • Lithology 94 = • Lithologic Modifier 97 = •

AQUIFER DATA (2)

R = 94 • T = A D M • add, delete, modify Geohydrologic Unit Entry No 256 # •

Date 95 # / / • month day year Water Level 126 = • % Water Contributed 132 = •

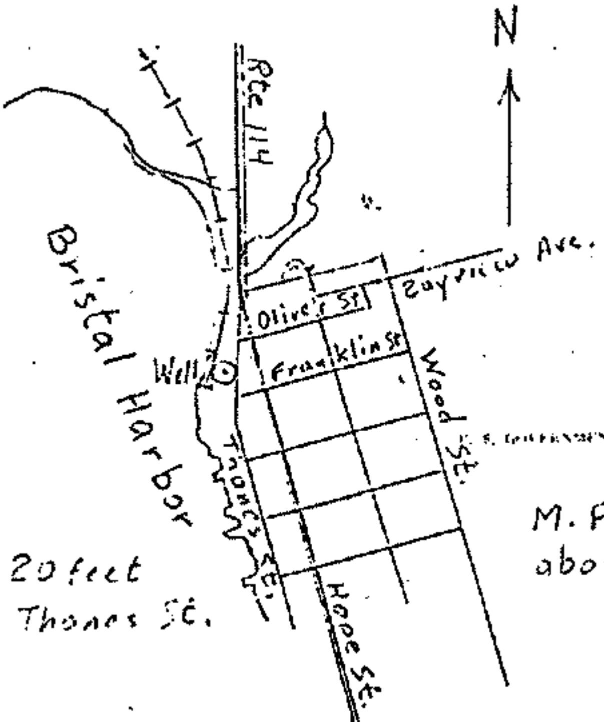
PERTINENT REMARKS

R = 183 • T = A • add 185 = •

185 = •

New Card Same HAT 185 = •

NOTES:



Well is 20 feet west from Thames St.

M.P. is 1.20 Feet above LSD

BRISTOL

U.S. GOVERNMENT PRINTING OFFICE

#64
151
(152)

FORM NO 9-1904-A

SITE NO.

U.S. DEPT. OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION
GROUND WATER SITE INVENTORY
SITE SCHEDULE

Recorded by MAEVSKY

Date 07-18-77

Check One ✓ English ___ Metric Units

GENERAL SITE DATA (0)

Site Ident No 414021071164801

RG Number R=0 *

Transaction T= [✓ A] D M V * (add, delete, modify, verified)

Site-Type 2= C D H I M P T [✓ W] * (unknown, drain, drainhole, excavation, multiple, pond, tunnel or shaft, well)

Data Reliability 3= [✓ C] U L M * (field checked, unchecked, location not accurate, minimal data)

Reporting Agency 4= USGS *

Project No. 5= MA77045 *

District 6= 25 *

State 7= 44 *

County (or town) BRISTOL 8= 001 *

Latitude 9= 414021 * (deg min sec)

(152)

Longitude 10= 0711648 * (deg min sec)

Lat-Long Accuracy 11= [✓ S] F T M * (sec, 5 sec, 10 sec, Min)

Local Number 12= BRW 151 Y*

Land Net Loc. 13= ¼ ¼ ¼ S T R *

Location Map 14= BRISTOL *

Scale 15= 24000 *

Altitude 16= 10. *

Method of Measurement 17= A L [✓ M] * (altimeter, level, map)

Accuracy 18= .5 *

Topo Setting 19= D C E F H K L S P [✓ S] T U V W * (depression, stream channel, dune, flat, hilltop, sinkhole, swamp, offshore, pediment, hillside, terrace, undulating, valley flat, upland draw)

Hydrologic Unit (OWDC) 20= 01090004 *

Date of First Construction/Completion 21= 07/12/1977 * (month day year)

Use of Site 22= A D E G H O M P R S [✓ T] U W X Z *

Use of Water 24= A B C D E F H I M N P R S T U Y [✓ Z] * (air cond., bottling, commercial, dewater, power, fire, domestic, irrigation, medicinal, industrial, public supply, recreation, stock, institution, unused, desal, other)

Secondary Water Use 25= *

Tertiary Use of Water 26= *

Depth of Hole 27= 800. *

Depth of Well 28= 200. *

Source of Depth Data ① 29= G *

Water Level 30= *

Date Measured 31= / / * (month day year)

Source ① 33= *

Method of Measurement 34= A C E G H L M R [✓ S] T V Z *

Site Status 37= D F G H S P R S T V X Z *

273= Y*

Source of Geohydrologic Data ① 36= *

Pump Used 35= *

Measuring Point 286= *

Measuring Point Date 287= / / * (month day year)

OWNER IDENTIFICATION (1)

R=150 * T= [✓ A] D M * (add, delete, modify)

Date of Ownership 160# 07/12/1977 * (month day year)

Name: Last 161= BRISTOL *

First 162= TOWN *

Middle Initial 163= *

OTHER SITE IDENTIFICATION NUMBERS (1)

R=185 * T= [✓ A] D M * (add, delete, modify)

Ident 190# *

Assignor 191= NE DIST. *

New Card Same R & T

Ident 190# *

Assignor 191= *

SITE VISIT DATA (1)

R=186 * T= [✓ A] D M * (add, delete, modify)

Date of Visit 187# 07/12/1977 * (month day year)

Name of Person 188= MAEVSKY A *

FIELD WATER QUALITY MEASUREMENTS (1)

R=192 * T= A D M * (add, delete, modify)

Date 193# / / * (month day year)

Geohydrologic Unit 195# *

New Card Same R thru 195

Temperature 196# 0,0,0,1,0 *

Degrees C 197= *

Conductance 196# 0,0,0,9,5 *

μ Mhos 197= *

Other (STORET) Parameter 196# *

Value 197= *

Other (STORET) Parameter 196# *

Value 197= *

FOOT NOTES:

① Source of Data Codes:

	D	O	A	R	L	G	Z

#64

GEOHYDROLOGIC UNIT DESCRIPTIONS (1)

R-86 ● T- [✓ A] D M ● add, delete, modify Entry No 266 # 1 ● Depth to Top 91- 0.0 ● Depth to Bottom 92- 802 ●

Unit Identifier 93- ● Lithology 96- ● Lithologic Modifier 97- ●

AQUIFER DATA (2)

R-94 ● T- A D M ● add, delete, modify Geohydrologic Unit Entry No 266 # ●

Date 86 # / / ● month day year Water Level 128- ● % Water Contributed 132- ●

GEOHYDROLOGIC UNIT DESCRIPTIONS (1)

R-86 ● T- A D M ● add, delete, modify Entry No 266 # ● Depth to Top 91- ● Depth to Bottom 92- ●

Unit Identifier 93- ● Lithology 96- ● Lithologic Modifier 97- ●

AQUIFER DATA (2)

R-94 ● T- A D M ● add, delete, modify Geohydrologic Unit Entry No 266 # ●

Date 86 # / / ● month day year Water Level 128- ● % Water Contributed 132- ●

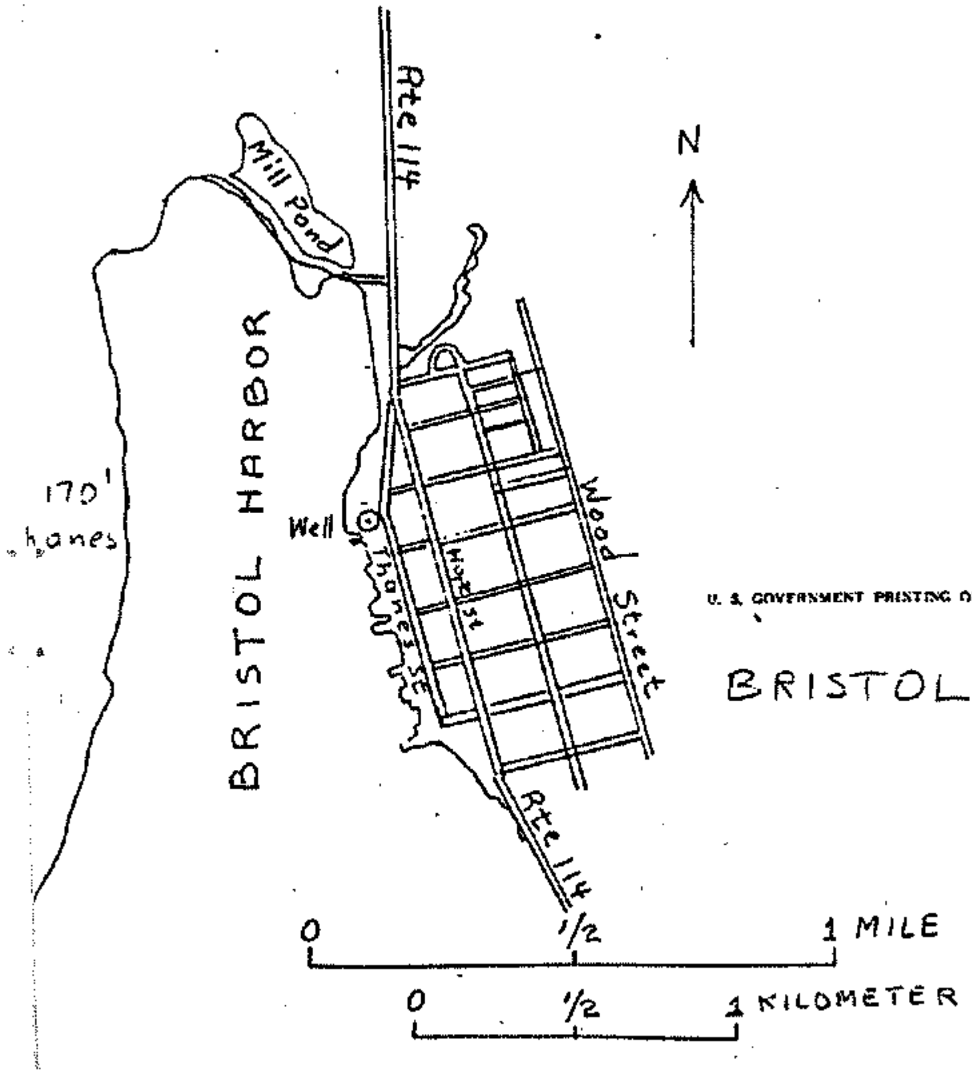
PERTINENT REMARKS

R-123 ● T- A ● add 185- ' '●

New Card Same R&T 185- ' '●

185- ' '●

NOTES:



U. S. GOVERNMENT PRINTING OFFICE : 1975 O - 579-015

BRISTOL R.I.

RECOVERY AND TRANSPORT OF HEAVY METALS BY *SPARTINA ALTERNIFLORA* FROM DREDGING SPOILS

UNIVERSITY OF RHODE ISLAND
HOPE
1892

Rhode Island
Water Resources Center

RECOVERY AND TRANSPORT OF HEAVY METALS BY *SPARTINA ALTERNIFLORA* FROM DREDGING SPOILS

by Richard J. Hull, Principal Investigator
Plant and Soil Science Department

and

Jodi R. Shann, Co-Investigator
Plant and Soil Science Department

University of Rhode Island
Kingston, R.I. 02881

Project No. A-074-RI

Matching Grant Agreement No. 14-34-0001-1142

Final Technical Completion Report
to
Office of Water Policy
U.S. Department of the Interior
Washington, D.C. 20240

ABSTRACT

The capacity of smooth cordgrass (Spartina alterniflora Loisel.), a dominant grass of Atlantic tidal salt marshes, to transport heavy metal from sediments to estuarine waters was studied. The DTPA extractable heavy metal content of marsh sediments from upper Narragansett Bay was correlated with the metal content of S. alterniflora growing in those sediments. The plant Zinc content correlated well with the extractable zinc levels in the sediments. The plant content of cadmium, copper and nickel was best correlated with the sediment content of other metals. Plant cadmium was particularly well correlated with sediment zinc.

The mobility of cadmium and zinc within S. alterniflora was determined in solution cultured plants grown in 0 and 15 ppt NaCl. Salinity reduced the root absorption rate of cadmium and zinc by almost fifty percent. Translocation of zinc from roots to shoots was reduced by salinity while cadmium transport was not affected. Both metals were phloem mobile translocating from leaves to roots and other sink regions. The presence of these metals on leaf surfaces following root absorption, indicated elimination from leaves via salt glands. These findings demonstrate that heavy metal absorption and transport occurs in S. alterniflora which can serve as a vector of heavy metals from tidal marsh sediments to estuarine waters.

PROJECT OBJECTIVES

The viability of tidal salt marsh construction as an environmentally sound means of dredging spoil disposal may hinge upon the capability of marsh vegetation to transport heavy metals from contaminated sediments to estuarine waterways. Field and laboratory studies were employed to establish the relationship between sediment metal content and the metal burden in aerial plant parts. The capacity of the common marsh grass *Spartina alterniflora* to absorb metals and translocate them to leaves was also investigated. Specific objectives of this study included:

1. Determining the plant available metal content of marsh sediments from several sites along upper Narragansett Bay.
2. Correlating the metal content of plants with the available metal loads of sediments in which the plants were growing.
3. Formulating predictive equations by which the metal content of vegetation can be calculated based upon the extractable metal content of the sediment.
4. Determining the rate of metal absorption by plant roots and the impact of salinity on that rate.
5. Measuring the mobility of metals within *S. alterniflora* plants following absorption by roots or leaves.

Data generated from this study will be utilized to evaluate the environmental impacts of proposed marsh construction (dredge disposal) projects in Rhode Island marine waterways.

INTRODUCTION

The disposal of dredging materials has become a major problem in the management of coastal waterways. Increasing costs and environmental concerns have restricted ocean dumping of these materials, forcing the search for alternative disposal methods. Prominent among the alternatives being considered is the establishment of salt marshes on tidal banks created with dredged spoil. Such marsh areas would not only permanently stabilize spoil banks but also provide an energy source for estuarine life and, in many cases, replace marsh acreage lost to land reclamation and harbor development. This approach to dredge disposal appears to offer an environmentally acceptable and reasonably priced solution to the disposal problem at least for moderate sized dredging operations.

However, when the dredging spoil contains heavy metals, disposal via tidal marsh construction presents problems. The grasses utilized to stabilize spoil beds could absorb and concentrate metals from contaminated spoil transporting them to above ground shoots which can enter the food chain of detrital feeders and ultimately contaminate human food sources. Industrial coastal states, which for many years have experienced heavy metal discharges into estuarine waters, are most affected by this problem. The disposal dilemma is aggravated by the fact that such contaminated spoils are usually not suitable for ocean dumping or land disposal and even marsh construction on heavy metal contaminated spoils may negatively affect the quality of estuarine waters.

The research reported here attempts to quantify the heavy metal recovery capacity of Spartina alterniflora, the grass most commonly used for stabilizing dredged materials. Emphasis has been placed on cadmium and zinc because of their common occurrence in estuarine benthic sediments. Some studies have considered copper because of its high level in most Narragansett Bay sediments (Seavey and Pratt 1979) and nickel which is widely used in the electroplating industry. S. alterniflora cultured hydroponically has been used to measure heavy metal uptake and translocation under various salinity conditions. By relating these findings to heavy metal recovery by S. alterniflora grown in selected sediments under similated marsh conditions, we have initiated an information base for evaluating the magnitude of the heavy metal recovery problem from spoil based marshes and have furnished some of the analytical tools necessary for predicting the potential heavy metal inputs into estuarine waters.

METHODS

Field Sampling

Sediment samples were collected from ten sites along upper Narragansett Bay during the summers of 1980, 1981 and 1982. The data from the 1980 collections are presented in Table 1. Sediments represented several textural classes ranging from coarse sand or gravel to fine silty materials. These were sampled to a depth of 8-10 cm usually at the base of S. alterniflora plants. All collections were made at low tide when access to tidal flats and sample recovery was not hampered by standing water. Sediment samples were stored in closed plastic containers during transport to the laboratory.

At the time of sediment sampling, five to ten S. alterniflora plants were removed intact from the sites of sediment collection. Excess sediment was dislodged in estuarine water, shoots were separated from roots, and both were transferred to cloth bags for transfer to the laboratory.

Sediment Analysis

Prior to analysis, sediments were oven dried at 65°C and ground to pass a 2 mm screen. Three 10 g replicates from each site were extracted using the method of Lindsey and Norvell (1974). This involved shaking with 20 ml of DTPA (Diethylenetriaminepentaacetic Acid) solution adjusted to pH 7.0 for two hours. The extracts were analyzed for Cd and Zn using a Perkin-Elmer 5000 atomic absorption spectrophotometer. All controls and standards were prepared with DTPA extracting solution.

Plant Analysis

Field collected plant materials were thoroughly cleaned with distilled water prior to oven drying at 65°C. When leaves were coated with sediment, they were wiped with tissue soaked in 80% ethanol followed by distilled water washing. Oven dried plant tissues were ground in a Wiley mill to pass a 20 mesh screen. Duplicate one g samples were ashed for five hours at 315°C in a muffle furnace and the ash dissolved in 5 ml of 2N HCl. The filtered ash solutions were assayed for Cd, Zn, Cu, Pb, and Ni using atomic absorption spectrophotometry.

In a controlled experiment, sediments collected from two sites were maintained under wet reducing conditions prior to being transferred into 10 cm plastic pots. Each 10 cm pot was placed within a 15 cm pot lined with a plastic bag. The space between the two pots was filled with a quartz sand and perlite mixture and saturated with sea water. In this way, the sediment in the inner pot was maintained in a water-logged marsh-like condition. One *S. alterniflora* tiller was planted into each sediment filled pot, and maintained in a growth chamber under 16 hour, 25°C, 50% R.H. days and 8 hour, 15°C, 70% R.H. nights. After two months the plants and sediments were assayed for Cd, Cu, Ni and Zn using methods employed for field samples.

Statistical Analysis and Equation Development

All computations were performed by the statistical analysis system (SAS) (Helwig and Council, 1979). Duncan's multiple range test was used to separate the mean metal concentrations of plant and sediment samples. Coefficients of determination (R^2) were generated and predictive equations developed by linear and stepwise multiple regression of the metal concentrations in both field and growth chamber cultured plants (dependent variable) and their substrate extractable metals (independent variable).

Metal Absorption Rates and Translocation

Single *S. alterniflora* culms, collected from an unpolluted salt marsh in Jerusalem, R.I., were hydroponically cultured in opaque 300 ml flasks containing aerated nutrient solution designed for C_4 plants (Chevalier and Schrader) 1977. Plants were maintained in a growth chamber under the same conditions described for sediment cultured plants. Seven days prior to an experiment, nutrient solutions were made 0 or 15 ppt NaCl and either 1 ppm Cd or 100 ppm Zn. At the initiation of an experiment all plants, roots and shoots, were rinsed with distilled water. For root absorption studies .5 μCi of ^{115m}Cd or ^{65}Zn were introduced via fresh nutrient solution containing the same metal and salinity as the pretreatment solution. One ml aliquots of each solution were taken for radioassay. For leaf treated plants, 2.5 μCi of ^{115m}Cd or ^{65}Zn were applied to a fully expanded leaf of plants cultured in 1 ppm Cd or 100 ppm Zn respectively. The radioisotope was applied in solution containing a surfactant (X-77) to insure wetting the leaf surface. Leaf applications were confined within lanolin paste dikes placed at right angles to the axis of the leaf blades.

After five days, plants were harvested and nutrient solutions, after returned to original volume, were sampled for radioassay. Leaves of individual plants were washed with 15 ml distilled water and the wash assayed for radioactivity and metal content. The plants were freeze dried, after which half were prepared for gross radioautography while the remaining half were subdivided into roots, lower shoot, upper shoot, and treated leaf when appropriate, ground in a Wiley mill, and radioassayed in a planchet counter. Methods used were those described by Lytle and Hull (1980).

RESULTS AND DISCUSSION

Metal Content of Sediments and Plants: Field Study

The ten sites selected for sediment analysis exhibited wide variation in their content of Cd and Zn (Table 1). Generally sediments high in extractable Zn were also high in Cd, and coarse textured sediments normally contained less extractable metal. The Edgewood site was a notable exception to this rule. Those sites in the proximity of industrial discharge were highest in metals while the more remote locations, e.g. Prudence Island, were much less affected.

Spartina alterniflora plants growing in some of the above mentioned sediments also demonstrated wide variation in metal content (Table 2). Generally roots were the most heavily contaminated plant organs. Leaves and aerial stems also contained substantial metal but generally much less than the roots. Cadmium in the upper Pawtuxet Cove site was a notable exception to this rule. Rhizomes exhibited substantial variability in metal content. Zinc was often more concentrated in rhizome tissue than it was in aerial shoots. Although care was taken to remove all sediment from root and rhizome samples, some undoubtedly remained and may have inflated the metal content of those tissues. Except for plants from the upper Pawtuxet Cove site, Pb was least mobile of the metals studied being barely detected in most shoot and rhizome samples. By comparison, Zn exhibited greatest mobility. The relatively high Zn levels in most sediments may have contributed to greater transport but Zn is generally recognized as being among the most mobile divalent cations in plants.

A good relationship between sediment Zn content and that recovered in roots and shoots of _S. alterniflora_ was confirmed by the stepwise regression analysis (Table 3). Extractable sediment Zn and shoot Zn were highly correlated ($R^2 = 0.91$). The variation in root Zn content was better explained if the sediment Cd levels were included in the model. Rhizomes exhibited a poor relationship between sediment and tissue Zn levels even when Cd and the Zn:Cd ratio were considered.

The shoot content of Cd was best correlated with the sediment content of extractable Zn (Table 4). The inclusion of sediment Zn levels also improved the model's predictive value of root Cd content. Again sediment metal content proved to be a poor indicator of rhizome metal load. The best three variable equation for predicting the shoot Cd concentration was:

$$\text{Shoot Cd} = 0.005\ \text{DTPA Zn} - 0.004\ \text{DTPA Zn:Cd} - 1.34\ \text{DTPA Cd} \qquad + 1.27.$$

In this equation, 98% of the variation in shoot Cd can be attributed to the three sediment variables at the highly significant 0.0001 level.

Sediment - Plant Metal Interactions: Growth Chamber Study

The sediment extractable metal content of six replicate samples after two months of supporting plant growth proved to be unexpectedly variable (Table 5).

Although all sediments in the six pots for each location were drawn from a common field sample, significant differences in extractable Cd, Zn, and Ni were detected. This supports the high degree of marsh sediment variability reported by Lee et. al. (1978).

Plant tissue analyses of S. alterniflora culms growing in each pot were related via a step-wise regression analysis with extractable sediment content (Table 6). As with the field study, shoot Cd content was best correlated with sediment Zn levels. All tissue levels of Zn were best related to sediment Zn while root and shoot Ni levels were positively influenced by sediment Cu and negatively correlated to sediment Cd. Tissue Cu was poorly predicted by the extractable metals assayed in this study.

It appears that the metal content of S. alterniflora shoots is related to the available metals in the marsh sediment but in a complex fashion. Zinc was the only metal that consistently exhibited good corlelation between plant and sediment content. Cadmium and Ni in plant tissues were often best related to other metals in the sediment but good predictive equations could be written. Plant Cu content apparently was most influenced by sediment factors not measured in this study.

Heavy Metal Absorption and Distribution

The absorption rates of Cd and Zn by S. alterniflora roots as measured by radioisotope loss from nutrient solutions over a five day period, showed some inhibition by 15 ppt NaCl especially for Zn (Table 7). Salt inhibited Zn absorption almost 50% and translocation from roots to shoots approximately 65%. The much greater absorption rate of Zn over Cd was undoubtedly related to the 100X excess of solution Zn over Cd. The high absorption rates of Zn suggest that the uptake process is strongly related to the external ion concentration and probably less by the number or turnover rate of carrier sites in root cell plasma membranes. A preliminary study suggested that Cd absorption was related to solution Cd concentration as a hyperbolic function (Table 8). This indication of saturation absorption kinetics provides support for the idea that Cd entry into root cells is limited by a specific ion carrier. This is inconsistent with our findings that high sediment Zn levels stimulate Cd absorption. An alternative explanation would place the ion interaction at binding sites within the sediment and not carrier sites on cell membranes.

Radiotracer distribution patterns within S. alterniflora plants following root or leaf exposure to ^{115m}Cd or ^{65}Zn indicated marked symplastic translocation (Table 9). Within five days, the roots contained 35% of the leaf applied Cd and about 20% of leaf applied Zn. Salinized culture solutions appeared to have no effect on Cd distribution within S. Alterniflora while Zn translocation from roots to shoots was somewhat inhibited. This agrees with the lower Zn content found in shoots of plants cultured in nutrient solution containing 15 ppt NaCl (Table 7). The rate of Zn translocation from leaves to roots appeared to be facilitated by culture in a salinized medium (Table 9). Because transport was measured over a five day interval, the greater Zn levels in the roots following leaf exposure might reflect reduced circulation within the plant due to inpaired apoplastic return of Zn from roots to leaves. Thus, ^{65}Zn accumulation in roots regardless of the site of application might be a manifestation of a common response to salinity i.e. reduced acropetal translocation.

When leaves were washed following five days of culture in ^{115m}Cd or ^{65}Zn labeled nutrient solution, the wash solution contained radioactivity (Table 10).

This was especially true of Cd treated plants growing in 15 ppt NaCl enriched solution. Zinc was recovered on leaf surfaces independent of the culture solution salinity. Because S. alterniflora leaves contain numerous salt glands, it is highly likely that divalent metal ions are excreted along with salt via the salt glands to the leaf surface. This elimination of metal ions might explain why the leaf metal content often is much less than that of roots (Table 1). This also suggests that S. alterniflora can extract heavy metals from marsh sediments and transport them to estuarine waters in quantities greater than that indicated by shoot metal concentrations.

LITERATURE CITED

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5. Lytle, R.W. and R.J. Hull. 1980. Photoassimilate distribution in Spartina alterniflora Loisel. I. Vegetative and floral development. Agron. J. 72:933-38.

6. Seavey, G.L. and S.D. Pratt. 1979. The disposal of dredged material in Rhode Island: An evaluation of past practices and future options. Mar. Tech. Rpt. 72. Coastal Resources Center, Univ. of Rhode Island, Kingston. p. 96.

Table 1. Metal Concentration of Ten Marsh Sediments from upper Narragansett Bay, R.I. (Summer 1980)

Site	Metal Concentration		Texture Grade
	Cd	Zn	
Pawtuxet Cove (L)	0.48 d*	213.3 d	mc**
Pawtuxet Cove (U)	1.65 b	1603.3 a	f
Pawtuxet Cove Marina	0.51 d	232.7 d	f
Edgewood Y.C.	0.10 e	48.0 e	mc
Edgewood	1.25 c	356.0 c	c
Port of Providence	0.06 e	15.0 ef	c
I-195 Bridge	0.11 e	26.7 ef	c
Blackstone Park	2.14 a	507.0 b	f
Prudence Island (E)	0.03 e	3.3 f	mc
Prudence Island (W)	0.02 e	3.7 f	c

* Means within a column followed by the same letter are not significantly different p = 0.05.

** Texture grades: c = coarse, mc = medium coarse, f = fine.

Table 2. Metal concentration in *Spartina alterniflora* Collected at Five Sites in Upper Narragansett Bay, R.I. (Summer 1980).

Site	Plant Part	Metal Concentration Cd	Cu	Pb	Zn
			ppm		
Pawtuxet Cove (U)	Root	2.0	174	288	175
	Rhizome	0.0	15	20	67
	Shoot	3.2	38	45	114
Pawtuxet Cove (L)	Root	3.5	31	74	135
	Rhizome	1.0	11	9	60
	Shoot	0.0	3	0	19
Edgewood Y.C.	Root	1.0	26	96	88
	Rhizome	0.0	4	0	18
	Shoot	0.2	4	0	18
Seekonk River	Root	6.0	82	106	153
	Rhizome	1.0	10	4	39
	Shoot	0.0	4	10	30
Prudence Island	Root	1.4	17	21	82
	Rhizone	0.5	6	1	55
	Shoot	0.1	4	0	22

Table 3. Regression Summary between Zn Content of Field Collected *S. alterniflora* and Sediment Metal Concentration

Plant Part	Variable	R^2	Significance
Root	Zn	0.66	0.0001
	Zn:Cd	0.77	0.0001
	Zn,Cd,Zn:Cd	0.79	0.0001
Rhizome	Zn:Cd	0.18	0.0808
	Zn + Cd	0.48	0.0070
	Zn,Cd,Zn:Cd	0.49	0.0223
Shoot	Zn	0.91	0.0001
	Zn + Cd	0.97	0.0001
	Zn,Cd,Zn:Cd	0.99	0.0001

Table 4. Regression summary between Cd content of S. *Alterniflora* and sediment metal concentration

Plant Part	Variable	R^2	Significance
Root	Cd	0.34	0.0113
	Cd + Zn	0.50	0.0055
	Cd,Zn,Zn:Cd	0.55	0.0086
Rhizome	Zn	0.21	0.0537
	Cd + Zn	0.32	0.0572
	Cd,Zn,Zn:Cd	0.46	0.0324
Shoot	Zn	0.71	0.0001
	Cd + Zn	0.91	0.0001
	Cd,Zn,Zn:Cd	0.98	0.0001

Table 5. Metal Concentrations of Two Narragansett Bay Marsh Sediments after Cultured for Two Months with S. alterniflora

Site	Pot No.	Metal Concentration[+]			
		Cd	Zn	Cu	Ni
		ppm			
Pawtuxet Cove	1	0.90 a[*]	149 a	16 a	5.1 a
	2	1.33 a	200 a	43 a	5.9 a
	3	2.15 a	201 a	56 a	6.6 a
	4	0.83 a	152 a	20 a	5.4 a
	5	0.69 b	124 b	13 a	5.3 a
	6	0.96 a	145 a	18 a	5.4 a
Seekonk River	1	4.23 a	139 a	45 a	8.8 bc
	2	3.82 ab	123 a	41 a	7.7 c
	3	3.74 ab	129 a	42 a	8.1 c
	4	4.23 a	140 a	43 a	9.8 ab
	5	4.39 a	142 a	55 a	10.9 a
	6	2.90 b	111 b	58 a	8.5 c

[*] Values within columns for each site followed by the same letter are not significantly different at $P = 0.05$.

[+] Each value is the mean of three extractions.

Table 6. Regression Summary between Greenhouse Cultured *S. alterniflora* and Sediment Metal Content

Metal	Plant Part	Significant R^2	Variable
Cd	Root	0.65	Cd, Zn:Cd
	Rhizome	0.51*	Ni, Zn:Cd
	Shoot	0.45	Zn
Zn	Root	0.72	Zn
	Rhizome	0.48	Zn
	Shoot	0.63	Zn
Cu	Root	0.50*	Cd, Ni,$^-$ Zn:Cd
	Rhizome	0.44*	Cu, Ni,$^-$ Cd$^-$
	Shoot	0.56*	Cu, Ni, Zn:Cd
Ni	Root	0.83	Cu + Cd$^-$
	Rhizome	0.72	Cd$^-$ + Zn:Cd
	Shoot	0.85	Cu + Cd$^-$

* Regression not significant at the 0.05 level.

$^-$ Negatively correlated with metal content.

Table 7. Metal Uptake Rates and Plant Content of Root Exposed *S. alterniflora* plants.

Metal	Salinity	Plant No.	Uptake	Metal Content Root	Metal Content Shoot
	ppt		µg/g/day	µg	
Cd	0	1	6.27	36.0	9.6
		2	5.88	30.1	3.5
	15	1	1.58	8.3	1.8
		2	4.97	29.7	4.9
Zn	0	1	260	588	616
		2	294	699	206
	15	1	166	925	145
		2	134	226	112

Table 8. Uptake by *S. alterniflora* Roots at Varying Solution Concentrations

Cd Concentration	Uptake Rate
ppm	µg/g/day
0.1	0.01
1.0	6.10
10.0	15.80

Table 9. Distribution of Cd and Zn in S. alterniflora Exposed Via Roots or Leaves.

Metal	Organ Exposed	Salinity	Metal Content Root	Metal Content Shoot Lower	Metal Content Shoot Upper
		ppt		%	
Cd	Leaf †	0	35.6 a*	44.4 a	20.0 a
		15	36.2 a	45.7 a	18.1 a
	Root ‡	0	76.5 a	23.5 a	
		15	77.0 a	23.0 a	
Zn	Leaf †	0	17.2 b	55.3 a	27.5 a
		15	29.1 a	44.8 b	26.1 b
	Root ‡	0	54.5 b	45.5 a	
		15	63.0 a	37.0 b	

* Values in columns for each metal and exposure method followed by the same letter are not significant p = 0.05.

† All leaf exposure means are based on two experiments with three to five replications of salinity treatments in each.

‡ All root exposure means are based on four experiments with three to five replications of salinity treatments in each.

Table 10. Radioactivity and Metal Concentration of Leaf Wash solutions from Root or Leaf Exposed *S. alterniflora*

Metal	Organ Exposed	Salinity	Radioactivity Plant	Radioactivity Leaf Wash	Metal Conc. of Leaf Wash
		ppt	cpm		ppm
Cd	Root	0	81846	0	0.3
		15	81878	240	0.8
	Leaf	0	6240	5	1.2
		15	4408	88	0.4
Zn	Root	0	2552	174	52.2
		15	3206	252	18.6
	Leaf	0	602	66	21.6
		15	2695	64	6.6

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1982

AN OVERVIEW OF THE CURRENT STATUS OF HAZARDOUS WASTE MANAGEMENT IN NEW ENGLAND

UNIVERSITY OF RHODE ISLAND
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RHODE ISLAND
WATER RESOURCES CENTER

AN OVERVIEW OF THE CURRENT STATUS OF HAZARDOUS WASTE MANAGEMENT IN NEW ENGLAND

Raymond M. Wright
Assistant Professor
Civil and Environmental Engineering

Water Resources Center
The University of Rhode Island
Kingston, Rhode Island

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FOREWARD

Hazardous waste management is a national environmental problem. Uncontrolled dumping of hazardous wastes has occurred in all of the New England states and affected a number of municipal water supplies. Proper waste management is critical for preservation of our water resources but regulations must not be so restrictive as to stifle industry and actually encourage uncontrolled dumping.

This report was prepared as part of the Rhode Island Centers contribution to New England regional research. It outlines the current (March 1982) status and federal regulatory situation. It is hoped that this report will be of use to those planning for and regulating hazardous waste disposal in New England.

William E. Kelly
Director
Rhode Island Water Resources Center

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EXECUTIVE SUMMARY

A primary goal of this report was to provide an overview of the current rules and regulations (March 1982) contained in the federal hazardous waste management program, defined under Subtitle C of the Resource Conservation and Recovery Act (RCRA) of 1976, as amended.

The federal RCRA program is being administered by EPA or federally approved states in two phases. Phase I, which is complete, has defined the universe of hazardous waste and has set the regulations governing generators and transporters and the interim standards controlling existing hazardous waste management facilities. Phase II, when completed, will have set all final standards for hazardous waste management facilities, provided regulations for the federal permit program, and listed requirements for federally approved state permit programs.

To date the only final standards effective involve storage and treatment of hazardous wastes in tanks, waste piles, incinerators, and surface impoundments. Currently, EPA is preparing other facility standards and regulations. The most pertinent actions expected in 1982 involve:

(a) Final regulations concerning Part 264 Subparts F Ground Water Monitoring and G Financial Responsibilities;

(b) Final decision by EPA concerning existing surface impoundments and incinerators;

(c) Final standards concerning new and existing land disposal facilities, Part 264 Subparts K Surface Impoundments, I Waste Piles, M Land Treatment, N Landfills, and R Underground Injection Wells;

(d) Final standards governing landfill disposal of containers holding liquid wastes and ignitable liquid wastes.

The delay in the final development and promulgation of land disposal standards has resulted in interim standards for new land disposal facilities (Part 267). This action has lifted the moratorium on new facility construction. Owners and operators seeking to build a new landfill, surface impoundment, land treatment facility, or Class I underground injection well have been able to apply for an RCRA permit since August 1981.

Also in this report is an investigation into hazardous waste management in New England. Each state in this region has either obtained or has submitted an application to obtain interim RCRA program authorization. The relationship between the federal RCRA program and each New England state, the current status of each state's program, and the current and future status of hazardous waste management facilities in New England was discussed. This report utilized information from discussions with state and federal officials, state Phase I applications and state publications.

EPA currently retains the authority to issue RCRA permits in each New England state until the states obtain Phase II interim authorization. At the time of this report EPA had not issued any RCRA permits in New England.

All of the New England states have an existing state permit program. It is, therefore, possible for a permit applicant to receive both a federal RCRA permit and a state permit. Close contact between federal and state regulatory agencies and the regulated community is essential to minimize the confusion and the duplication of effort that may occur prior to state authorization.

Under the authority of the state programs, all existing facilities have been issued interim status. Of the New England states, only Massachusetts has started to issue formal state permits. The other state programs are in various stages of development concerning the issuance of formal permits. For instance, Vermont is reviewing completed facility applications and expects to be issuing formal state permits shortly. Connecticut is still developing facility standards and expects to move on formal permitting as the standards become effective.

The majority of the states hazardous waste programs cover a broader universe of hazardous waste than the federal program. Additional coverage included by many New England states involves PCB's and waste oil.

One basic difference in the scope of the hazardous waste programs is the small generator exclusion rule. The federal cutoff of 1000 kg/mth has been replaced in New Hampshire and Vermont by 100 kg/mth. In Massachusetts and Rhode Island no generator is excluded from coverage.

An estimate of the number of licensed transporters, generators and existing hazardous waste management facilities were given in this report. Of the New England states, only Connecticut and Massachusetts have off-site disposal of hazardous waste. Rhode Island has no disposal facilities in the state.

The New England states use the New England Manifest System. This system requires the review of each manifest by state regulatory agencies. These reviews provide an agency the opportunity to check for irregularities in the transport and ultimate disposal of each hazardous waste shipment.

In general, the New England states regulatory authorities appear to favor the location of hazardous waste management facilities in their states providing that assurances are made for the protection of public health and the environment. The benefit to industry and the local economies is the motive most often cited. The recent issuance of siting legislation in many of the states provide local guidelines for operation of new hazardous waste management facilities.

Siting legislation, in general, gives the responsibility for technical permit review to specific state agencies. A council or committee established by state law allows local authorities to participate in the review process. In general, local authorities may reject a state approved facility plan if all local zoning and permitting ordinances are not met.

A number of new facilities are being considered in New England. The success of each application depends on public acceptance in the host community. Many of the proposed operations are being strongly opposed locally.

I. INTRODUCTION

The recent connections between past hazardous waste disposal activities and current public health problems and contamination of the nation's natural resources have made the safe management of hazardous waste a national priority. Since the passing of the Resource Conservation and Recovery Act (RCRA), the federal government has been developing a hazardous waste management plan. The plan requires the promulgation of regulations to protect human health and the environment from improper hazardous waste management. Due to the complexity of the rulemaking, the plan is not complete although various parts of the plan have been authorized and are presently being administered

In general, states may obtain federal approval to administer the RCRA hazardous waste management program in place of and corresponding to the federal program, but until federal authorization, state and federal programs will continue to operate independently. This includes the issuance of state and federal permits and dual regulatory authority over all existing and proposed hazardous waste management operations.

The objective of this report was to provide an overview of the federal RCRA program and the current status of hazardous waste management in New England. Specific elements of this report include:

1. An overview of the rules and regulations contained in the federal RCRA program and how they pertain to federal authorization of state programs;

2. A chronological outline of the regulatory actions taken during the development of the federal RCRA program;

3. The determination of the current status of the New England states' applications for interim authorization;

4. A description of the present state hazardous waste management programs in New England and the most current estimate of generators and transporters of hazardous waste and existing hazardous waste management facilities.

II. OVERVIEW OF THE FEDERAL REGULATIONS GOVERNING ISSUANCE OF STATE INTERIM AUTHORIZATION

Intent of this Section

This section is an overview of the effective regulations pertaining to the hazardous waste program. Its purpose is to familiarize a person with the federal program and state authorization requirements. It is not the intention in this report to discuss all the details of or the exceptions to the final regulations. For further detail or clarification, the reader is referred to the listing of all effective regulations pertaining to hazardous waste management, which is revised each July 1 in the Code of Federal Regulations, Volume 40 Protection of the Environment, Chapter 1 Environmental Protection Agency, and to the most current issues of the Federal Register.

Also included in this section is a discussion of the regulatory actions concerning the hazardous waste management program. These regulatory actions, published in the Federal Register, provide insight to the interaction between EPA, the public and the regulated community during the development of the hazardous waste regulations, standards, and state authorization requirements. A listing of the most pertinent actions may be found in Appendix I.

General

The intent and scope of the federal hazardous waste program are described in sections of the Resource Conservation and Recovery Act (RCRA) (Table 1). An outline of the parts and subparts of EPA's final regulations concerning this program appear in Appendix II.

EPA has the authority to administer the hazardous waste program or under Section 3006 of the RCRA it may authorize individual states to

Table 1 - THE RESOURCE CONSERVATION AND RECOVERY ACT (RCRA) AS IT PERTAINS TO THE HAZARDOUS WASTE MANAGEMENT PROGRAM (40 CFR 91)

RCRA Section	Coverage	Final Regulation
Subtitle C	Overview and Definitions	40 CFR Part 260
3001	Identification and Listing of Hazardous Wastes	40 CFR Part 261
3002	Generators of Hazardous Wastes	40 CFR Part 262
3003	Transporters of Hazardous Wastes	40 CFR Part 263
3004	Standards for Hazardous Waste Management Facilities	40 CFR Part 264, 265, 266
3005	Permit Requirements for Hazardous Waste Management Facilities	40 CFR Part 122, 124
3006	Guidelines for State Programs	40 CFR Part 123
3010	Preliminary Notification of Hazardous Waste Activity	(Public Notice)

administer it if the state meets the requirements of the law. These requirements are covered in the final regulation Part 123 Subpart A General and B Additional Requirements for State Hazardous Waste Programs. Essentially the state programs must be consistent with the federal program to obtain authorization.

States may apply for final authorization after the last component of the final regulations are published in the <u>Federal Register</u>. Authorized state RCRA programs will become effective after the effective date of the last component of the final regulations. At the present, EPA has not promulgated all regulations.

Until states obtain final authorization, they may be granted interim authorization by meeting the requirements of Part 123 Subpart F Requirements for Interim Authorization of State Hazardous Waste Programs. Interim authorization is being granted in two phases. Phase I defines the universe of hazardous waste and sets the regulations governing generators and transporters and the interim standards controlling existing hazardous waste management facilities. Phase II sets the final standards for hazardous waste management facilities, provides the regulations for the federal permit program, and lists the requirements for a federally approved state permit program. The state permit program would be in place of and corresponding to the federal permit program.

There is no regulation that restricts a state program to the limits of the federal program. States, for instance, may elect to consider wastes that do not appear on the federal hazardous waste list, Part 261 Subpart D Lists of Hazardous Wastes, or they may include generators, transporters, or disposal facilities of hazardous waste that are exempt under the federal program. Any additional coverage is not considered a part of the federally approved state program.

Under the federal program, certain operations are exempt from complying with Parts 261 through 265 and Parts 122 and 124, and the notification requirements of Section 3010 of RCRA including:

1. An operation that generates less than 1000 kilograms per calender month (kg/mth) of hazardous waste providing it meets the requirements of Part 261.5;
2. An operation that uses, re-uses, recycles or reclaims hazardous waste as defined in Part 261.6;
3. Empty containers with levels of residual hazardous wastes as defined in Part 261.7.

Phase I

Phase I covers the listing and identification of hazardous wastes (Part 261), generators (Part 262) and transporters (Part 263) of hazardous wastes, and interim status standards for existing hazardous waste treatment, storage and disposal facilities (Part 265).

Part 261 Identification and Listing of Hazardous Waste

In order for a state program to obtain Phase I interim authorization, it must include a coverage of hazardous wastes nearly identical to that covered in Part 261 and a set of characteristics for identifying hazardous wastes equivalent to Part 261 Subpart C Characteristics of Hazardous Wastes.

Basicly a waste is considered to be a hazardous waste if it is listed in Part 261 Subpart D or it fits the characteristic of a hazardous waste as defined by Part 261 Subpart C. There are exemptions from this definition which are discussed in detail in Parts 260 and 261. If an individual is undecided whether a waste is to be considered under rules and regulations of Subtitle C, EPA has provided discussion with flowcharts to assist in this determination (Volume 40 Code of Federal Regulations page 346 - 40 CFR 346).

A waste is considered hazardous if it exhibits any of the following characteristics; ignitability, corrosivity, reactivity, or EP toxicity. These characteristics are discussed in Parts 261.21 through 261.24. A waste not listed in Subpart D but which exhibits one or more of these characteristics is considered a hazardous waste and must comply with the rules and regulations of Subtitle C, with exceptions.

On May 19, 1980, EPA initially promulgated a listing and identification of 85 process wastes and approximately 400 chemicals considered to be hazardous wastes (Volume 45 Federal Register page 33084 - 45 FR 33084). This action was subject to review and comment by the public and went into effect on November 19, 1980. Any person or persons generating, transporting, storing, or disposing of hazardous wastes listed or identified in these regulations had to comply with the rules and regulations contained in the RCRA. The final form of the May 1980 listing appeared in the Federal Register on November 12 and 25, 1980 (45 FR 74884, 45 FR 78532). A supplement to this listing was promulgated on July 16, 1980, effective January 16, 1981 (45 FR 47832).

Numerous petitions have been received under Part 260 Subpart C Rulemaking Petitions from individual companies that seek to amend

Part 261 to exclude a waste produced from a particular facility. EPA is handling these petitions on an individual basis. A listing of the petitions received by January 31, 1981 was given in the Federal Register (46 FR 59537, 47 FR 9007).

Part 262 Standards Applicable to Generators of Hazardous Waste

In order for a state to obtain interim authorization, it must include coverage of all generators of hazardous wastes unless they are defined as small generators or are otherwise exempt under federal regulations contained in Part 262. All hazardous wastes generated require EPA identification numbers.

Any generator may accumulate hazardous wastes on-site without a permit if it is shipped off-site to an approved management facility before 90 days and he meets the requirements of Part 262.34. If a generator accumulates hazardous wastes for more than 90 days, he must obtain a storage permit and is subject to the requirements of Part 264, 265 and 122.

Any hazardous waste that is transported off-site must have a manifest initiated by the generator (Subpart B The Manifest). A complete list of the manifest information required is provided in Part 262.21. The generator must designate a facility approved by a state or the federal government to handle his waste. If in any case the shipment cannot be delivered to the designated facility, it is the responsibility of the generator to provide the transporter with an approved alternate site or instruct the transporter to return the waste.

The generator must obtain the transporter's signature on the manifest at the time of pickup, retain one copy for his records, and send the remaining copies with the transporter. The generator must receive a second copy of the manifest signed by the operator of thereceiving facility. If this copy is not received in 35 days, the generator must make inquiries into the status of the hazardous waste. If the copy is still not received in 45 days an Exception Report must be filed with EPA. The generator's copies of the manifest must be retained as a record for at least three years. Instead of a copy of each manifest, an Annual Report is submitted to EPA based on the generator's records.

The standards applicable to generators of hazardous wastes were first promulgated on February 26, 1980 in the Federal Register (45 FR 12722) with subsequent administrative amendments on May 19, 1980 (45 FR 33140). The standards went into effect on November 19, 1980. The following clarifications and interpretations to the standards were requested by the regulated community:

1 November 19, 1980 - Small quantity generator status (45 FR 76620);

2. December 10, 1981 - Interim status for generators who accumulate hazardous wastes after November 19, 1980 (46 FR 60446).

The following amendments were made to the standards:

1. December 4, 1980 - Pipelines were excluded from storage facility regulations provided they meet the requirements of this part (45 FR 80286);

2. December 31, 1980 - Owners and operators of treatment, storage, and disposal facilities are required to comply with standards applicable to generators as described in Part 262 (45 FR 86968).

Part 263 Standards Applicable to Transporters of Hazardous Waste

In order for a state program to obtain Phase I interim authorization, it must include coverage of all transporters of hazardous waste manifested under Part 262. Certain of theseregulations are adopted from the federal Department of Transportation regulations. By this action EPA expedited the promulgation of Part 262 and maintained a continuity in the regulations, thus avoiding confusion and a duplication of effort.

Transporters must comply with the manifest system and recordkeeping requirements as detailed in Subpart B of this part. A transporter may not accept a hazardous waste shipment without an approved manifest. The manifest must be signed by the receiving carrier and a copy retained for his record. The remainig copies are turned over with the hazardous waste shipment to the approved management facility designated on the manifest or the next designated transporter. If a shipment cannot be delivered, it is the responsibility of the transporter to notify the generator for further instruction. A transporter is also responsible for taking immediate action to protect the public health and environment in case of a spill and any subsequent cleanup required by law.

The standards applicable to transporters of hazardous wastes were first promulgated on February 26, 1980 in the <u>Federal Register</u> (45 FR 1272) with subsequent administrative amendments on May 19, 1980 (45 FR 33150). The standards went into effect on November 19, 1980. An amendment on December 31, 1980 allows a transporter to hold a manifested shipment of hazardous waste for 10 days without requiring a RCRA storage permit (45 FR 86966).

Part 265 Interim Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities

In order for a state program to obtain Phase I interim authorization they must have interim status standards applicable to hazardous waste facilities that are substantially equivalent to Part 265. These standards apply to facilities that have met the regulations under Part 122.22 and have been given interim status as defined under Part 122.23. Interim status is given to owners and operators of "existing hazardous waste management facilities." An existing facility is defined as a facility conducting a hazardous waste activity on or before November 19, 1980. The owner or operator of an existing facility was required to notify EPA by August 19, 1980 followed by the submission of Part A of the permit application by November 19, 1980. Facilities under planning or construction by these deadlines would be considered for interim status if resources had been committed to the point that substantial loss would occur if the construction was terminated. No permit was actually issued but written acknowledgement of interim status was given by EPA. These regulations apply until final disposition of Part 264 and RCRA permits are issued. Exemptions from these requirements are discussed in Subpart A of this part.

A facility receiving a manifested shipment from off-site must sign the manifest, return a copy to the generator within 35 days and retain a copy on file for at least 3 years. An Annual Report must be submitted to EPA based on the requirements of Part 265.75.

Within one year of the effective date of these regulations owners and operators of surface impoundments, land treatment, and landfills must implement a ground water monitoring program capable of determining the facilities impact on the ground water quality. The program must be maintained during the life of the facility and during the post-closure care period (30 years past the date of complete closure). The requirements of the monitoring system and the water analyses required are detailed in Parts 265.91 and 265.92. The requirements for ground water monitoring may be waived in part or entirely if the operators of the facility can prove that there is low potential for migration of hazardous waste into the ground water. The facts to be demonstrated to obtain waiver are described in Part 265.90.

The closure and post-closure and financial responsibilities of a facility owner and operator are discussed in Subparts G and H. The specific requirements for each type of facility are contained in Subparts I through R.

The interim status standards of Part 265 were first published in the Federal Register May 19, 1980 with an effective date of November 19, 1980 (45 FR 33154). Specifically, the subparts promulgated were Subparts A General, B General Facility Standards, C Preparedness and Prevention, D Contingency Plan and Emergency Procedures, E Manifest System, Recordkeeping and Reporting, F Ground Water Monitoring, G Closure and Post-Closure, H Financial Requiremnts, I Containers, J Tanks, K Surface Impoundments, L Piles, M Land Treatment, N Landfills, O Incinerators, P Thermal Treatment, Q Chemical, Physical, and Biological Treatment, and R Underground Injection. Proposed amendments to subparts H and R were also promulgated in May 1980 (45 FR 33260, 45 FR 33280).

On November 17, 1980 regulations in Part 265 governing publicly owned treatment works receiving hazardous waste and neutralization tanks were suspended if active National Pollutant Discharge Elimination System (NPDES) permits were in effect (45 FR 76074).

On May 19, 1980 (45 FR 33154) EPA set restrictions prohibiting the landfill disposal of liquid wastes after November 19, 1981. Specifically, landfill disposal of bulk waste or non-containerized liquid waste or waste containing free liquid is restricted unless (Part 265.314(a)):

a) the landfill has a liner and leachate collection and removal system that will prevent migration of the leachate in the soil or groundwater;

b) the free liquid is treated with an absorbent solid essentially eliminating free liquids from the waste.

Containers holding liquid wastes or waste containing free liquids are also restricted after November 19, 1981 unless (Part 265.314(b)):

a) the container is of the size of an ampule;

b) the container is originally designed to hold liquid waste or waste for purposes other than storage (battery).

On February 20, 1981 (46 FR 13492) restrictions for the disposal of liquid ignitable wastes in landfills (Part 265.312 (b)) was temporarily suspended until May 19, 1981, providing the liquid waste is protected from any material or condition that may cause it to ignite. The compliance date was further extended to coincide with the compliance date of Part 265.314 on June 29, 1981 (46 FR 33502).

Prior to the November compliance date, the regulated community brought to EPA's attention a number of difficulties they were having meeting the restrictions of liquid waste disposal. The principle arguement was the capital cost of decanting equipment required to meet the interim standards of Part 265.314 (b). Currently, EPA is considering amending these standards. As a result, on February 25, 1982, EPA extended the compliance date for prohibition of landfill disposal of containers holding liquid wastes (Part 265.314 (b)) and of ignitable liquid wastes (Part 265.312 (b)) to May 26, 1982 (47FR3304) to allow time for completion of the rulemaking. A public hearing concerning this action was held on March 11, 1982.

Also in this same amendment EPA is exempting from regulation under interim status the practice of adding absorbent material to hazardous waste in a container or adding hazardous waste to absorbent material in a container providing:

a) the waste, material and container are compatible as described under Part 265.17 (b);

b) the container complies with Part 265.171 and 172;

c) the absorbent treatment process occurs at the time of waste placement in the container.

This conditional exemption is made to encourage generators to institute absorbent treatment practices since the administration requirements under the RCRA are eliminated with this action.

Phase II

Phase II of interim authorization covers the development of a federally approved state permit program and final state standards for hazardous waste management facilities. The state program is in place of and corresponding to the federal hazardous waste program (Part 122, 124, and 264).

Currently, only a portion of the facility standards are complete. To avoid delaying the entire program, EPA is publishing the final facility standards in three components. A state with Phase I interim authorization may apply for authorization to administer each component, as it is announced in the Federal Register. If a state's application is approved, that state begins to administer state RCRA permits in place of federal RCRA permits to those treatment, storage, or disposal facilities affected.

As an alternative, states may elect to apply after all the facility standards are final. This maintains Phase II in a single application, which simplifies the process administratively and gives states additional time to review EPA's regulations, to provide a complete program, and to enact state legislation that will expedite implementation. Under this alternative EPA does retain, however, the authority to issue permits for a longer period. This fact is significant in states with existing hazardous waste permit programs not as yet authorized under RCRA. The longer EPA has the authority to issue RCRA permits the greater the potential for a facility to end up with a federal and a state permit causing confusion and duplication of effort.

Part 122 EPA Administered Permit Programs: NPDES, Hazardous Waste Permit Program and the Underground Injection Control Program

In order for a state to obtain interim authorization of Phase II, it must comply with regulations governing the federal permit programs (Subpart A) and additional requirements specific to the hazardous waste permit program under the RCRA (Subpart B).

RCRA permits may not be issued until the effective date of the final facility standards (Part 264). An "existing facility," defined earlier, with interim status, as defined in Part 122.23, is considered to be under interim permit until final RCRA permits are issued. Any facility not in operation or not under construction by November 19, 1980, is defined as a "new facility." A person may apply for and receive the authorization to construct a new hazardous waste treatment or storage facility, but the facility may not go into operation until a final RCRA permit is issued. Land disposal facilities, including landfills, injection wells, land treatment and surface impoundments, were not included in this regulation, but were considered under separate action (Part 267).

A permit application requires two separate submissions, Part A (Part 122.24) and Part B (Part 122.25). Part A provides the location and description of the existing facility, a description of the processes to be used in the treatment, storage, or disposal of hazardous waste, a listing of the hazardous waste to be managed, and an estimate of the quantity of hazardous wastes to be handled annually . Part B basically includes information specific to Part 264 standards that is necessary for EPA to determine complicance.

Operations are considered under permit by rule regulations (Part 122.26) to have an RCRA permit if they meet applicable regulations and involve the following:

1. Ocean transport of hazardous wastes to ultimate disposal if this practice is covered by a permit issued under Ocean

Dumping Part 220, as authorized by the Marine Protection, Research, and Sanctuaries Act, as amended;

2. Disposal of hazardous wastes in injection wells if this practice is covered by a permit issued under the Underground Injection Control Program Part 122, as authorized under the Safe Drinking Water Act;
3. Discharge of hazardous wastes to publicly owned treatment works if the practice is covered by a permit issued under the NPDES program as authorized by the Clean Water Act.

Part 264 Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities

In order for a state program to obtain interim authorization of Phase II, they must have standards applicable to hazardous waste treatment, storage, and disposal facilities substantially equivalent to Part 264. Facilities with interim status must comply with these regulations upon final issuance of the RCRA permit. Requirements concerning the manifest, recordkeeping, and reporting discussed earlier for Part 265 are essentially the same for this part.

The initial rulemaking applicable to owners and operators of hazardous waste treatment, storage, and disposal facilities was first proposed in December 1978. After considerable public input and consideration, EPA promulgated the first five subparts to Part 264 on May 19, 1980, effective November 19, 1980 (45 FR 33254); Subparts A General, B General Facility Standards, C Preparedness and Prevention, D Contingency Plan and Emergency Procedures, and E Manifest System, Recordkeeping and Reporting.

On October 8, 1980 EPA proposed standards for maintaining ground water quality as covered by Subpart F Ground Water Monitoring (45 FR 66816). Further action is pending.

On January 12, 1981 EPA promulgated Subparts G Closure and Post-Closure, H Financial Requirements, I Use and Management of Containers, J Tanks, K Surface Impoundments, and L Waste Piles (46 FR 2802). Sections of Subparts K and L included storage and treatment practices only. These standards were scheduled to go into effect on July 13, 1981. Regulations for Subpart O incinerators were published on January 23, 1981 with an effective date of July 22, 1981 (45 FR 7666).

During the comment period for these subparts a number of questions were raised concerning financial responsibilities. The financial requirements, Subpart H, was deferred on two occasions with the effective date presently set at April 13, 1982. The specific regulations being re-evaluated concern the provision of financial assurance of closure and post-closure requirements and the question of liability insurance during the operating life of the facility. EPA is presently considering the elimination of the liability regulation in its entirety.

The January 12, 1980 action had amended permit regulations (Part 122) to comply with facility regulations (Parts 264 and 265). With these amendments EPA or authorized states could begin processing RCRA permits applications for owners and operators of containers and tanks, and surface impoundments and waste pile treatment and storage facilities. Incinerators were included as a result of EPA's action of January 23, 1981.

With the promulgated regulations of January 12 and 23, EPA announced on January 26, 1981 that states could begin application for interim authorization of Components A and B of Phase II (46 FR 7964). Component A corresponds to the federal regulations permitting the storage and treatment of hazardous waste in tanks, surface impoundments, and waste piles and for permitting the use and management of containers of hazardous waste. Component B corresponds to the federal regulations for permitting the treatment of hazardous waste in incinerators. The effective dates for Components A and B were July 13 and 27, 1981, respectively.

During the months following publication, EPA received a number of comments from the regulated community concerning the standards on existing incinerators and surface impoundments. One specific arguement was the requirement of all surface impoundments to have a suitable liner. If a facility did not have a suitable liner the owner or operator would be required to install one. In most cases this would require the temporary removal of the hazardous waste. An operation that may have greater risk than the present situation. This consideration coupled with the expense of such an operation would, in many cases, result in the covering and closing of the facility.

Existing incinerator regulations involve performance standards. In order to meet the regulations many facilities would require substantial modifications. The cost of such modifications would be unfeasible in may cases resulting in shutdowns.

Due to the potential impact of these regulations on the regulated community, EPA temporarily suspended the effective dates, July 13 and 27, 1981 of the January 12 and 23 , 1981 standards for existing incinerators and surface storage impoundments only, in order to examine the questions raised (46 FR 51407). This suspension had no affect on the other facility standards and the January 1981 effective dates, nor did it affect new surface impoundments and incinerator construction.

The question was raised by a number of states as to the fairness and legality of this postponement. Unless EPA actually suspends the effective dates they legally remain effective parts of Components A and B. Consequently, EPA, on February 24, 1982, removed its temporary suspension concerning permitting of existing incinerators and surface storage impoundments. Instead, EPA has included a suspension proviso in the Memorandum of Agreement, which gives them authority to automatically suspend the state's authorization to permit these types of facilities if EPA should suspend the effective dates of the January standards at a later date.

Conspicuously absent from the January rules were those subparts concerning land disposal facilities. The original standards for land disposal were included in the December 1978 action. EPA considered the comments submitted by the public and regulated community and subsequently proposed on October 8, 1980 a desire to base land disposal standards on "best engineering judgement" (45 FR 66816). From the comments received and the complexity of the rulemaking, EPA substantially changed the original standards and reproposed the standards on February 5, 1981 (46 FR 11126). Included in these standards were surface impoundments and waste piles which dispose of hazardous wates (Subparts K and L), land treatment facilities (Subpart M), landfills (Subpart N), and underground injection facilities (Subpart R). With the review of the comments complete by December 1981, EPA prepared and presented an overview of the basic federal progam proposed for land disposal facilities at a public meeting on December 21, 1981. At the time of this report further action on the regulations are pending the review of the public meeting.

Land Disposal

The delay in issuing the final standards for land disposal contained in Part 264 has resulted in the promulgation of minimum temporary permitting standards for new land disposal facilities under Part 267 Interim Standards for Owners and Operators of New Hazardous Waste Land Disposal Facilities. These standards were published on February 13, 1981 with an effective date of August 13, 1981 (46 FR 12414). Essentially these regulations remove the moratorium on new construction of landfills, surface impoundments, land treatment facilities, and Class I underground injection wells. In addition to the requirements covered under this part, new land facilities must meet the requirements of Subparts B, C, D, E, G, and H of Part 264 and the location standards under 264.18.

Subpart B Environmental Performance Standards

This subpart details the considerations that must be taken during the construction, operation and post-closure period of any hazardous waste disposal facility to prevent ground water, surface water and air contamination and subsurface migration of hazardous wastes, that would in any way endanger human health or damage wildlife, crops, vegetation or physical structure.

Basically these standards require the assessment for potential contamination from and migration of hazardous waste, an estimation of the persistence and permanence of potential adverse effects, and a determination of the present state of the environment at the proposed site to permit the evaluation of facility performance. Owners and operators of new landfills, surface impoundments, land treatment facilities, and undergrouond injection wells must be operated and cared for after closure to assure compliance with Subpart B.

Subpart C Landfills

Each landfill requires a liner and a leachate and runoff control system. The design of each facility must consider the management of any contaminated leachate or runoff collected at the facility. Closure includes the placement of a cover over the landfill. The post-closure period includes the maintenance of any ground water monitoring or leachate and runoff control system.

Subpart D Surface Impoundments

Each surface impoundment requires a liner. The facility must be designed to prevent overtopping. Closure includes the placement of a cover over the impoundment. The post-closure period includes the maintenance of any ground water monitoring system. No leachate and runoff control system are required for these facilities.

Subpart E Land Treatment

Each land treatment facility requires a runoff control system. The design of each facility must consider the management of contaminated runoff collected from the facility. In addition to a ground water monitoring program a land treatment facility must have an unsaturated zone monitoring program. Both programs must be in operation during the life of the facility and maintained after closure.

III. STATUS OF STATE HAZARDOUS WASTE MANAGEMENT PROGRAMS IN NEW ENGLAND

General

At the date of this report no New England state had formally applied for Phase II interim authorization. Consequently, EPA retains the authority to issue RCRA permits to storage and treatment facilities under Components A and B and to new disposal facilities under final regulations in Part 267. Although EPA has notified certain priority facilities to submit Part B of their applications, no RCRA permits have been issued as yet in Region I (February 1982).

Since all the New England states have existing hazardous waste permit systems, it is conceivable that in the time prior to state Phase II interim authorization, an industry may be issued both a federal RCRA and a state permit. Given the present situation, many different scenarios are possible. When a state obtains interim authorization:

1. If a state permit is essentially the same as the effective federal RCRA permit issued, the effective federal RCRA permit becomes the effective state RCRA permit;

2. If a state permit is more stringent than the effective federal RCRA permit, the effective federal RCRA permit is revoked and the state permit becomes the effective state RCRA permit;

3. If a state has not issued a permit but regulations are more stringent than the federal program, the state must write a new RCRA permit and the effective federal RCRA permit is revoked.

The issuance of two different permits at two different times could lead to confusion and a duplication of effort. It is possible for an industry to comply with the requirements for a federal permit only to have to conform with more stringent state permit requirements at a later date. In all cases the more stringent permit controls. EPA is aware of these potential problems and, in an attempt to affect a smooth transition to a state RCRA permit system, is conducting informational meetings between federal and state officials and the regulated community. In this way industry will be made aware of the more stringent standards early in the permit procedure.

State Programs

General

Information for this section was obtained through discussions and correspondence with state and federal officials, from Phase I Program Descriptions (1,2,3,4,5,6) and from state publications (7,8,9). Some general information concerning the structure of the regulatory agencies is summarized in Table 2. The state officials, whose names appear below the bureau or division head, were the individuals contacted during the development of this report. The EPA officials contacted are listed in Table 3.

In the six New England states comprising EPA Region I, legislation has been passed enabling states to develop and administer hazardous waste programs (Table 4). All the states, except for Connecticut, have received Phase I interim authorization (Table 5). Connecticut's authorization is expected in March 1982.

Universe and Scope of Hazardous Waste Coverage

The majority of the New England states have exercised their rights to adopt a universe greater than the current universe covered

Table 2 - STATE OFFICIALS AND REGULATORY AGENCIES CONCERNED WITH HAZARDOUS WASTE MANAGEMENT

Connecticut	Pat Bowe, Section Chief Barry Giroux Hazardous Material Management Unit Department of Environmental Protection (DEP) 203-566-4869
Maine	John Brochu, Director Jack Krueger Bureau of Oil and Hazardous Materials Control Department of Environmental Protection (DEP) 207-289-2251
Massachusetts	Bill Cass, Division Head Ann Rappaport Division of Hazardous Waste Department of Environmental Quality Engineering (DEQE) 617-292-5572
New Hampshire	Thomas Sweeny, Bureau Chief Chuck Knox Bureau of Solid Waste Management (BSWM) Department of Public Health 603-271-4623
Rhode Island	Thomas Wright, Division Chief Thomas Dolce Division of Air Resources and Hazardous Materials, Department of Environmental Management (DEM) 401-277-2797
Vermont	Dick Valentinetti, Program Chief John Malter Air and Solid Waste Program Agency of Environmental Conservation (AEC) 802-828-3395

Table 3 - FEDERAL OFFICIAL TO CONTACT FOR INFORMATION CONCERNING THE NEW ENGLAND STATES' INTERIM AUTHORIZATION

Waste Management Branch
United States Environmental Protection Agency (EPA)
Region I
John F. Kennedy Federal Building
Boston, Massachusetts 02203

Connecticut	William R. Torrey	617-223-5775
Maine	Jean Mackey	617-223-5775
Massachusetts	Gary B. Gosbee	617-223-1591
New Hampshire	Susan L. Hanamoto	617-223-1591
Rhode Island	Kenneth E. Wenger	617-223-5775
Vermont	Barbara L. Walsh	617-223-5775

Table 4 - STATE STATUTORY AUTHORITY

State	Statutory Authority
Connecticut	Act Concerning Contamination, Pollution, or Emergency Resulting from the Disposal, Discharge, Spillage, Loss, or Filtration of Oil, Petroleum, Chemical Liquids, Solids or Gaseous Products or Hazardous Waste, 1979; Public Law 79-605.
Maine	Maine Hazardous Waste, Septage and Solid Waste Management Act, 1977 as amended; Title 38 M.R.S.A.
Massachusetts	Massachusetts Hazardous Waste Management Act, Chapter 704 of the acts of 1979; also Chapter 21C of the Massachusetts General Laws, as amended
New Hampshirre	New Hampshire Hazardous Waste Management Act, 1981; House Bill 456; R.S.A. 147-A
Rhode Island	Rhode Island Hazardous Waste Management Act; Title 23, Chapter 19.1 of the General Laws of Rhode Island, 1956, as amended in 1978.
Vermont	Vermont Solid Waste Management Act of 1979; Title 10, Chapter 159, as amended

Table 5 - PHASE I INTERIM AUTHORIZATION

State	Effective Date
Connecticut	*
Maine	March 18, 1981
Massachusetts	February 25, 1981
New Hampshire	November 3, 1981
Rhode Island	May 29, 1981
Vermont	January 8, 1981

* Authorization is expected in March 1982

under the federal program. Typical additions to the states' hazardous waste lists are PCB's and waste oil (Table 6). Specifically, Maine's program covers the original universe contained in the May 19, 1980 federal regulations, and Connecticut, because of its late application, essentially covers the same hazardous wastes as does the current federal program.

Some states have elected not to adopt the federal small generator exclusion cutoff of 1000 kg/mth (Table 6). Specifically, New Hampshire and Vermont have adopted a 100 kg/mth cutoff, and Rhode Island and Massachusetts include all generators under their program's regulations.

Manifest System

The manifest system used by the New England states requires a greater involvement of the regulatory agency than the system described in the federal regulations. The Federal Manifest System requires generators to initiate a manifest for each off-site shipment of hazardous waste. Each individual handling the shipment from generation to ultimate disposal must retain a copy of the manifest for at least three years. Both generators and management facilities submit an Annual Report to EPA based on these records.

All of the New England states except Rhode Island are currently using the New England Manifest System. Rhode Island is in the process of changing to this system. The program is essentially a load by load tracking system from generation to ultimate disposal. A similar type of system is in effect in New York, California, New Jersey, Maryland, and Pennsylvania. The generator is responsible

Table 6 - BASIC DIFFERENCES IN HAZARDOUS WASTE PROGRAMS

State or Federal Program	Small Generator* Exclusion Cutoff	Hazardous Waste Coverage Includes	
		Waste Oil	PCB
EPA	1000	NO	NO
Connecticut	1000	NO	NO
Maine	1000	NO	NO
Massachusetts	NONE	YES	YES
New Hampshire	100	NO	NO
Rhode Island	NONE	YES	YES
Vermont	100	YES	YES

*in kilograms per month hazardous waste generated for initiating a manifest for each off-site waste shipment. The manifest is initially signed by the tansporter and generator, a copy is retained by the generator, and a copy is sent to the state regulatory agency. The transporter delivers the shipment to the designated management facility, acquires the receiving facility operator's signature, retains one copy for his record and turns the remaining copies over to the operator. The operator returns one copy of the completed manifest to the generator and one to the state regulatory agency. If the shipment was transported from the state where it was generated, a copy is also sent to the state regulatory agency in the state receiving the waste. If in 35 days the generator does not receive the manifest copy from the facility, he must initiate an investigation. The results of this investigation are then turned over to the state regulatory agency within 45 days of the shipment. If at that time the manifest, sent to the state by the generator, is still unmatched by the facility's copy, the state agency will take action.

The principle difference in the programs is the extent of involvement of each agency. EPA does not become involved in each manifest but relies on Exception Reports from the generators to designate potential problems. If there are other irregularities in the manifest system, EPA many not become aware of them until review of the Annual Reports. The New England states, by comparison, review each manifest for non-compliance. The state regulatory agencies responsible for the review of the manifests are given in Table 7.

Table 7 - STATE REGULATORY AGENCY WITH AUTHORITY OVER MANIFESTS AND NEW FACILITY PERMIT REVIEW

State	Manifests	Permit Review
Connecticut	DEP	DEP
Maine	DEP	DEP
Massachusetts	DEQE	DEM DEQE
New Hampshire	DOS BSWM	BSWM WSPCC
Rhode Island	DEM	DEM
Vermont	AEC	AEC

DEP - Department of Environmental Protection
DEQE - Department of Environmental Quality Engineering
DOS - Department of Saftey
BSWM - Bureau of Solid Waste Management
WSPCC - Water Supply and Pollution Control Commission
DEM - Department of Environmental Management
AEC - Agency of Environmental Conservaton

Transporters

In accordance with the New England Manifest System all transporters intending to carry hazardous wastes generated in the state from that state or any tansporter that carries hazardous waste in a state with the intention of delivery to an approved facililty within that state must obtain a license to transport pursuant to that state's law. The most current estimate of licensed transporters in each state, according to state records, are listed in Table 8.

Generators

States were required in Phase I Progam Descriptions to give an estimate of the number of generators producing in excess of 1000 kg/mth hazardous waste. Either these estimates or more current figures are presented in Table 8. The number of generators covered under the Massachusetts, New Hampshire, Rhode Island, and Vermont programs is greater than those reported in this table, since these states have lower small generator exclusion limits. These figures were not available.

State Permit Programs and Existing Hazardous Waste Management Facilities

The following is a brief account of the current state permit programs. An estimate of the number of existing facilities in five New England states are given in Table 9. Masachusetts is currently licensing transporters and storage, treatment, and disposal facilities. The number of licenses that have been issued are summarized in Table 10.

Table 8 - NUMBER OF GENERATORS AND LICENSED TRANSPORTERS IN EACH NEW ENGLAND STATE

State	Licensed Transporters	Generators[a]
Connecticut	156	831
Maine	48	80
Massachusetts	147	20[b]
New Hampshire	43	500
Rhode Island	55	311
Vermont	89	135

(a) Generators producing in excess of 1000 kg/mth hazardous waste

(b) An estimate of major generators producing in excess of 1 million gallons hazardous waste per year from the Phase I Program Description. The estimate of nonmajor generators was given as 10,000.

Table 9 - NUMBER OF EXISTING HAZARDOUS WASTE MANAGEMENT FACILITIES IN FIVE NEW ENGLAND STATES

State	Storage		Treatment		Disposal	
	On[a]	Off[b]	On	Off	On	Off
Connecticut	109	21	70	4	70	14
Maine	32	0	10	0	1	0
New Hampshire	60	5	50	5	8	0
Rhode Island	131	14	7	0	0	0
Vermont	12	0	4	0	2	0

(a) On-site Hazardous Waste Management Facilities
(b) Off-Site Hazardous Waste Management Facilities

Table 10 - LICENSES ISSUED IN MASSACHUSETTS BY DECEMBER 1981 (10)

Hazardous Waste	Transport License	Storage License	Treatment and/or Disposal License
Hydrocarbon liquids	128	37	13
Aqueous liquids	65	13	4
Solids and Sludges	83	15	6
Special Hazards	41	7	2

Hydrocarbon liquids:	Motor Oils and Hydrocarbon Fuels; Industrial Oil; Non-Halogenated Solvents; Halogenated Solvents.
Aqueous liquids:	Organic Chemicals; Inorganic Chemicals; Acids and Alkalines; Plating Wastes.
Solids and Sludges:	Chemical Compounds; Contaminated Filter Media; Still Bottoms; Plating and Metal Sludges; Oily Solids.
Special Hazards:	Reactive Materials; Expolsives; Pesticides; PCB's; Pathological Wastes.

Connecticut: Existing facilities, meeting the requirements of the state law, were granted interim status on November 3, 1980. These facilities are considered under permit until formal permits are issued. Formal permits will be issued when the final disposition of state regulatory standards is known and the review of the permit applications, Part B's, are complete.

The majority of disposal sites involve wastewater treatment plant sludges from the metal plating industry. The off-site facilities are typically designated areas at public landfills. The on-site facilities are either landfills or lagoons.

Maine: Facilities in existence by April 1, 1980 were granted interim licenses if they compiled with the standards of 40 CFR 265 on or before November 11, 1980 and the state regulations covered in Chapter 855 and 857 of Title 38 M.R.S.A. entitled Interim Licenses for Hazardous Waste Facilities and Hazardous Waste Manifest Requirements, respectively. Formal permits have not been issued, as yet.

All of the operations in the state are on-site. Nine of the facilities are multiphase involving storage and treatment operations. The disposal site is a private industrial land disposal operation.

Massachusetts: Historically, licensing of facilities has been limited to off-site management operations and large management facilities. The operators and owners not issued a license were granted interim status. The Department of Environmental Quality Engineering began to issue formal permits with the passing of Massachusetts GL c 21C in November 1979. Table 10 is a summary of the types of operations licensed as of December 1981 and the hazardous wastes involved.

There are no existing hazardous waste landfills in the state. There are, however, uncontrolled sites of hazardous waste contamination being investigated, that were either a result of spills and leaks or of unknown origin.

New Hampshire: Prior to October 1981 all facilities in existence as of June 3, 1981, that met the state regulations, were considered to be under interim permit. In special situations where a facility could not immediately meet the state regulations and closure would significantly damage the local economy, a facility was granted a temporary interim permit until it complied.

In October 1981 operators of disposal sites were required to notify the Bureau of Solid Waste Management and begin formal application for a state permit. Operators of treatment and storage facilities are required to notify the state and begin formal application by October 1, 1982. At the present time no formal state permits have been issued.

Surface impoundments without liners are considered to be disposal facilities. There are no operating landfills in the state accepting hazardous wastes.

Rhode Island: Prior to 1982 the permit program was self-executing. Existing facilities meeting the state regulations were granted interim status but no formal permits were issued. Since January 20, 1982 all facilities are required to obtain a written permit. Applications are being reviewed.

Approximately 95 percent of the storage facilities are on-site locations. Among the treatment facilities are two on-site incinerators. There are no operating land disposal sites for hazardous waste. In 1977 there were a number of landfills accepting hazardous wastes. Within 1 1/2 years from the original notification to the Department of Environmental Management, the facilities either closed voluntarily or were ordered closed. Closures were ordered on the basis that land disposal of hazardous waste represented a potential threat to the ground water resources of the state. Site inspections and ground water monitoring at the closed facilities are done routinely by DEM.

All public landfills must have existing ground water monitoring programs. Of the 22 landfills accepting solid waste in the state, eight have shown traces of volatile organics in the leachate and are being monitored by DEM.

Vermont: Historically hazardous waste management facilities were granted interim certification if they met the state regulations. Under the Hazardous Waste Management Regulations of November 3, 1981, the AEC now requires all existing facilities to obtain formal permits. Applications from 13 facilities, some of which are multiphase, were received by December 31, 1981. No formal permits have as yet been issued.

All management facilities are on-site operations. The disposal operations involve the effluents from two industrial wastewater treatment facilities. One of the effluents is discharged to a subsurface leachfield and the other is discharged into a surface water. The latter operation is also regulated by an NPDES permit.

New Facility Siting Legislation and Construction

The majority of the New England States have passed specific siting legislation. The state regulatory agencies involved in site evaluation and permit review are listed in Table 7.

Connecticut: The regulations governing significant expansion of existing facilities or new facility construction are contained in the 1981 Connecticut Act Concerning Siting of Hazardous Waste Facilities, Public Law 81-369. Under this act approval requires two reviews. DEP provides the technical review and issues an environmental state permit. The Siting Council, consisting of state officials and representatives of the host community, assess the social, economic as well as environmental impact of the proposed facility. If approval is given by the Council, construction may begin if local zoning and permitting ordinances are met. At the present time there are no new facility applications under review.

Maine: Any owner or operator desiring to construct or substantially expand a hazardous waste management facility must obtain approval from the Board of Environmental Protection under Regulations Pursuant to site Location of Development Law Sections 481 to 488 of Title 38 M.R.S.A. Before issuance of a license the Board must consider the following:

(a) The potential hazard to the public and to the environment;

(b) The financial solvency of the operation;

(c) The consistency of the construction and subsequent operation with standards, requirements, and procedures in Title 38;

(d) That in the case of disposal, maximum practical treatment is available to reduce the volume and risk of handling before disposal.

Local participation concerning the siting of a new management facility, which is intended to receive off-site shipments of hazardous waste, is defined in Section 1304-A Municipal Participation for Commercial Hazardous Waste Facilities. The municipalities may not enact police power ordinances that are more stringent than the state requirements. When an owner or operator applies for a permit written notification must also be sent to the municipality. The municipal officers will then be granted intervenor status in any site review. At least one public hearing must be held in the proposed host community. Municipalities may have direct interaction with the Board through the site review by appointing four non-voting representatives to the Board.(7)

Massachusetts: Procedures and guidelines for the treatment and disposal of hazardous wastes in Massachusetts are established under the Hazardous Waste Facility Siting Act, Chapter 508 of the Acts of 1980; also Chapter 210 of the Massachusetts General Laws. The Department of Environmental Management (DEM) is largely responsible for implementing the siting procedures. the DEQE and Massachusetts Environmental Protection Act (MEPA) office provide technical assurances of human and environmental protection and an informed decisionmaking process. In addition, this act creates a Hazardous Waste Facility Site Safety Council that will oversee the siting process, facilitate negotiations, and provide assistance and information to all concerned. No state agency has the authority to site a facility until approved locally or after binding arbitration.

The following steps are to be taken in the siting process (9):

(a) A developer submits a Notice of Intent (NOI) to the state naming the site if chosen and providing other pertinent data as to type of facility and wastes to be processed;

(b) The Site Safety council reviews and accepts those notices "feasible and deserving" of state attention;

(c) A Local Assessment Committee (LAC) is formed in the proposed host community through grants available from the Council;

(d) DEM presents the proposal to the public at a series of briefing sessions where questions may be directed to state officials and the developer;

(e) A Project Impact Report is prepared by the developer delineating the potential environmental and socio-economic impact of the facility;

(f) Negotiations between the LAC and the developer will either lead to a Siting Agreement, establishing the conditions under which the facility will be built, or end in binding arbitration;

(g) State and local permits will then be issued or denied;

(h) Facility construction will begin on permitted sites.

Currently, four developers are seeking approval to construct new hazardous waste management facilities in the state. The SRS Corporation is seeking to build a solvent recovery plant in Haverhill. The Liquidcon Corporation has proposed sites in New Bedford and Newburyport for a plating waste solvent and recovery plant. The IT Corporation is proposing to build in Warren a storage and treatment facility with final disposal in a landfill at a total cost of 100 million dollars. The General Chemical Company is seeking to build a solvent recovery plant in Gardner.

New Hampshire: The statutory authority governing new facility siting is included in the Hazardous Waste Review Act of 1981; House Bill 468. The final state technical approval of a new facility site rests with the BSWM. In addition, the WSPCC reviews site applications where surface or ground water quality may be impacted.

At the local level a hazardous waste municipal review committee considers the proposal and weighs the possible social and economic impacts in the community.

Currently, two facilities are actively seeking permits, one disposal facility by the Stablex Company in Hooksett and a chemical recycle treatment plant in Merrimack.

Rhode Island: At the present time DEM is the state authority involved in site selection for new hazardous waste management facilities. Formal siting legislation is being pursued, but as yet, no legislation has been enacted. There does appear to be some question in the state whether land disposal operations are compatible with the hydrogeology or whether the potential for ground water contamination is too great.

Although new storage, treatment, and disposal facilities could have been permitted since May 15, 1981, only one permit has been issued to the Hunt Chemical Company of East Providence for treatment and recovery of spent etching wastes. There have been a number of other inquiries concerning standards, regulations, and administrative procedures, but no other applications have been received.

Vermont: Currently, there is no specific hazardous waste management facility siting legislation. The procedures and regulations governing new facility siting and construction are contained in the state Land Use and Development Act of 1969, Title 10, Chapter 151; also Chapter 250 of th acts of 1969, as amended. Ths act provides the basis for assessing the potential environmental, public health, economic, and social impact of a new facility as well as providing technical guidence. On the state level the AEC evaluates the technical aspects of the proposed operation and ultimately issues or denies a state permit. On the local level, any community can become a party to the siting application through Act 250. A state issued permit does not give the right for new facility construction until all local ordinances are met. A new facility many, therefore, be denied the right to build if local zoning or building permits are denied. At the present time, there are no new facility applications in review.

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7. Maine Department of Environmental Protection, "Waste Management Laws: Solid Waste, Hazardous Waste, Hazardous Matter, Hazardous Waste Fund," Office of the Commissioner, Bureau of Oil and Hazardous Material Control, Augusta, Maine, September 1981.

8. Massachusetts Department of Environmental Quality Engineering, "Hazardous Waste Management Regulations for Massachusetts Phase I Public Hearing Draft," The Hazardous Waste Regulatory Task Force, Division of Hazardous Waste, Boston, Massachusetts, October 1981.

9. Massachusetts Department of Environmental Management, "Preliminary Hazardous Waste Facility Siting Guide," Executive Office of Environmental Affairs, Publication Number: 12394-9-2000-5-81-CR, Boston, Massachusetts, May 1981.

10. Communication Directive from Executive Office of Environmental Affairs, Department of Environmental Quality Engineering, Division of Hazardous Wastes, Boston, Mass., September 23, 1981.

Appendix I EPA REGULATORY ACTIONS CONCERNING THE HAZARDOUS WASTE MANAGEMENT PROGRAM

Date	Location	CFR Parts	Regulatory Action	Effective Date
2/26/80	45 FR 12722	260	Hazardous Waste Management: Overview and Definitions	8/26/80
2/26/80	45 FR 12724	262	Standards applicable to generators of hazardous waste	8/26/80
2/26/80	45 FR 12737	263	Standards applicable to transporters of hazardous waste	8/26/80
5/19/80	45 FR 33066	260	Amends February 26, 1980 action	11/19/80
5/19/80	45 FR 33084	261	Lists 85 process wastes and 400 chemicals as hazardous wastes; defines the 4 characteristics of hazardous wastes	11/19/80
5/19/80	45 FR 33136	261	Proposed rule to amend hazardous waste list to include 11 wastes from wood preservation, organic chemicals, pesticides and secondary lead	Proposed
5/19/80	45 FR 33140	262	Amends February 26, 1980 action	11/19/80
5/19/80	45 FR 33150	263	Amends February 26, 1980 action	11/19/80
5/19/80	45 FR 33154	264,265	Standards applicable to owners and operators of hazardous waste treatment, storage and disposal facilities. Included in these regulations is the prohibition of landfill disposal of liquids after November 19, 1981.	11/19/80
5/19/80	45 FR 33260	264,265	Proposal to revise methods for financial assurance of closure and monitoring and maintaining after closure. First proposed December 18, 1978	Proposed

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5/19/80	45 FR 33280	265	Amends interim status requirements for underground injection	Proposed
5/19/80	45 FR 33290	122,123 124,125	Final consolidation of the hazardous waste RCRA permit regulations	Varies
5/19/80	45 FR 33516	122,123 124,125	Consolidated permit application forms for the hazardous waste program	Varies
7/16/80	45 FR 47832	261	Amends hazardous waste list to include 18 wastes	1/16/81
7/16/80	45 FR 47835	261	Proposed rule to amend hazardous waste list to include 18 wastes	Proposed
7/21/80	45 FR 48620	122,123 124,125	Amends wording of May 19, 1980 action (45 FR 33290)	Varies
10/8/80	45 FR 66816	264	Sets forth a broad outline of EPA's intended approach for controlling hazardous waste contamination of ground water	Proposed
11/12/80	45 FR 74884	261	Finalizes the listing of hazardous wastes promulgated May 19, 1980 that include specific and nonspecific sources	Varies
11/12/80	45 FR 74893	261	Amends list of hazardous waste to include all sludges from primary and secondary oil/solids/water separation in the petroleum refining industry	Proposed
11/17/80	45 FR 76074	122,260 264,265	Suspension of RCRA regulations to POTW covered under the Clean Water Act and neutralization tanks, transport vehicles or containers which neutralize wastes which are hazardous because they are corrosive	11/19/80

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11/17/80	45 FR 76076	122,260 264,265	Proposed amendments to include POTW and neutralization tanks under permit by rule	Proposed
11/19/80	45 FR 76620	261,262	Amends and clarifies small quantity generator status	11/19/80
11/19/80	45 FR 76630	122	Clarifies the circumstances under which hazardous waste management facilities may qualify for interim status	11/19/80
11/25/80	45 FR 78524	261,262 265	Clarifies the situations in which residues of hazardous wastes must be damaged as hazardous wastes	11/19/80
11/25/80	45 FR 78532	261	Finalizes the listing of hazardous wastes including commercial chemical products, off specification products and intermediates, when disposed of, are considered to be hazardous wastes.	11/19/80
12/04/80	45 FR 80286	261	Clarifies that such product or raw material pipelines which have hazardous wastes generated in them, are not considered as treatment or storage facilities, unless the hazardous waste remains in the pipe for greater than 90 days after the pipeline ceases to operate	11/19/80
12/31/80	45 FR 86966	122,263 264,265	Clarifies that a transporter may hold a manifested shipment of hazardous waste for 10 days without a RCRA permit and without complying with the storage facilities standards	12/31/80
12/31/80	45 FR 86968	262,264 265	Amendment requires owners and operators to comply with the standards applicable to generators (Part 262)	12/31/80

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1/12/81	45 FR 2802	122,264 265	Sets forth requirements for location, closure and post-closure care, financial requirements, use and management of containers and storage and treatment tanks, surface impoundments and waste piles	7/13/81
1/12/81	46 FR 2893	264,264	Proposes (a) containment inspections of waste piles and tanks; (b) control of air emissions from tank facilities; (c) notification of local land authority of hazardous waste activity	Proposed
1/16/81	46 FR 4614	261	Finalizes 13 hazardous wastes published July 16, 1980	1/16/81
1/19/81	46 FR 5616	123	State hazardous waste programs: Requirements for public participation in the state enforcement process during interim authorization	1/19/81
1/23/81	46 FR 7666	122, 264 265	This amendment (a) sets final incinerator standards (b) finalizes the interim status incinerator standards issued May 19, 1980 (c) amends the permit regulations to correspond to the facility regulations	7/2/81
1/26/81	46 FR 8298	123	Changes the standaad approach to Phase II by offering interim authorization in three components	1/26/81
1/26/81	46 FR 7964	123	With this announcement states may apply for: (a) Component A - governing the permitting of storage and treatment of hazardous waste in tanks, surface impoundments and waste piles and the use and management of containers of hazardous wastes	7/13/81

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			(b) Component B - governing the permitting of treatment in incinerators	7/27/81
1/26/81	46 FR 8312	123	Gives states direct federal authority to conduct compliance inspections after they have received interim authorization	1/26/81
2/05/81	46 FR 11126	122,260 264	Reproposing final permitting standards applicable to owners and operators of hazardous waste land disposal facilities (Part 264). Comments accepted to August 4, 1981	Proposed
2/13/81	46 FR 12414	122,267	Published temporary standards for four classes of hazardous waste land disposal facilities: landfills, surface impoundments, land treatment facilities and Class I underground injection wells (Part 267).	8/13/81
2/20/81	46 FR 13492	265	Allows liquid ignitable wastes to be disposed of in landfills until May 19, 1981, provided they are protected from ignition. After this date landfill disposal of containerized liquid ignitable waste is prohibited	2/20/81
6/29/81	46 FR 33502	265	Amends February 20, 1981 action. After November 19, 1981 landfill disposal of containerized liquid ignitable waste is prohibited. This date now coincides with the November compliance date of the general restrictions on landfill disposal of liquids set May 19, 1980 (45 FR 33154).	6/29/81
7/21/81	46 FR 37527	122,260 264	Comments extended on February 5, 1981 action to October 4, 1981	7/21/81

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7/24/81	46 FR 38318	123	Effective dates for Components A and B Phase II published January 26, 1981 were confirmed (46 FR 7964)	7/24/81
10/20/81	46 FR 51407	264	Revision of Components A and B - Temporary suspension of the effective dates of the January 12 and 23, 1981 actions for existing incinerators and surface impoundments	Proposed
10/30/81	46 FR 54612	---	EPA regulations under consideration RCRA	Public Notice
11/06/81	46 FR 55110	122,264	Amended container and waste pile standards to waive the containment system requirements for wastes that do not contain free liquids provided they are protected from the elements	11/6/81
11/17/81	46 FR 56582	261	Amends the hazardous waste listing	11/17/81
11/17/81	46 FR 56592	265	Allows liquid containers of hazardous waste into landfills provided they are packed in overpacked drums	11/17/81
12/07/81	46 FR 59537	260	List of companies requesting specific exclusions	Public Notice
12/10/81	46 FR 60446	122,262	Interprets interim status for generators	12/10/81
12/15/81	46 FR 61145	122,123 264,267	Presents the basic conceptual framework EPA is developing for its hazardous waste land disposal regulations	Proposed
01/11/82	47 FR 1254	265	Amendments proposed to waive groundwater monitoring requirements for surface impoundments that neutralize corrosive wastes so that	Proposed

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			human health and the environment are not endangered by such wastes	
02/02/82	47 FR 4706	122,260 264,265 266	Comment period reopened concerning November 17, 1980 action (45 FR 76076). Comments will be accepted to March 4, 1982	Proposed
02/24/82	47 FR 8010	123	This action overrides the temporary suspension of regulations discussed on October 20, 1981 (45 FR 51407). As of this date states with Phase II interim authorization may issue RCRA permits for existing incinerators and surface impoundments	2/24/82
02/25/82	47 FR 8304	122,264 265	Extension of the November compliance date for the general restrictions on landfill disposal of liquids and landfill disposal of containerized liquid ignitable wastes to May 26, 1982. This action also exempts from hazardous waste management regulations the act of adding absorbent material to hazardous waste in containers and adding hazardous waste to absorbent material with the purpose of reducing free liquids at the time of disposal.	2/18/82
02/25/82	47 FR 8307	265	Proposed amendments to allow some containers holding free liquids to be disposed of in a landfill, in some circumstances	Proposed
3/3/82	47 FR 9007	260	Updates 12/7/81 (46 FR 59537) of companies requesting specific exclusions	Public Notice
3/4/82	47 FR 9336	123,260 262	Proposed amendment to require the use of a specific manifest form described in this action.	Proposed

Appendix II OUTLINE OF FEDERAL REGULATIONS CONCERNING THE RCRA HAZARDOUS WASTE PROGRAM

- Chapter I Environmental Protection Agency
  - Subchapter D Water Programs
    - Part 122 EPA Administered Permit Programs: National Pollutant Discharge Elimination System; Hazardous Waste Permit Program; Underground Injection Control Program
      - Subpart A Definitions and General Program Requirements
      - Subpart B Additional Requirements for Hazardous Waste Program under the RCRA
    - Part 123 State Program Requirements
      - Subpart A General Program Requirements
      - Subpart B Additional Requirements for State Hazardous Waste Program
      - Subpart F Requirements for Interim Authorization of State Hazardous Waste Programs
    - Part 124 Procedures for Decisionmaking
      - Subpart A General Program Requirements
      - Subpart B Specific Procedures Applicable to RCRA Permits (Reserved)
      - Subpart E Evidentiary Hearing for EPA-Issued NPDES Permits and EPA-terminated RCRA Permits
      - Subpart F Non-Adversary Panel Procedures
  - Subchapter I Solid Wastes
    - Part 260 Hazardous Waste Management System: General
      - Subpart A General
      - Subpart B Definitions
      - Subpart C Rulemaking Petitions

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Part 261	Identification and Listing of Hazardous Waste
Subpart A	General
Subpart B	Criteria for Identifying the Characteristics of Hazardous Waste and for Listing Hazardous Waste
Subpart C	Characteristics of Hazardous Waste
Subpart D	Lists of Hazardous Waste
Part 262	Standards Applicable to Generators of Hazardous Waste
Subpart A	General
Subpart B	The Manifest
Subpart C	Pre-transport Requirements
Subpart D	Recordkeeping and Reporting
Subpart E	Special Conditions
Part 263	Standards Applicable to Transporters of Hazardous Waste
Subpart A	General
Subpart B	Compliance with the Manifest System and Recordkeeping
Subpart C	Hazardous Waste Discharges
Part 264	Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities
Subpart A	General
Subpart B	General Facility Standards
Subpart C	Preparedness and Prevention
Subpart D	Contingency Plan and Emergency Procedures
Subpart E	Manifest System, Recordkeeping, and Reporting
Subpart F	(Reserved)
Subpart G	Closure and Post-Closure
Subpart H	Financial Requirements

Subpart I Use and Management of Containers
Subpart J Tanks
Subpart K Surface Impoundments
Subpart L Waste Piles
Subpart M (Reserved)
Subpart N (Reserved)
Subpart O Incinerators

Part 265 Interim Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities

Subpart A General
Subpart B General Facility Standards
Subpart C Preparedness and Prevention
Subpart D Contingency Plan and Emergency Procedures
Subpart E Manifest System, Recordkeeping, and Reporting
Subpart F Ground Water Monitoring
Subpart G Closure and Post-Closure
Subpart H Financial Requirements
Subpart I Use and Management of Containers
Subpart J Tanks
Subpart K Surface Impoundments
Subpart L Waste Piles
Subpart M Land Treatment
Subpart N Landfills
Subpart O Incinerators
Subpart P Thermal Treatment
Subpart Q Chemical, Physical, and Biological Treatment
Subpart R Underground Injection

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Part 267	Interim Standards for Owners and Operators of New Hazardous Waste Land Disposal Facilities
Subpart A	General
Subpart B	Environmental Performance Standard
Subpart C	Landfills
Subpart D	Surface Impoundments
Subpart E	Land Treatment
Subpart F	Ground Water Monitoring
Subpart G	Underground Injection

LAND APPLICATION OF SEWAGE SLUDGE LANDFILL LEACHATE

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Water Resources Center

UNIVERSITY OF RHODE ISLAND

WATER RESOURCES CENTER

Final Report

Land Application of Sewage Sludge Landfill Leachate

W. R. Wright and H. J. Brown

OWRT Project #A-078-RI

Completion Report

DECEMBER 1982

Abstract

This investigation evaluated the feasibility of the "living filter" concept as an alternative method of heavy metal leachate disposal to prevent contamination of ground-waters. Leachate collected from a simulated sewage sludge landfill was applied at rates of 0, 200, 400, and 600 Kg N/ha/yr to plots of rye grass (L. perenne) to evaluate the attenuation of contaminants. The concentrations of metals Cd, Cu, Fe, Ni, Pb and Zn, as well as nitrogen content, were analyzed over a 5 month period in soil, soil-water lysimeter extracts, and grass samples before, during and after application of landfill leachate. Exchangeable nitrogen (NH_4 + NO_3^- + NO_2^-) concentrations in soil were significantly higher at the 600.Kg N/ha/yr rate while significantly greater concentrations were retained within the surface 30 cms. Soil-water extracts were significantly higher at the 400 and 600 Kg N/ha/yr rate and also highest in the surface layers. The concentrations of metals in the soil and soil-water extracts remained generally unchanged statistically. Yields of rye grass did not differ significantly within the three rates of N application, but exchangeable nitrogen was highest at the 600 Kg N/ha/yr rate. In general, heavy metal accumulation in the soil was not a problem but nitrogen contamination to ground-waters could be an area legitimate concern when applying sewage sludge landfill leachate to a grass crop.

Land Application of Sewage Sludge Landfill Leachate

W. R. Wright and H. J. Brown

Objective

The objective of this research was to evaluate the feasibility of applying sewage sludge landfill leachate to a grass crop as a means of attenuating heavy metal contaminants. The effectiveness of such a "living filter" system was assessed over a five month period from June - November 1982. The concentration of metals Cd, Cu, Fe, Ni, Pb and Zn, as well as nitrogen content were analyzed in soil, soil-water lysimeter extracts, and grass samples collected from experimental plots before, during, and after treatment with landfill leachate at rates of 0, 200, 400 and 600 kg N/ha/yr.

Methods

A miniature landfill, 2 m deep x 8 m x 1.5 m was excavated, lined with 6 mil polyethylene, equipped with a leachate collection system and filled with primary treated, super-chlorinated sewage sludge from South Kingstown's treatment facility. Sludge samples were collected, oven dried at 60°C for 12 hours and ground in a Wiley mill through a 40 mesh sieve. One gram samples were ashed over night in a muffle furnace at 800°F, dissolved in 5 ml of 2N HCl, vacuum-filtered into a 50 ml volumetric flask and brought to volume with distilled water according to standard dry ashing procedures (Perkin Elmer Corporation, 1976). Heavy metal concentrations were determined using a Perkin Elmer (Model 5000) atomic absorption through #2 Whatman filter paper and analyzed by atomic absorption. Suction lysimeters were installed within each plot at depths of 30, 60 and 90 cm and sampled on a bi-weekly basis. Soil-water extracts were analyzed for nitrogen and metals according to previously referenced standard procedures. Each month, prior to heading, rye grass was harvested, oven dried at 60°C for 1 week, with dry weights and percent yields recorded. Samples were ground on a Wiley mill through a 40 mesh sieve and analyzed for metals following standard Perkin Elmer procedures. Total nitrogen content was determined using standard macro kjeldahl methods (Bremner, 1965). Duncan's multiple range test was performed on all laboratory and field data at the 95% level of confidence.

Results

Total analyses of the sewage sludge are presented in Table 1. Concentrations of Cu, Fe, Ni, and Pb were somewhat higher than concentrations extracted from similar material by Galgowski (1980), while concentrations of Cd and Zn were slightly lower. Total nitrogen data were comparable.

Properties of sewage sludge landfill leachate are presented in Table 2. Overall, metal and inorganic nitrogen concentrations significantly increased over time, with the exception of Pb.

Table 2. Average metal ion concentrations and total inorganic nitrogen content in raw leachate over time.

Sample Date	Metals						Exch. Nitrogen
	Cd	Cu	Fe	Ni	Pb	Zn	$NH_4 + NO_3 + NO_2$
Month	μg/gm						
7/82	0.03bc*	0.5b	55b	N.D.	1.1a	0.5b	964a
8/82	0.03bc	0.6b	76ba	0.01b	0.2a	0.7b	1349c
9/82	0.04b	0.7b	89a	0.05a	0.2a	0.9a	1458b
10/82	0.06a	1.9a	94a	0.07a	0.1a	1.6a	1504b

N.D. None detected.

*Values followed by the same letter within a column are not significantly different at the 5% level (Duncan's Multiple Range Test).

Table 3. Average metal ion and nitrogen concentration in soil samples as affected by rate of leachate application.

Leachate Rate	Metals						Exch. Nitrogen
	Cd	Cu	Fe	Ni	Pb	Zn	$NH_4 + NO_3 + NO_2$
kg N/ha/yr	μg/ml						
0	0.04ab*	0.32a	3.9a	0.16a	2.5a	0.53a	26.5b
200	0.04ab	0.30a	4.9a	0.16a	2.1a	0.57a	28.6b
400	0.03b	0.27a	3.2a	0.22a	2.1a	0.75a	32.6b
600	0.05a	0.23a	3.3a	0.18a	2.7a	0.84a	47.0a

*Values followed by the same letter within a column are not significantly different at the 5% level (Duncans Multiple Range Test).

Table 5. Average metal ion and nitrogen concentration in soil samples as affected by depth.

Soil Depth	Metals						Exch. Nitrogen
	Cd	Cu	Fe	Ni	Pb	Zn	$NH_4 + NO_3 + NO_2$
—cm—	µg/gm						
30	0.07a*	0.14a	1.5b	0.20a	3.4a	0.74a	41a
60	0.02b	0.29a	4.0ab	0.13a	2.1a	0.77a	32b
90	0.02b	0.39a	6.3a	0.19a	1.5a	0.51a	29b

*Values followed by the same letter within a column are not significantly different at the 5% level (Duncan's Multiple Range Test).

with 400 kg N/ha (Table 6). Cd levels in the soil-water extracts increased with higher rates of N application and attained highest concentrations in the top 30 cm of the profile (Table 7). This indicates that Cd would not present a problem to ground-water contamination at the present levels of leachate application. No differences in concentrations of Cu or Zn in depth were detected in the soil-water extracts. Sampling date was not significantly relevant to levels of Cu or Cd in soil-water extracts. However, concentrations of Cd were highest on 6/29, while Fe and Ni concentrations were generally highest in the last two sampling months. Zn concentrations increased ten fold after 1 month then significantly decreased each successive month thereafter (Table 8).

Nitrogen content and yield in grass harvests as affected by leachate application rate is presented in Table 9. In general, no significant differences in metal concentrations were detected. A slight increase in nitrogen content was shown in harvests from plots receiving higher rates of nitrogen when compared to control plots. Grass yields were significantly greater in samples from plots that were treated with leachate at a rate of 400 kg N/ha. Although no obvious trends in metal concentrations in harvested grass were detected for sampling dates, significant differences were observed. The concentrations of Cd were significantly higher in the initial month. Iron and Zn concentrations increased over time and were significantly more concentrated in grass samples collected from the final harvest. Levels of

Table 8. Average metal ion concentration and nitrogen content in soil-water extracts as affected by sampling date.

	Metals						Exch. Nitrogen
Sample Date	Cd	Cu	Fe	Ni	Pb	Zn	$NH_4 + NO_3 + No_2$
Month	µg/ml						
6/15	§	0.02ab*	0.06b	§	0.02c	0.06c	3.3b
6/29	0.03	§	0.02b	0.02b	0.04b	0.11bc	2.2b
7/20	§	0.01ab	0.06b	0.03b	0.18a	1.04a	6.8b
8/24	§	0.01ab	0.07b	0.02b	0.01c	0.92a	37.9a
9/28	§	0.03a	0.35a	0.12a	0.01c	0.47b	35.0a
10/13	§	0.02ab	0.03b	0.15a	0.02c	0.39bc	28.5a

*Values followed by the same letter within a column are not significantly different at the 5% level (Duncan's Multiple Range Test).

§Below detection limits.

Table 10. Average metal ion concentration, nitrogen content and yield in grass samples as affected by sampling date.

Sample Date	Metals						Exch. Nitrogen	Yield
	Cd	Cu	Fe	Ni	Pb	Zn	$NH_4 + NO_3 + NO_2$	
—month—	µg/gm							—kg/ha—
6/82	2.32a*	9c	222c	0.7b	3.6b	22d	3.0c	1915c
7/82	0.03b	17a	322b	3.2a	4.2b	27b	2.6d	4675a
8/82	0.05b	13b	281bc	1.0b	8.3a	24c	3.7b	3246b
9/82	0.23b	11bc	594a	0.6b	5.4b	29a	3.9a	3500b

*Values followed by the same letter within a column are not significantly different at the 5% level (Duncan's Multiple Range Test).

ment with sewage sludge landfill leachate was well within the expected range of soil nitrogen for this region (Millar, 1955). Preliminary analysis of the nitrogen content in soil-water extracts indicates that the nitrate-N exceeds maximum concentration levels of 10 ppm. Percent total nitrogen content in harvested rye grass samples was comparable to percent total nitrogen content typically found in 10-14" tall rye grass plants (Millar, 1955). In conclusion, accumulation of heavy metals in the soil was not a problem but nitrate-N in soil-water extracts is an area of legitimate concern when applying sewage sludge landfill leachate to a grass crop. However, further study is recommended to validate these results before any conclusive recommendations can be made regarding the effectiveness of the "living filter" system.

RHODE ISLAND
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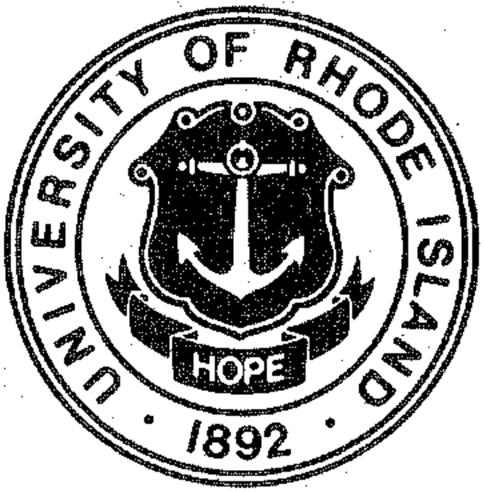

COMPLETION REPORT, FY-1983 PROGRAM
SOURCE OF ACID PRECIPITATION AND ITS EFFECTS ON WATER QUALITY

by

C.P.C. Poon, T. Wright and M. North

Completion Report

Acid Precipitation: Source Identification and Its Effects on Water Quality

Submitted by

Calvin P.C. Poon, Principal Investigator
Department of Civil and Environmental Engineering
University of Rhode Island
Kingston, RI 02881

Thomas Wright, Co-principal Investigator
Michael North,
Rhode Island Department of Environmental Management
Providence, R.I. 02908

Project No. 374204

to

U.S. Department of The Interior

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1. PROJECT OBJECTIVE

Acidic deposition is a pervasive phenomenon occurring primarily in the eastern portion of the United States and parts of Canada. The increasing acidity of precipitation in the northeast U.S. with a mean pH on the order of 4.0 has a long term and adverse effects on fish, plant life, and other terrestrial biota. The New England River Basin Commission has estimated the damage costs to aquatic and terrestrial ecosystems and materials in New England and New York from acid deposition to be $250 to $500 million per year.

Rhode Island and its neighboring northeast states feel that they share an unfair burden of sulfur emission reduction to minimize the problem of acid precipitation. The conventional knowledge points out that the long range transport of sulfates and nitrogen oxides from midwestern states is the major source of acid deposition in the northeast. However this is difficult to prove and quantify in Rhode Island and in the northeast region as a whole. South-southwesterly storms indicate a potential source of acid precipitation from Atlantic coast states as well. The first objective of this study is to collect precipitation data over a one-year period in order to determine if there is a recognizable pattern of the relative amount of acidity associated with groups of storms coming from various directions.

The quality of water in headwater stream reaches is usually more sensitive to acidic deposition than that in downstream reaches as the latter carries chemicals from urban runoff and pollutants from land development activities. Presently there are no pH, acidity, and alkanity data available for the headwaters of many class A rivers in Rhode Island. There is a great need to collect such data for establishing a useful data base. The second objective of this study is to quantify the potential long term effect of acidic deposition on the water quality of three rivers in the rural area of Rhode Island.

Short term effects of acidic deposition from individual storms can be significant as the change of pH can be so sudden and large in magnitude that the environmental impact is quite different from that of the long term effects. The third objective of this study is to monitor the water quality of several rivers before, during, and after individual storm events so that short term effects and recovery periods can be quantified.

2. RELATED RESEARCH

The problem of acidic deposition and its adverse effects in N.E. United States have been documented in the literature (ref. 1-9). The final draft of the joint US/Canadian report on Acid precipitation and the Long Range Transport of Air Pollutants in Eastern Canada and New England (ref. 10) has expressed great concern on the acidification of freshwater ecosystems, reduction in visibility, nutrient and toxic metal leaching from soil, effects on human health and damage to materials.

Many studies and calculations show evidence of long range transport of sulfate particulates from the Ohio River Valley to the N.E. region Altshuller et al (ref. 11) reported in 1980 their calculations of sulfate deposits for the months of January and August 1977 using the EURMAP model that one-quarter of the deposition occurring in New York and New Jersey region originated in Pennsylvania, Virginia, and W. Virginia; another quarter originated in Ohio, Indiana, Illinois, Mississippi, Wisconsin. Similarly, Galvin et al (ref. 12), Miller et al (ref. 13), Kolak et al (ref. 14) recently reported that high sulfate depositions were associated with emissions of SO_4 to the south and southwest of New York state, i.e., Ohio River Valley origin.

While many studies tend to indicate most sulfate deposits originate from the midwestern states, the same study by Altshuller et al (ref. 11) also showed calculations that one-quarter of the sulfate deposition occurring in NY and NJ originated in regions north and south of the NY-NJ area. In addition, Harr et al (ref. 15) suggested in their study that acid deposition in the Adirondack Mountains could come from Ontario. Statistical analyses of precipitation data by Peters et al (ref. 16) in 1982 show little change in pH from 1965-78 within New York State as a whole but the pH of bulk precipitation has decreased in the western part of the state by 0.2 pH units since 1965 and increased in the eastern part by a similar amount. Also stream water analyses show that sulfate concentrations decreased an average of 1 to 4 percent per year.

In the New England states, Bruckman (ref. 17) conducted a statistical analysis of air quality and meteorological data in Connecticut and showed that as much as 70% of the atmospheric particulates, of which 25% were sulfates and nitrates were attributable to sources outside the state. Recently, data of peak sulfate loadings in Maine and Vermont were compared (ref. 18) and they were almost identical. Similarly, Cortell's report (ref. 19) indicates a relatively uniform spread of SO_4 from west to east across the state of Massachusetts in precipitation events. These findings suggest that outside sources associated with the prevailing air trajectory from west to east account for much of the sulfate deposition in the New England area. However, hard evidence of the midwest originated sources of sulfate depositions and their quantification are difficult to obtain. In fact, there is a general weather pattern of a south-southwesterly depression track that often guides storms from the south moving along the Atlantic seacoast up north to the New England states. Sulfates from the Atlantic coast states can therefore be another outside source of acidic deposition. Kenneth Rahn of the University of Rhode Island (ref. 20), on the basis of a tracer study, suggests that the midwest may be responsible for different proportions of the pollution at different sites in the Northeast, but that sources more to the south may make the largest contribution of this pollutant in coastal areas of the Northeast. Also sources of sulfate from the north are possible.

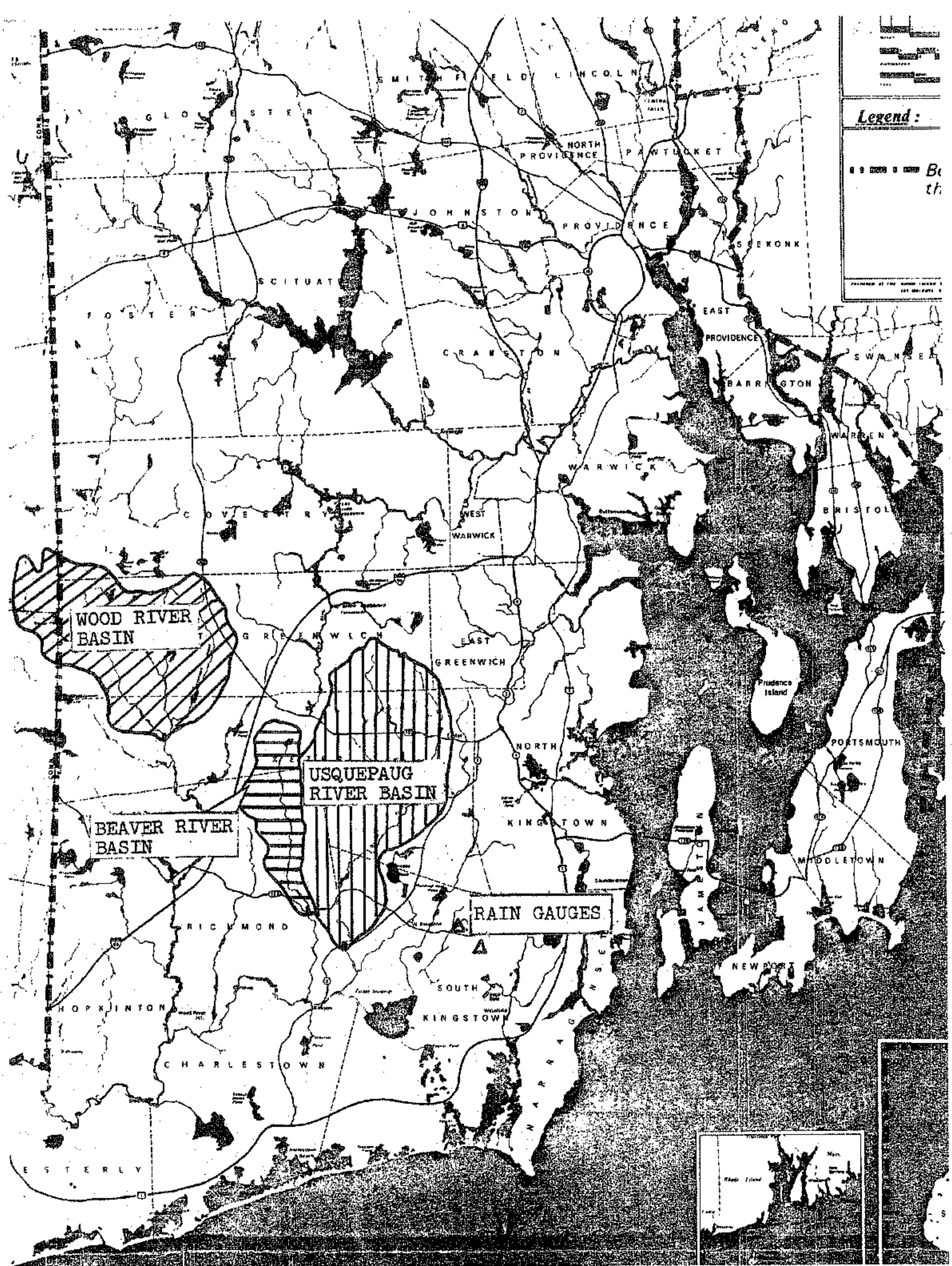
There is therefore the controversy about the outside sources of sulfates which are transported to the N.E. region. More data are required for source identification and quantification. A study in RI (ref. 21) indicates that there is no clear relationship between the amount of sulfate deposits and the prevailing wind direction according to wind rose and SO_4 analyses. For long range transport study, a synoptic scale air mass movement can be used, providing better correlation between the air mass movement and the interregional deposition phenomenon. Wolff et al (ref. 22) used this approach and were successful in demonstrating that the cold fronts and air masses associated with west or southwest winds yielded the lowest pH in precipitations recorded in the New York Metropolitan area from 1975 through 1977. Air parcel trajectory analyses were required in this approach, along with wind direction data, to identify the source origin of acidic deposition.

Water quality data are routinely collected for major rivers as a part of the nationwide water resources data informational program conducted by U.S. Geological Survey. However the majority of the data are collected for downstream sections near population centers. Normally the water in these locations is not very sensitive to acidic deposition as it is already contaminated with chemicals. The headwaters usually are of high quality and are very sensitive to acidic deposition if they contain a low buffering capacity. This is normally the case for the N.E. states. Presently headwater water quality data are grossly lacking. Many states are stepping up their efforts to expand their monitoring programs to include the headwaters, e.g., in Massachusetts and Connecticut. In RI, no data exists on water quality of headwaters of all major rivers, with the exception of the Scituate Reservoir System. Some sporadic pH and alkalinity measurements were taken by RI DEM on some tributaries of the Wood River. A part of this proposed project work is to monitor the buffering capacity of the headwaters of Wood, Beaver, and Usquepaug Rivers in Rhode Island throughout the project period.

FIGURE 3-1

Location of the Study Area in the State of Rhode Island

Wood River Watershed upstream of Route 165 Bridge
Beaver River Watershed upstream of Route 138 Bridge
Usquepaug River Watershed upstream of Route 2 Bridge
Rain Gauges at the University of Rhode Island


WOOD RIVER BASIN
USQUEPAUG RIVER BASIN
BEAVER RIVER BASIN
RAIN GAUGES
Legend :
GLOCESTER
SMITHFIELD
LINCOLN
NORTH PROVIDENCE
PAWTUCKET
JOHNSTON
PROVIDENCE
SEEKONK
SCITUATE
FOSTER
EAST PROVIDENCE
CRANSTON
SWANSEA
BARRINGTON
WARREN
WARWICK
COVENTRY
WEST WARWICK
BRISTOL
GREENWICH
EAST GREENWICH
Prudence Island
PORTSMOUTH
NORTH KINGSTOWN
MIDDLETOWN
JAMESTOWN
RICHMOND
NEWPORT
SOUTH KINGSTOWN
HOPKINTON
CHARLESTOWN
NARRAGANSETT
WESTERLY
Rhode Island
Mass.

3. AREA AND METHOD OF STUDY

This study was conducted in southwestern Rhode Island with three major streams being the subject of analysis. All three streams are considered class A high quality water with great biological and recreational value. The area of study as outlined in Figure 3-1 is generally rural, with open land, individual housing, and agricultural land dominating the area, the center of the general area of study is approximtely 22 miles southwest of Providence, Rhode Island, 71 miles northeast of New Haven, Connecticut, and 135 miles northeast of New York City. Soils throughout the area range from strongly acidic to very strongly acidic and most local waters in the area are slightly acidic with low alkalinity.

3-1 Wood River Watershed

The Wood River watershed upstream from the sampling station is 35.2 square miles in size, with the center of the watershed located approximately 23 miles southwest of Providence, Rhode Island. Approximately 7.2 square miles of this area is located in Connecticut. The watershed is dominated by forested land located within the Arcadia Management Area. Of the 28 square miles of watershed located in Rhode Island, 93.4% is considered open land, forest, and public land. Agricultural uses account for 4.5% of the land use, and 2.1% of the watershed is used for residential purposes. Soil type is dominated by the Canton-Charlton-Sutton series, followed by Hinckley-Merrimack soils. These soils range from strongly acidic to very strongly acidic. Other strongly acidic soils are found within the watershed to a lesser extent (ref. 25).

The sampling station for Wood River is located on Ten Rod Road, Route 165, Exeter. A staging gauge is operated by the U.S. Geological Survey, providing continuous flow measurements of the river's discharge. This station is located 12.4 miles from the rain sampling station located at East Farm. Historical records at a downstream gauging station at Hope Valley from 1967 to 1981 show that average discharge from Wood River was 76.0 cfs, with maximum recorded discharge being 896 cfs. For Wood River downstream from the sampling station, the minimum recorded flow is 4.9 cfs. The U.S. Geological survey also monitors temperature and specific conductance of streamflow on a continuous basis and monitors other water quality parameters randomly. From October 1977 to September 1981, average specific conductance was 73 umhos, with maximum and minimum values being 216 and 21, respectively. The average year-round temperature is 11.5^{0}C with the maximum temperature being 28^{0}C and a minimum temperature of 0^{0}C when the river freezes over in winter.

3-2 Beaver River Watershed

The Beaver River watershed upstream from the sampling station is a relatively small area encompassing 8.9 square miles of land, with its central point located approximately 23 miles from Providence, Rhode Island. Of the land located within the watershed, 81.2% is designated as open, forest, or public lands. Agriculture land occupies 11.4% of the watershed, with turf farms being the dominant users. Residential land accounts for 4.5% of the watershed. Soil type is dominated by the strongly and very strongly acidic Canton-Charlton-Sutton series. The strongly acidic Narragansett-Bridgehampton-Wapping series is of secondary importance and other soils of a strongly and very strongly acidic nature make up the rest of the watershed (ref. 25).

The sampling station is 6.0 miles from the East farm sampling station, at the U.S. Geological Survey gauge located at Beaver River Bridge on State Highway Route 138 in Richmond. All river sampling is done from this bridge. Data from the U.S.G.S. flow gauge from October 1975 to September 1982 indicate that the average discharge from Beaver River was 21.6 cfs, with maximum and minimum discharges being 370 cfs and 1.7 cfs, respectively. For the periods June 1979 to September 1980 amd May to September 1982, average specific conductance was 51 umhos, maximum conductance was 69 umhos and minimum was 28 umhos. The average temperature was 9.9°C, maximum was 26.0°C, and minimum temperature was 0°C.

3-3 Usquepaug River Watershed

The Usquepaug River watershed, shown in Figure 3-1, includes 36.1 square miles of land upstream from the sampling station. This rural area, with its center located 20.5 miles from Providence, Rhode Island, has only 1.3% of the watershed being used for residential purposes. Open land, forest, and public land account for 84.1% of the area and 9.0% is designated as agricultural land. This farmland is dominated by turf farms and to a lesser extent by strawberry fields. Soils in the area are dominated by the strongly to very strongly acidic Canton-Charlton-Sutton series. Strongly acidic Narragansett-Bridgehampton-Wapping and Enfield-Bridgehampton-Agawan Soils series are of secondary importance, with other strongly and very strongly acidic soils making up the rest of the watershed (ref. 25).

The sampling station on Heaton Orchard Bridge, Route 2 in South Kingston, is 4.4 miles from the rain sampling station at East Farm. River sampling is done from this bridge, where a U.S. Geological survey stream gauge is located. Stream flow data collected at this station from October 1958 to September 1959, and from December 1974 to September 1982, show that the average discharge from the Usquepaug River is 76.2 cubic feet per second. Maximum discharge recorded is 1,060 cfs and minimum streamflow is 3.9 cfs. Specific conductance and temperature were recorded at this station from December 1974 to September 1980. Average conductance was 62 umhos, with maximum and minimum values being 250 umhos and 21 umhos, respectively. Average temperature was $11.0^{o}C$, with a maximum value of $25.5^{o}C$ and a minimum occurring at freeze-over, $0^{o}C$.

3-4 Sampling and Analytical Procedures

River water samples were collected from each of the three sampling stations before, during, and after a precipitation event. Sampling before the storm established a baseline set of data, while the following samples indicated any changes in water quality due to the event and the time period needed to recover from the changes. Samples were collected from midstream using a Kahlsico Van Dorm bottle, model #135 WA103, modified to hold one liter of sample and to trigger the closure mechanism with a trip wire instead of the usual messenger. This allowed the bottle to be used horizontally in shallow streams. Samples were stored in one liter polyurethane bottles for laboratory analysis. Each bottle was filled leaving no air space, eliminating any changes in water chemistry due to air effects. Field measurements were taken at the site after pouring water collected with the Van Dorm bottle into a plastic bucket.

Field analyses included measurement of temperature, specific conductivity, and pH. Specific conductivity and temperature were measured using a YSI salinity, conductance, and temperature meter, model 33. A Cole-Palmer Digisense digital pH meter, model #5986, was used to measure the pH in the field.

Laboratory analysis was performed with the samples at room temperature. If the samples could not be analyzed immediately after collection they were refrigerated (at 4^0C) and then allowed to warm to room temperature immediately prior to analysis. Laboratory analyses included the measurement of pH, alkalinity and acidity. A Cole-Palmer Digital Chemcadet pH meter, model #5984-00, was used in the laboratory for pH determination. Alkalinity was determined using the low alkalinity method described in Standard methods (ref. 23). Acidity was also determined according to Standard Methods.

Precipitation samples were collected at University of Rhode Island, East Farm Agricultural Station, one mile south of the main campus. The sampler consisted of a plastic bucket fitted with an eight inch diameter funnel. A rubber tubing allowed precipitation to drain from the funnel into the bucket without water loss due to evaporation. During snowstorms, the funnel was removed to allow direct fallout into the bucket. This apparatus was held in place and maintained at a height of 4 ft. by a wooden frame, located in an open field on East Farm. The sampler was covered during dry periods and manually opened before a precipitation event. The sample was manually collected after the storm was over and brought back to the laboratory for analysis.

Laboratory analysis of the precipitation sample consisted of determining the quantity of precipitation during the event and the construction of a titration curve necessary for the determination of acid components in the sample by the Gran Plot method.

Sample volume was measured in a graduated cylinder. Precipitation quantity was determined by dividing the sample volume by the surface area of the funnel for rain storms or the surface area of the bucket during snow storms. These results were compared to measurements taken at East Farm and measurements taken by the Agricultural experiment station on the main campus.

A titration curve was constructed using a 100 ml volume of sample. The sample was placed in a 250 ml beaker atop a magnetic stirrer, with the unit then covered with a plexiglass box. The pH probe was placed in the sample through a small hole in the box. Nitrogen gas was bubbled through a 500-ml Erlenmeyer flask of distilled water and then flowed through tubing into the box and hooked over the edge of the beaker. Nitrogen was allowed to flow over the sample and make up the atmosphere within the box. The sample was then gently stirred and the initial pH taken. A burette of 0.02N NaOH was placed through the top of the box and the sample was titrated to an endpoint of pH 10. pH was recorded with each addition of NaOH and the titration curve was constructed. This curve was used to obtain the concentrations of strong acid, H_2CO_3, NH_4^+ and HCO_3^- which constitute the acidity in the precipitation. This was calculated using the modified Gran Plot method described by M.D. Seymour et al (ref. 24).

3-5 Meteorological Information

The origin of each storm and its subsequent route to Rhode Island area was required in order to determine the probable source of the acidity in the precipitation and to determine the local effects on the rivers due to this precipitation. Storm track was determined for each storm using a set of meteorological weather maps supplied by a major television station in Providence. Weather maps for the period prior to the storm's arrival in Rhode Island were used to trace the storm's path. Satellite photos, radar scans, and pressure maps were the main sources of information used to follow the storm paths.

4. DATA COLLECTION

4-1 Collection of Baseline Information

Data collection began in August of 1983 with the collection of background samples. River samples were taken from each location during a period of low flow and dry weather:

			Field			Lab.	
River	Date	Time	pH	T (^{o})	Spec. Cond. (umhos at 25^{o}C)	pH	Alkalinity (mg/l as $CaCO_3$)
Wood	Aug. 17, 1983	1:30P	---	19	38	6.65	9.1
Beaver	Aug. 17, 1983	2:20P	6.40	19.6	48	6.04	4.58
Usquepaug	Aug. 17, 1983	2:45P	5.60	21.8	68	5.88	7.46
Wood	Aug. 25, 1983	11:00A	---	16.0	37	6.71	9.26
Beaver	Aug. 25 1983	12:00N	---	14.2	41	6.87	10.12
Usquepaug	Aug. 25 1983	12:30P	---	21.9	70	6.64	11.08

These samples provided baseline data for the rivers during periods of dry weather and low flows. Flow rates of the Wood, Beaver, and Usquepaug river during the period were approximately 20 cubic feet per second, 1.8 cfs, and 34 cfs, respectively.

During this period sediment samples were also collected from each of the rivers. Three samples were collected upstream from the sampling station for each of the rivers.

Samples were collected from the top layer of sediment from the river bottom for subsequent elutriate analysis.

River	Date	Distance Upstream from Sampling Station	Spec. Cond. (umho at 25°C)	pH	Alkalinity mg/l as $CaCO_3$	Acidity mg/l
Wood	Aug. 25, 1983	150 feet	55	8.41	71.82	1.85
Wood		450 feet	28	7.48	15.66	3.33
Wood		850 feet	39	7.44	26.74	2.96
Beaver	Aug. 25, 1983	25 feet	42	7.35	29.80	2.78
Beaver		50 feet	49	7.52	28.27	2.96
Beaver		1.25 mile	41	7.35	24.83	3.33
Usquepaug	Aug. 25, 1983	25 feet	42	6.94	15.66	4.07
Usquepaug		0.25 mile	75	6.44	8.79	4.44
Usquepaug		0.50 mile	40	7.02	13.37	2.78

4-2 Data from Individual Storm Event

River sampling in conjunction with precipitation events began in October of 1983. Each storm to be analyzed was examined using the following procedures, with the storm event of November 15, 1983 serving as an example of the process.

The storm path was determined using a set of meteorological maps as shown in Appendix A. Surface analysis pressure maps, radar summaries of precipitation regions, and satellite photos of cloud cover were used to follow the path of a storm event. The storm of November 15th can be seen as a low pressure system in the southern United States on November 14th, 1800 hours (Greenwich Time). Twenty-four hours later the storm had moved up the coast and was centered over Kentucky. The storm continued to move in a north easterly direction and had moved up the coast to New England by 1800 hours on November 16th. Satellite photos and radar scans of precipitation confirm the path of the storm continued to move in a north easterly direction and had moved up the coast to New England by 1800 hours on November 16th. Satellite photos and radar scans of precipitation confirm the path of the storm and show heavy rainfall over New England during the evening of November 15th and continuing into November 16th. It was concluded that this storm was of a south-southwesterly storm track. The storm caused 3.72 inches of rainfall as recorded at the East Farm sampling station. A previous storm on November 11, had left 2.63 inches of rainfall.

This rainfall was titrated and then analyzed for acid components using the Gran Plot method of analysis.

Strong Acid	Concentration	0
H_2CO_3	Concentration	2.08×10^{-5} N
NH_4^+	Concentration	3.65×10^{-5} N
HCO_3^-	Concentration	1.60×10^{-4} N

This analysis shows that no strong acid component was present in the rainfall, with sample acidity comprised of the weak acids H_2CO_3, NH_4^+, and HCO_3.

River data was collected before, during, and after the storm for each of the three rivers.

Wood River

		Field			Lab.		
Date	Time	pH	T (°C)	Spec. Cond. (umho at 25°C)	pH	Alkalinity (mg/l) as $CaCO_3$	Acidity (mg/l)
11/15/83	4:10P	6.35	7.8	42	6.20	7.83	6.24
11/16/83	11:00A	6.60	9.8	36	5.44	3.25	6.24
11/16/83	2:30P	6.50	10.9	36	5.23	2.87	7.94
11/17/83	10:45A	6.40	8.2	38	5.37	2.67	7.18

Beaver River

Date	Time	pH	T (°C)	Spec. Cond. (umho at 25°C)	pH	Alkalinity (mg/l) as $CaCO_3$	Acidity (mg/l)
11/15/83	4:30P	6.1	6.0	42	6.22	6.30	4.54
11/16/83	10:35A	6.5	11.2	35	5.20	2.10	10.21
11/16/83	3:00P	6.4	11.9	28	5.11	1.34	11.53
11/16/83	10:20A	6.5	8.1	39	5.00	1.72	10.02

Usquepaug River

11/15/83	4:30	5.8	6.0	49	6.05	8.60	9.26
11/16/83	10:25A	6.6	11.5	45	5.90	5.92	8.32
11/16/83	3:15P	6.9	9.5	41	5.88	5.92	8.69
11/17/83	10:10A	5.7	9.5	50	5.17	2.48	12.66

This data is also displayed graphically for each of the three rivers (Figures 4-1, 4-2 and 4-3). Each graph shows the pH, alkalinity, acidity, and stream flow plotted against time.

Data for each individual storm event was collected and analyzed with the same procedures used in the typical storm event described above. The data for each of these individual storms is presented in the following tables, Tables 4-1 through 4-13.

4-3 Stream Flow

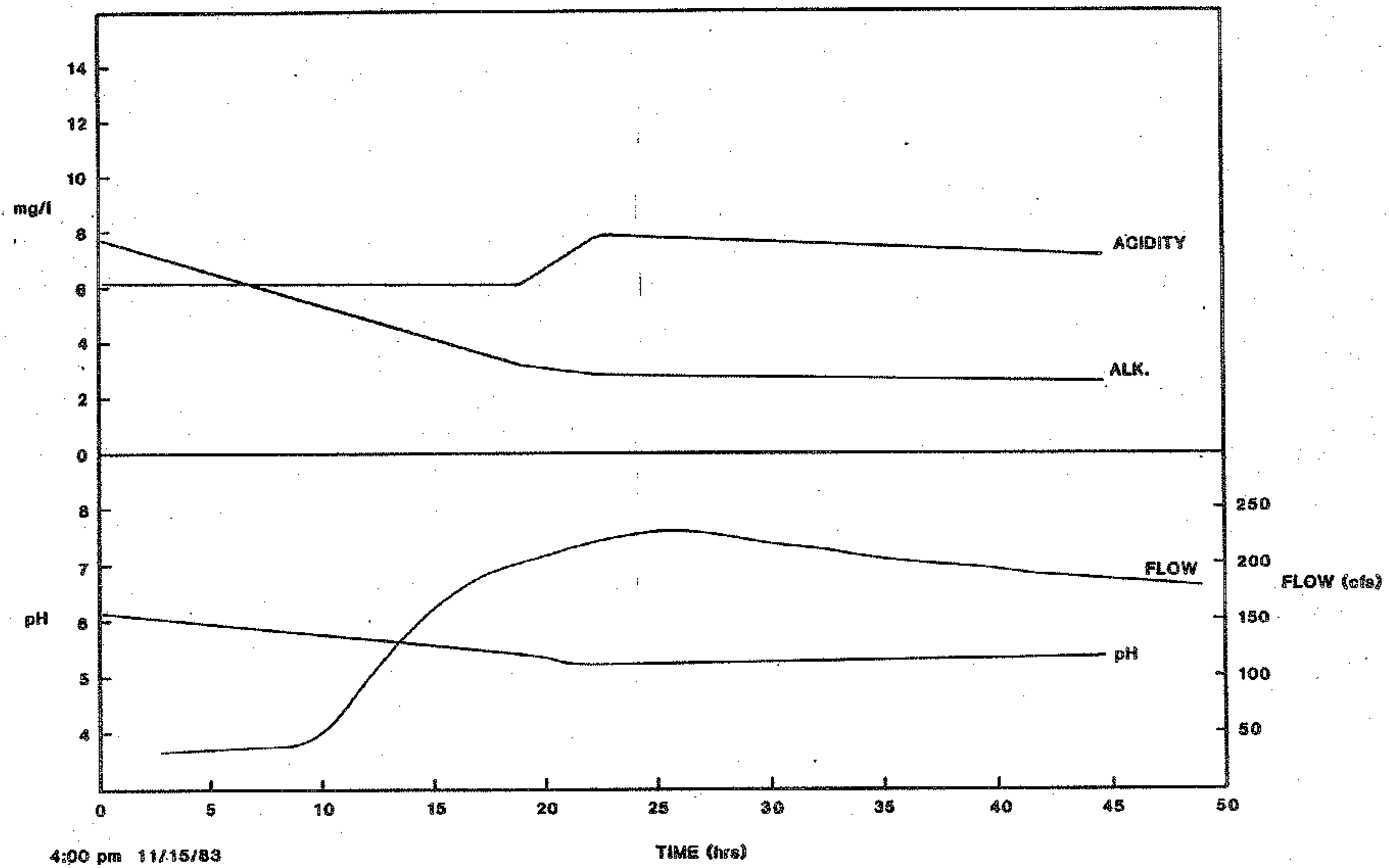
Stream-stage data and rating curves were provided by the USGS Rhode Island Office, with stream flow computations carried out from these uncorrected data and curves.

APPENDIX A

Secuential Meteorological Maps
Sattelite Photos
Pressure Maps
Radar Scan of Precipitation
for the November 15, 1983 Storm

FIGURE 4-1

Temporal Variations of Flow, pH, Alkalinity and Acidity of Wood River before, during and after the November 15, 1982 storm.



WOOD RIVER NOV 15, 1983

FIGURE 4-2

Temporal Variations of Flow, pH, Alkalinity and Acidity of Beaver River, before, during, and after the November 15, 1983 storm.

BEAVER RIVER NOV 15, 1983

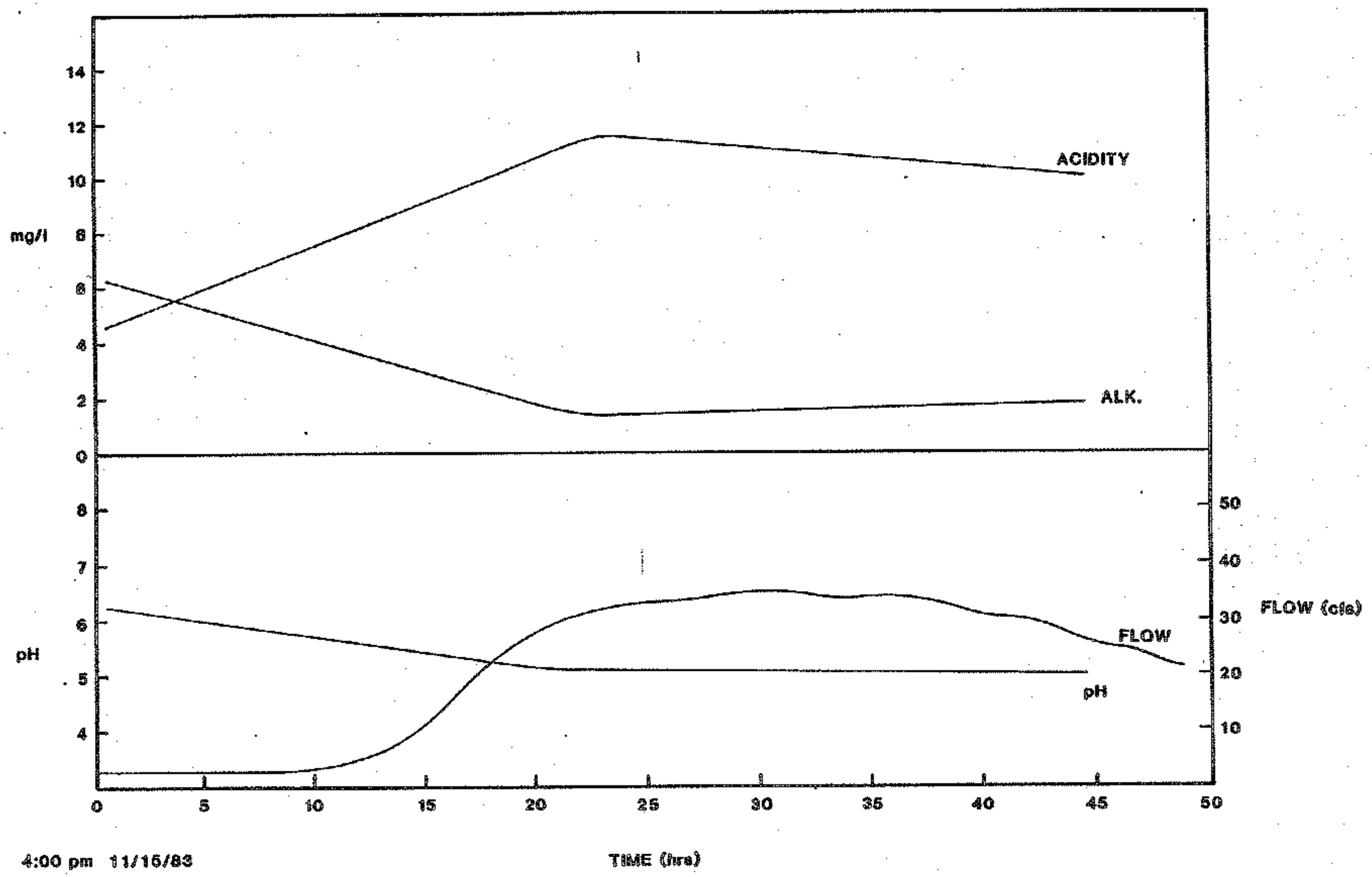


FIGURE 4-3

Temporal Variations of Flow, pH, Alkalinity and Acidity of Usquepaug River, before, during and after the November 15, 1983 storm.

USQUEPAUG RIVER NOV 15, 1983

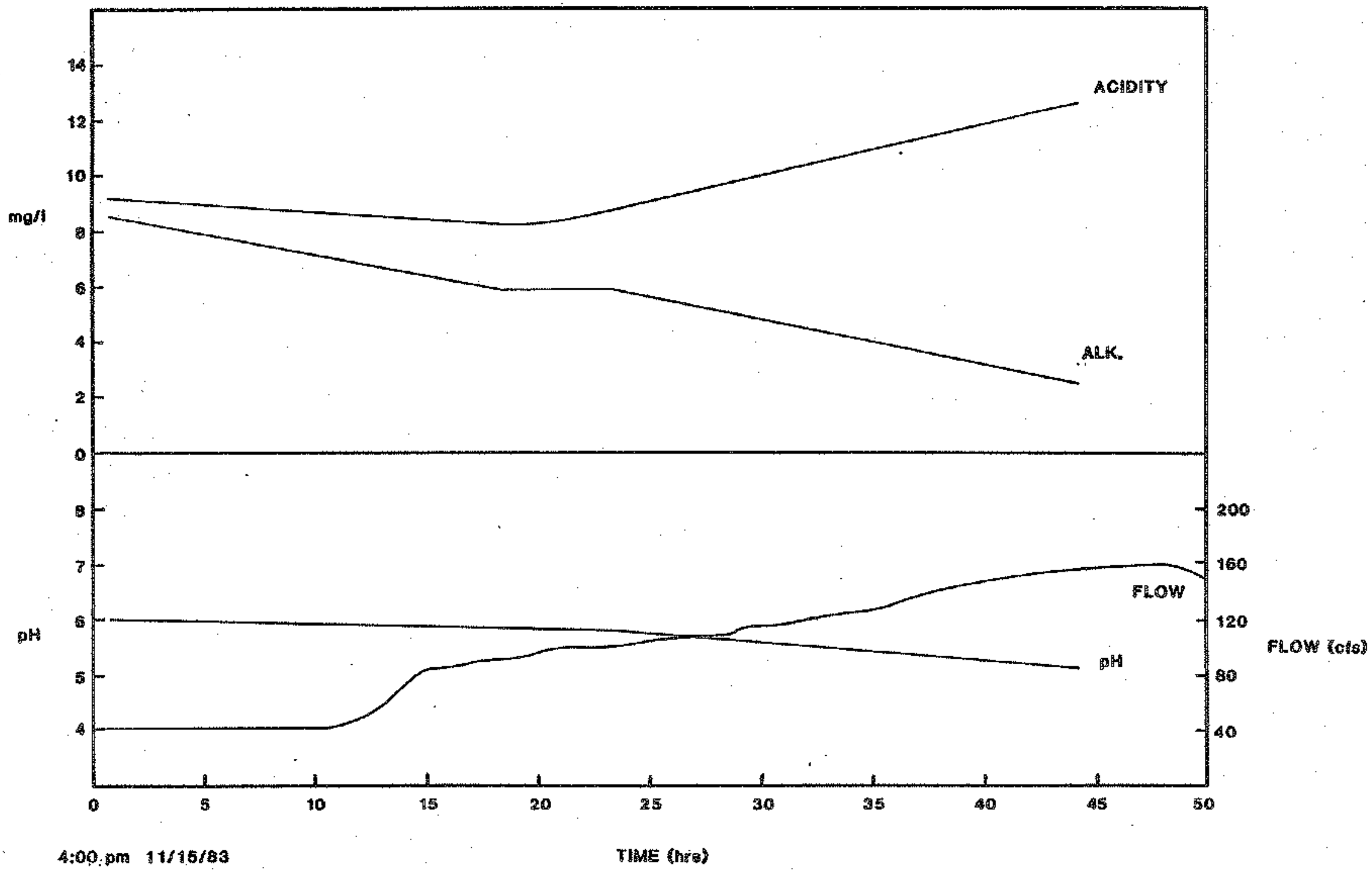


TABLE 4-1

STORM OF OCTOBER 12, 1983

STORM TRACK: A low front approached New England from the southwest, moving in from the ocean and the southeastern United States. A second low front from the west approached New England and drove the original low system out over New England. The second system continued to pass off to the north of Rhode Island.

PRECIPITATION DATA: East Farm reports 1.05" of rain. URI Agricultural Station reports 0.95". Last storm on October 2, 1983, 0.68".

Calculations of acidity using the Gran Plot method determined the following:

Strong Acid Concentration		o
H_2CO_3	"	5.1×10^{-5} normal
NH_4^+	"	3.4×10^{-5}
HCO_3^-	"	1.12×10^{-4}

RIVER DATA:

Wood River -- at Route 165 Bridge

		Field			Lab		
Date	Time	pH	T(°C)	Spec. Cond.	pH	Alkalinity	Acidity
10/12/83	2:00P	6.3	14.5	46 umhos	6.44	11.84 mg/1	2.22 mg/1
10/13/83	10:15A	6.8	16.8	49	6.02	9.36	9.07
10/13/84	4:00P	6.5	17.5	49	6.09	8.21	9.99
10/14/83	11:00P	6.2	17.1	41	4.29	0	21.09

Table 4-1

Storm of October 12-13, 1983 (cont.)

Beaver River - collected at bridge on Route 138.

		Field			Lab		
Date	Time	pH	T(C°)	Specific Conductance(umhos)	pH	Alkalinity as $\frac{mg}{l}$ $CaCO_3$	Acidity as $\frac{mg}{l}$ $CaCO_3$
10/12	2:30 pm	6.1	14.2	44	6.39	11.08	1.39
10/13	10:40 am	6.6	16.0	50	6.15	9.55	7.40
10/13	4:20 pm	6.5	17.0	54	6.05	8.02	10.18
10/14	10:35 am	5.9	16.9	61	5.85	3.44	10.92

Usquepaug River - collected at bridge on Route 2.

		Field			Lab		
Date	Time	pH	T(C°)	Specific Conductance(umhos)	pH	Alkalinity as $\frac{mg}{l}$ $CaCO_3$	Acidity as $\frac{mg}{l}$ $CaCO_3$
10/12	2:45 pm	6.2	15.5	64	6.45	19.00	1.11
10/13	10:50 am	6.5	17.0	68	6.31	16.43	5.74
10/13	4:30 pm	6.5	17.2	68	6.45	16.43	8.88
10/14	10:25 am	6.8	16.8	52	6.31	13.18	12.21

TABLE 4-2

STORM OF OCTOBER 24-25, 1983

Storm Track: Not Available.

Precipitation Data: East Farm reports 2.35" of rain from the storm. Last storm Oct. 18, 1983 1.0". URI Agricultural Station reports 2.26".

Calculations of acidity determined the following:

Strong Acid Concentration		1.80×10^{-5} N
H_2CO_3	"	2.46×10^{-5} N
NH_4^+	"	3.72×10^{-5} N
$HCO-_3$	"	1.38×10^{-4} N

River Data: Sampling began in the morning on the 24th with the storm already having begun.

Wood River - collected at bridge on Route 165.

		Field			Lab.		
Date	Time	pH	T(C°)	Specific Conductance(umhos)	pH	Alkalinity as $\frac{mg}{l}$ $CaCO_3$	Acidity as $\frac{mg}{l}$ $CaCO_3$
10/24	11:00 am	6.1	12.0	39	6.3	9.74	7.18
10/24	3:10 pm	6.0	11.3	39	6.05	7.83	6.24
10/25	10:00 am	6.05	10.2	31	6.0	5.35	5.48
10/26	Noon	5.50	12.9	35	5.85	5.92	5.1

Table 4-2

Storm of October 24-25, 1983 (cont.)

Beaver River - collected at bridge on Route 138.

Field					Lab		
Date	Time	pH	T(C°)	Specific Conductance(umhos)	pH	Alkalinity as $\frac{\text{mg}}{\text{l}}$ $CaCO_3$	Acidity as $\frac{\text{mg}}{\text{l}}$ $CaCO_3$
10/24	11:30am	5.9	11.1	47	5.84	6.11	9.07
10/24	3:40 pm	5.8	11.0	48	5.72	4.97	8.88
10/25	10:30 am	6.1	9.8	53	5.90	4.58	7.56
10/26	11:40 am	5.45	12.9	49	5.77	4.20	6.05

Usquepaug River - collected at bridge on Route 2.

Field					Lab		
Date	Time	pH	T(C°)	Specific Conductance(umhos)	pH	Alkalinity as $\frac{\text{mg}}{\text{l}}$ $CaCO_3$	Acidity as $\frac{\text{mg}}{\text{l}}$ $CaCO_3$
10/24	11:40 am	5.9	10.5	61	6.45	18.91	8.69
10/24	3.40 pm	5.9	12.3	58	6.23	12.80	7.94
10/25	10:45 am	5.95	8.5	48	6.27	11.27	7.18
10/26	11:30 am	6.65	8.0	60	6.20	7.07	8.88

TABLE 4-3

STORM OF NOVEMBER 4, 1983

Storm Track: A low front approached New England from the west and passed over the area on November 4. Last storm, October 24, 2.26".

Precipitation Data: East Farm has no rain data to report. URI Agricultural Station reports 0.66".

Calculations show the following acid concentrations were present in the rain.

Strong Acid Concentration		1.59×10^{-4} Normal
H_2CO_3	"	3.5×10^{-5} Normal
NH^+_4	"	6.05×10^{-5} Normal
HCO^-_3	"	3.5×10^{-5} Normal

River Data:

Wood River - collected at bridge on Route 165.

		Field			Lab		
Date	Time	pH	T(C°)	Specific Conductance (umhos)	pH	Alkalinity as $\frac{mg}{l}$ $CaCO_3$	Acidity as $\frac{mg}{l}$ $CaCO_3$
11/3	1:55 pm	6.6	11.0	42	6.47	7.45	4.54
11/4	9:45 am	-	9.0	35	6.50	8.02	4.91
11/4	3:15 pm	6.6	9.6	35	6.40	8.02	5.1

Table 4-3

Storm of November 4, 1983 (cont.)

Beaver River - collected at bridge on Route 138.

		Field			Lab.		
Date	Time	pH	T(C°)	Specific Conductance(umhos)	pH	Alkalinity as $\frac{mg}{l}$ $CaCO_3$	Acidity as $\frac{mg}{l}$ $CaCO_3$
11/3	1:30 pm	6.80	11.2	43	6.57	8.98	4.91
11/4	9:25 am	6.40	9.2	39	6.42	8.40	5.86
11/4	3:45 pm	6.6	8.9	41	6.40	8.21	5.48

Usquepaug River - collected at bridge on Route 2.

		Field			Lab		
Date	Time	pH	T(C°)	Specific Conductance(umhos)	pH	Alkalinity as $\frac{mg}{l}$ $CaCO_3$	Acidity as $\frac{mg}{l}$ $CaCO_3$
11/3	1:20 pm	6.0	11.5	65	6.03	13.37	7.94
11/4	9:05 pm	6.3	9.8	55	6.48	12.42	7.75
11/4	4:00 pm	6.80	10.5	53	6.47	12.61	7.56

TABLE 4-4

STORM OF NOVEMBER 15, 1983

STORM TRACK: A low front approached New England from the southwest. The storm originated in the southern United States and moved up the coast in a northeasterly direction. Last storm November 11, 1983, 2.12".

PRECIPITATION DATA: Heavy precipitation from this storm with East Farm reporting 3.72" of precipitation. URI Agricultural Station reports 3.53".

Calculations of rainfall acidity using the Gran Plot method determined the following:

Strong Acid Concentration		0
H_2CO_3	"	2.08×10^{-5} Normal
NH_4^+	"	3.65×10^{-5} Normal
HCO_3^-	"	1.60×10^{-4} Normal

RIVER DATA: Samples were collected before, during, and after the storm.

Wood River - at Route 165 Bridge

		Field			Lab		
Date	Time	pH	T(°C)	Spec. Cond. umhos	pH	Alkalinity mg/l	Acidity mg/l
11/15	4:10 pm	6.35	7.8	42	6.20	7.83	6.24
11/16	11:00 am	6.60	9.8	36	5.44	3.25	6.24
11/16	2:30 pm	6.50	10.9	36	5.23	2.87	7.94
11/17	10:45 am	6.40	8.2	38	5.37	2.67	7.18

Table 4-4
Storm of November 15, 1983 (cont.)

Beaver River - at Route 138 Bridge

		Field			Lab		
Date	Time	pH	T(°C)	Spec. Cond. umhos	pH	Alkalinity mg/l	Acidity mg/l
11/15/83	4:30 pm	6.1	6.0	42	6.22	6.30	4.54
11/16/83	10:35 am	6.5	11.2	35	5.20	2.10	10.21
11/16/83	3:00 pm	6.4	11.9	28	5.11	1.34	11.53
11/17/83	10:20 am	6.5	8.1	39	5.00	1.72	10.02

Usquepaug River

		Field			Lab		
Date	Time	pH	T(°C)	Spec. Cond. umhos	pH	Alkalinity mg/l	Acidity mg/l
11/15/83	4:40 pm	5.8	6.0	49	6.05	8.60	9.26
11/16/83	10:25 am	6.6	11.5	45	5.90	5.92	8.32
11/16/83	3:15 pm	6.9	9.5	41	5.88	5.92	8.69
11/17/83	10:10 am	5.7	9.5	50	5.17	2.48	12.66

TABLE 4-5

STORM OF NOVEMBER 28, 1983

STORM TRACK: Storm approached New England from the west-northwest. This storm was preceded by a storm on November 24 & 25 which left 4.66" of rain.

PRECIPITATION DATA: East Farm reports 1.70" of rain from this storm.
URI Agriculture Station reports 1.41".

Calculations of rainfall acidity by the Gran Plot method yielded the following:

Strong Acid Concentration		2.84×10^{-5} Normal
H_2CO_3	"	5.56×10^{-5} Normal
NH_4^+	"	6.71×10^{-5} Normal
HCO^-_3	"	1.15×10^{-4} Normal

RIVER DATE:

Wood River - at Route 165 Bridge

		Field			Lab		
Date	Time	pH	T(°C)	Spec. Cond. umhos	pH	Alkalinity mg/l	Acidity mg/l
11/28-83	2:15pm	5.75	6.5	32	5.49	6.45	9.69
11/29/83	11:15 am	5.95	8.2	32	5.41	1.43	11.81
11/29/83	1:45 pm	6.45	8.5	30	5.75	4.30	8.98
11/30/83	10:45 am	0	7.2	30	5.52	4.30	12.76

Table 4-5

Storm of November 28, 1983 (cont.)

Beaver River - at Route 138 Bridge

		Field			Lab		
Date	Time	pH	T(°C)	Spec. Cond. umhos	pH	Alkalinity mg/1	Acidity mg/1
11/28/83	1:45 pm	5.45	5.9	31	5.49	0.96	12.52
11/29/83	10:45 am	6.05	9.5	34	5.09	1.43	13.70
11/29/83	1:15 pm	6.10	9.0	32	5.00	0.48	14.18
11/30/83	10:15 am	5.45	7.0	31	5.03	0	12.76

Usquepaug River

		Field			Lab		
Date	Time	pH	T(°C)	Spec. Cond. umhos	pH	Alkalinity mg/1	Acidity mg/1
11/28/83	1:30 pm	5.30	6.5	31	5.23	1.91	15.12
11/29/83	10:30 am	6.40	8.2	32	5.19	0.96	15.12
11/29/83	1:00 pm	6.15	9.0	36	5.90	2.39	13.23
11/30/83	10:00 am	5.65	8.5	22	5.25	2.39	13.23

TABLE 4-6

STORM OF DECEMBER 28, 1983

STORM TRACK: A low front from central Canada combined with another low front from the southern U. S., forming a large low pressure system along the coastal U. S. This system then passed over Rhode Island and headed out to sea.

PRECIPITATION DATA: East Farm reports 0.78" of rain. Our sample contained 715ml of rainfall, equal to 0.89" of rain. Last storm on 12/24, 2.01".

Calculations of acidity determined the following:

Strong Acid Concentration		1.98×10^{-5} Normal
H_2CO_3	"	5.13×10^{-5} Normal
NH_4^+	"	8.24×10^{-5} Normal
HCO_3^-	"	1.14×10^{-4} Normal

RIVER DATA:

Wood River - at Route 165 Bridge

		Field			Lab		
Date	Time	pH	T(°C)	Spec. Cond. umhos	pH	Alkalinity mg/l	Acidity mg/l
12/28/83	11:00 am	--	1.9	26	5.50	2.98	6.12
12/28/83	4:00 pm	6.7	3.5	26	5.57	2.55	5.58
12/29/83	11:10 am	6.28	3.5	23	5.78	2.34	6.12
12/29/83	2:35 pm	6.66	3.5	24	5.32	0.75	5.58
12/30/83	11:10 am	6.05	2.0	20	5.53	2.13	5.94

Table 4-6

Storm of December 28, 1983 (cont.)

Beaver River - at Route 138 Bridge

		Field			Lab		
Date	Time	pH	T(°C)	Spec. Cond. umhos	pH	Alkalinity mg/1	Acidity mg/1
12/28/83	10:30 am	--	1.3	30	5.13	2.55	6.84
12/28/83	3:30 pm	6.03	3.2	30	5.21	1.28	7.02
12/29/83	10:40 am	5.50	3.9	28	5.13	0.43	6.84
12/29/83	3:00 pm	6.17	3.2	28	4.87	0	7.38
12/30/83	10:45 am	5.92	1.8	28	5.03	1.70	6.84

Usquepaug River - at Route 2 Bridge

		Field			Lab		
Date	Time	pH	T(°C)	Spec. Cond. umhos	pH	Alkalinity mg/1	Acidity mg/1
12/28/83	10:15 am	--	1.9	30	5.1	2.34	10:44
12/28/83	3:15 pm	6.40	3.0	35	5.18	0.43	10.26
12/29/83	10:30 am	6.19	3.2	30	5.28	2.55	9.00
12/29/83	3:30 pm	6.02	2.0	29	5.09	0.85	7.38
12/30/83	10:30 am	5.80	2.8	30	5.17	2.55	7.92

TABLE 4-7

SPECIAL STORM SERIES JANUARY 10, 18, 24, 30, 1984
FEBRUARY 3, 1984

GENERAL DESCRIPTION: Between January 10 and February 5, 1984, five individual storm events occured. The first two were snow storms with subfreezing temperatures in between the storms. There was no melting in between these two storms. The third one was a rain storm, causing partial melting of snow on the ground. River samples were taken for this storm. The temperature then dropped below freezing again until the fourth event produced a mixture of rain and snow. The last storm of this series produced heavy rain. Coupling with warm temperature, all remaining snow and ice melted and produced significant runoff and river flow in the study areas.

STORM TRACK (1/10/84): A low pressure system originated over the midwest in the Ohio Valley. The storm headed northeast, passing through New England and out to Atlantic Ocean.

PRECIPITATION DATA: 4.2 inches of snow resulted in 0.38 inch of precipitation. Last storm occured on 12/28/83.

Calculation of acidity of Gran Plot method determined the following:

Strong Acid Concentration		5.49×10^{-5} Normal
H_2CO_3	"	9.63×10^{-5} Normal
NH_4^+	"	1.28×10^{-4} Normal
HCO_3^-	"	3.33×10^{-4} Normal

Table 4-7 (cont.)

STORM TRACK (1/18/84): A low front originated in the southeastern U. S. continent and moved north along the east coast. Two smaller systems followed from the same area. All systems finally passed over New England and out to sea.

PRECIPITATION DATA: 0.25" of melted precipitation. The University of Rhode Island Agricultural Experiment Station reported 3.2" of snow and 0.43" of melted precipitation.

Gran Plot calculation of titration curve determined the following:

Strong Acid Concentration		5.58×10^{-5} Normal
H_2CO_3	"	9.32×10^{-5} Normal
NH_4^+	"	1.22×10^{-4} Normal
HCO_3^-	"	1.98×10^{-4} Normal

STORM TRACK (1/24/84): Storm system approached from due west, originating in the Ohio Valley-Great Lakes region.

PRECIPITATION DATA: 0.86" of rain. U.R.I. Agricultural Experiment Station reported 0.72" of rain.

Gran Plot calculation of titration curve determined the following:

Strong Acid Concentration		2.20×10^{-5} Normal
H_2CO_3	"	5.58×10^{-5} Normal
NH_4^+	"	9.81×10^{-5} Normal
HCO_3^-	"	1.32×10^{-4} Normal

Table 4-7 (cont.)

STORM TRACK (1/30/83): A low front originated in the west and merged with a system from the south. The combined system occured over Pennsylvania and moved northeast toward New England.

PRECIPITATION DATA: Mixture of rain and snow totaling 0.88" of melted precipitation. U.R.I. Agricultural Experiment Station reported 3" of snow and rain resulting in 0.9" of melted precipitation.

Gran Plot calculation of titration curve determined the following:

Strong Acid Concentration		5.53×10^{-5} Normal
H_2CO_3	"	8.78×10^{-5} Normal
NH_4^+	"	1.26×10^{-4} Normal
HCO_3^-	"	1.58×10^{-4} Normal

STORM TRACTK (2/3/84): A low pressure system originating over the Ohio Valley moved eastward. A long low pressure system then established itself along the entire east coast and eventually moved seaward.

PRECIPITATION DATA: 1.88" of rain recorded. U.R.I. Agricultural Experiment Station reported 1.94" of rain.

Gran Plot calculation of titration curve determined the following:

Strong Acid Concentration		2.87×10^{-5} Normal
H_2CO_3	"	5.02×10^{-5} Normal
NH_4^+	"	7.99×10^{-5} Normal
HCO_3^-	"	1.01×10^{-4} Normal

Table 4-7 (cont.)

RIVER DATA:

		Field			Lab		
Date	Time	pH	T(C°)	Spec. Cond. umhos	pH	Alkalinity mg/l $CaCO_3$	Acidity mg/l $CaCO_3$
Wood River - at Route 165 Bridge							
1/10/84	11:20 am	6.20	5.4	28	5.80	6.38	5.04
1/24/84	3:00 pm	6.48	3.8	28	6.33	7.01	4.95
1/25/84	3:00 pm	6.65	4.3	22	6.13	4.68	4.95
1/26/84	4:00 pm	6.45	4.0	28	5.86	4.25	5.40
1/30/84	3:00 pm	6.62	4.5	25	5.84	5.53	6.75
2/3/84	3:15 pm	6.91	4.9	23	6.60	7.76	4.10
2/7/84	2:00 pm	5.40	3.2	21	5.91	2.03	4.87
2/10/84	3:00 pm	6.42	3.0	21	5.87	6.75	5.64
Beaver River - at Route 138 Bridge							
1/10/84	10:50 am	5.97	4.8	32	5.69	5.53	5.76
1/24/84	2:30 pm	6.35	4.0	32	6.08	3.40	6.75
1/25/84	2:15 pm	6.00	2.5	32	5.65	4.25	6.75
1/26/84	3:30 pm	6.29	4.0	30	5.63	2.98	6.30
1/30/84	2:30 pm	6.27	4.5	28	5.00	5.78	9.45
2/3/84	2:45 pm	6.45	4.5	29	6.26	6.41	5.13
2/7/84	1:45 pm	5.36	3.8	28	5.58	2.03	8.20
2/10/84	2:15 pm	5.62	2.8	28	5.65	5.40	5.64
Usequepaug River - at Route 2 Bridge							
1/10/84	10:40 am	6.90	7.3	35	5.80	5.53	7.56
1/24/84	2:20 pm	6.63	3.5	40	6.04	8.50	8.10
1/25/84	2:00 pm	6.87	3.3	38	5.81	7.23	8.55
1/26/84	3:15 pm	6.61	3.5	35	5.70	4.25	8.10
1/30/84	2:15 pm	6.78	4.2	32	5.77	6.80	8.10
2/3/84	2:30 pm	7.37	4.8	39	6.23	8.10	6.92
2/7/84	1:30 pm	5.73	4.5	28	5.63	3.38	7.69
2/10/84	2:00 pm	6.52	3.2	31	5.78	6.75	8.20

TABLE 4-8

STORM OF FEBRUARY 28, 1983

STORM TRACK: The storm originated in the Gulf region of the United States. It then headed on a northeast track, passing over the Ohio Valley and continuing on into New England. Last storm event on February.

PRECIPITATION DATA: East Farm reports 3.20" of rain. We collected 1667 ml of rain, equal to 2.02". Last storm on 2/24/84, 1.15". U.R.I. Agricultural Station, 1.83".

Calculations of acidity using the Gran Plot method determined:

Strong Acid Concentration		0
H_2CO_3	"	3.08×10^{-5} Normal
NH_4^+	"	4.72×10^{-5}
HCO_3^-	"	1.15×10^{-4}

RIVER DATA:

Wood River - at Route 165 Bridge

		Field			Lab		
Date	Time	pH	T(C)	Spec. Cond. umhos	pH	Alkalinity mg/1	Acidity mg/1
2/27/84	4:00 pm	--	5.8	20	5.65	4.86	4.36
2/28/84	4:00 pm	5.98	4.9	19	5.76	5.40	5.38
2/29/84	4:00 pm	5.18	5.0	20	5.51	2.70	5.64
3/2/84	9:45 am	6.16	1.3	21	5.73	3.51	5.64
3/6/84	3:00 pm	5.92	3.3	20	5.84	5.84	5.13

Table 4-7

Storm of February 28, 1984 (cont.)

Beaver River - atRoute 138 Bridge

Date	Time	pH	T(C)	Spec. Cond. umhos	pH	Alkalinity mg/1	Acidity mg/1
2/27/84	3:30 pm	--	5.6	26	5.61	3.51	5.38
2/28/84	3:15 pm	5.52	5.1	22	5.45	2.43	6.41
2/29/84	3:30 pm	5.00	5.6	22	5.12	1.35	6.66
3/2/84	9:15 am	6.00	1.9	25	5.52	2.43	6.15
3/3/84	2:15 pm	5.65	3.1	27	5.74	5.13	5.38

Usquepaug River - at Route 2 Bridge

Date	Time	pH	T(C)	Spec. Cond. umhos	pH	Alkalinity mg/1	Acidity mg/1
2/27/84	3:20 pm	--	6.5	33	5.75	5.67	6.15
2/28/84	3:00 pm	5.78	5.4	29	5.61	3.78	6.66
2/29/84	3:15 pm	5.42	5.8	20	5.54	1.89	6.92
3/2/84	9:00 am	5.82	2.2	28	5.62	2.70	6.92
3/3/84	2:00 pm	5.84	3.8	32	5.97	6.75	6.66

TABLE 4-9

STORM OF MARCH 22, 1984

STORM TRACK: This storm originated in the mid-western states, gained intensity, and headed for the northeast. The storm passed through the Ohio Valley and passed by to the southeast of New England.

PRECIPITATION DATA: East Farm reports 0.11" of rain. U.R.I. Agricultural Station reports 0.37". We collected 238ml of rain, equal to 0.29". Last storm on 3/19/84, 0.43".

Calculation of acidity by the Gran Plot method shows:

Strong Acid Concentration		1.89×10^{-5} Normal
H_2CO_3	"	5.23×10^{-5}
NH_4^+	"	7.59×10^{-5}
HCO_3^-	"	1.89×10^{-4}

RIVER DATA:

Wood River - at Route 165 Bridge.

		Field			Lab		
Date	Time	pH	T(C)	Spec. Cond. umhos	pH	Alkalinity mg/l	Acidity mg/l
3/21/84	3:00 pm	5.78	6.3	21	5.70	4.86	3.33
3/22/84	11:40 pm	5.90	8.0	26	5.55	3.24	6.15
3/23/84	2:00 pm	5.83	8.0	25	5.86	6.48	5.18
3/24/84	3:00 pm	6.02	8.0	22	5.76	4.86	4.10

Table 4-9

Storm of March 22, 1984 (cont.)

Beaver River - at Route 138 Bridge

		Field			Lab		
Date	Time	pH	T(C)	Spec. Cond. umhos	pH	Alkalinity mg/1	Acidity mg/1
3/21/84	2:45 pm	5.82	7.0	29	5.63	2.97	5.64
3/22/84	12:00 noon	5.83	9.5	30	5.78	2.16	6.66
3/23/84	1:30 pm	5.39	8.4	28	5.52	3.78	6.15
3/24/84	2:45 pm	5.60	9.1	30	5.73	4.86	5.38

Usquepaug River - at Route 2 Bridge

		Field			Lab		
Date	Time	pH	T(C)	Spec. Cond. umhos	pH	Alkalinity mg/1	Acidity mg/1
3/21/84	2:30 pm	6.16	8.0	32	5.59	4.32	6.15
3/22/84	12:10 pm	5.78	8.3	29	5.58	3.24	7.94
3/23/84	1:15 pm	5.90	9.3	29	5.78	3.51	5.89
3/24/84	2:30 pm	5.72	9.2	32	5.85	7.02	5.13

TABLE 4-10

STORM OF APRIL 4, 1984

<u>STORM TRACK</u>: A low front originated in Texas. It then headed north and then east, passing through the Ohio Valley region and into New England.

<u>PRECIPITATION DATA</u>: East Farm reports 1.61" of rain. U.R.I. Agricultural Station reports 1.65". Our sampler lost funnel due to high winds, therefore no accurate measurement is possible. Last precipitation on 3/30/84, 1.29".

Calculation of acidity by Gran Plot yields:

Strong Acid Concentration		7.59×10^{-5} Normal
H_2CO_3	"	1.11×10^{-4}
NH_4^+	"	0
HCO_3^-	"	3.53×10^{-4}

<u>RIVER DATA</u>:

Wood River - at Route 165 Bridge

	Field				Lab		
Date	Time	pH	T(C)	Spec. Cond. umhos	pH	Alkalinity mg/1	Acidity mg/1
4/4/84	9:45 am	5.64	6.5	23	5.90	4.86	5.13
4/5/84	12:00 noon	5.63	8.5	21	5.53	2.46	7.43
4/6/84	11:45 am	5.28	9.5	21	5.22	0.22	8.78
4/9/84	12:00 noon	5.47	8.1	25	5.46	3.04	4.61

Table 4-10

Storm of April 4, 1984 (cont.)

Beaver River - at Route 138 Bridge

	Field				Lab		
Date	Time	pH	T(C)	Spec. Cond. umhos	pH	Alkalinity mg/l	Acidity mg/l
4/4/84	9:25 am	5.48	6.5	28	5.90	4.86	5.13
4/5/84	11:40 am	5.35	8.0	25	5.21	0.82	9.45
4/6/84	11:25 am	4.72	10.2	30	5.02	0.62	9.11
4/9/84	11:30 am	5.34	8.0	28	5.29	2.70	5.64

Usquepaug River - at Route 2 Bridge

	Field				Lab		
Date	Time	pH	T(C)	Spec. Cond. umhos	pH	Alkalinity mg/l	Acidity mg/l
4/4/84	9:15 am	6.18	9.0	30	5.72	5.94	6.41
4/5/84	11:30 am	5.58	8.5	31	5.56	3.28	8.10
4/6/84	11:15 am	5.27	11.5	28	5.36	0.82	9.79
4/9/84	11:20 am	5.26	8.8	32	5.50	4.38	5.89

TABLE 4-11

STORM OF APRIL 24, 1984

<u>STORM TRACK</u>: A low pressure system formed in the Gulf region and headed east to the coast of the southern United States. This whole system then moved up the coast and passed over New England.

<u>PRECIPITATION DATA</u>: East Farm reports 0" of rain. U.RI. Agricultural Station reports 1.02". We collected 914ml, equal to 1.11" of rain. Last precipitation of 1.62" on 4/16/84.

Calculation of acidity by the Gran Plot method determined:

Strong Acid Concentration		2.67×10^{-5} Normal
H_2CO_3	"	6.81×10^{-5}
NH_4^+	"	9.43×10^{-5}
HCO_3^-	"	1.36×10^{-4}

<u>RIVER DATA</u>:

Wood River - at Route 165 Bridge

		Field			Lab		
Date	Time	pH	T(C)	Spec. Cond. umhos	pH	Alkalinity mg/l	Acidity mg/l
4/23/84	11:45 am	5.97	10.5	26	6.10	5.40	4.36
4/24/84	2:00 pm	5.73	10.6	28	5.97	6.75	5.38
4/25/84	2:40 pm	5.77	11.6	23	6.01	5.74	4.10
4/26/84	11:15 am	5.65	11.0	22	5.93	5.40	4.10
4/27/84	11:40 am	5.88	12.2	25	6.03	7.09	4.10

Table 4-11

Storm of April 24, 1984 (cont.)

Beaver River - at Route 138 Bridge

	Field				Lab		
Date	Time	pH	T(C)	Spec. Cond. umhos	pH	Alkalinity mg/1	Acidity mg/1
4/23/84	11:30 am	6.31	10.1	31	5.75	5.13	4.87
4/24/84	1:30 pm	6.17	10.8	30	5.67	4.05	6.15
5/25/84	2:20 pm	5.48	10.2	31	5.57	3.78	6.15
4/26/84	11:40 am	5.51	10.5	31	5.63	4.05	5.64
4/27/84	11:25 am	5.49	12.0	30	5.70	6.08	4.36

Usquepaug River - at Route 2 Bridge

	Field				Lab		
Date	Time	pH	T(C)	Spec. Cond. umhos	pH	Alkalinity mg/1	Acidity mg/1
4/23/84	11:20 am	6.81	11.8	42	5.94	8.78	5.34
4/24/84	1:15 pm	6.64	12.0	36	5.95	7.76	5.64
4/25/84	2:10 pm	5.77	11.8	35	5.74	6.98	5.64
4/26/84	11:50 am	5.79	11.5	32	5.77	6.08	5.38
4/27/84	11:15 am	5.82	13.0	32	5.90	8.10	4.61

TABLE 4-12

STORM OF MAY 3, 1984

STORM TRACK: This storm originated in Texas and traveled northeast through the Ohio Valley-Tennessee area. It then headed east, passing to the south of New England.

PRECIPITATION DATA: East Farm reports 2.62" of rain. U.R.I. Agricultural Station reports 0.97". We collected 798 ml of rainfall, equal to 0.97". Last storm on 4/24/84, 1.02".

Calculation of acidity by Gran Plot determined the following:

Strong Acid Concentration		3.65×10^{-5} Normal
H_2CO_3	"	6.52×10^{-5}
NH_4^+	"	1.03×10^{-4}
HCO_3^-	"	1.31×10^{-4}

RIVER DATA:

Wood River - at Route 165 Bridge

		Field				Lab	
Date	Time	pH	T(C)	Spec. Cond. umhos	pH	Alkalinity mg/l	Acidity mg/l
5/3/84	12:30 pm	6.01	13.2	32	6.08	7.76	4.10
5/4/84	2:40 pm	5.94	13.5	25	5.97	4.73	5.13
5/7/84	12:30 pm	5.84	15.0	28	5.98	5.13	4.36

Table 4-12

Storm of May 3, 1984 (cont.)

Beaver River - at Route 138 Bridge

Field					Lab		
Date	Time	pH	T(C)	Spec. Cond. umhos	pH	Alkalinity mg/l	Acidity mg/l
5/3/84	12:10 pm	6.44	12.7	36	5.86	6.41	5.38
5/4/84	2:30 pm	5.81	13.0	30	5.67	4.73	6.15
5/7/84	12:15 pm	5.77	14.5	32	5.83	5.38	4.61

Usquepaug River - at Route 2 Bridge

Field					Lab		
Date	Time	pH	T(C)	Spec. Cond. umhos	pH	Alkalinity mg/l	Acidity mg/l
5/3/84	12:00 noon	6.55	14.9	35	6.06	10.13	5.89
5/4/84	2:20 pm	5.98	14.0	42	6.04	10.46	6.66
5/7/84	12:00 noon	6.15	16.2	40	6.09	7.18	5.13

TABLE 4-13

STORM OF MAY 23, 1984

STORM TRACK: A low pressure system originated in south-central Canada. The system then passed over the Great Lakes region and southern Canada, eventually passing over New England.

PRECIPITATION DATA: East Farm reports 0". U.R.I. Agricultural Station reports 0.16" of rain. We collected 136 ml of rain, equal to 0.17". Last storm on 5/21/84, 0.59".

Calculation of acidity determined by Gran Plot:

Strong Acid Concentration		3.96×10^{-5} Normal
H_2CO_3	"	1.03×10^{-4}
NH_4^+	"	1.58×10^{-4}
HCO_3^-	"	2.21×10^{-4}

RIVER DATA:

Wood River - at Route 165 Bridge

		Field			Lab		
Date	Time	pH	T(C)	Spec. Cond. umhos	pH	Alkalinity mg/l	Acidity mg/l
5/23/84	9:50 am	6.56	17.1	31	6.24	10.8	5.13
5/24/84	12:50 pm	6.20	19.5	35	6.46	10.13	3.84
5/25/84	3:45 pm	7.08	19.8	28	6.52	11.14	5.13

Table 4 - 13

Storm of May 23, 1984 (Cont.)

Beaver River - at Route 138 Bridge

		Field			Lab		
Date	Time	pH	T(C)	Spec. Cond. umhos	pH	Alkalinity mg/l	Acidity mg/l
5/23/84	9:30 am	6.22	15.0	39	6.11	8.10	5.89
5/24/84	1:15 pm	5.65	16.8	40	6.14	7.43	5.13
5/25/84	6:20 pm	5.79	17.0	38	6.24	6.41	6.41

Usquepaug River - at Route 2 Bridge

		Field			Lab		
Date	Time	pH	T(C)	Spec. Cond. umhos	pH	Alkalinity mg/l	Acidity mg/l
5/23/84	9:20 am	6.54	18.2	53	6.21	11.48	6.41
5/24/84	2:00 pm	6.32	19.7	49	6.36	11.81	4.87
5/25/84	6:30 pm	5.86	18.0	51	6.32	11.48	5.89

5. DATA ANALYSIS AND FINDINGS

5-1 Analysis of Precipitation

Precipitation events can be grouped according to their origin and storm path as they approached Rhode Island. Three categories of storms were developed; those approaching Rhode Island from a west or west-southwest direction, those from a south or south-southwest direction, and those approaching from a west-northwest direction. The storm of October 24, 1983 could not be tracked due to a lack of meteorological maps and the storm of December 28, 1983 did not fall into any of the above groups but was instead a mixture of two frontal systems, one from the northwest and one from the south. The precipitation data from each of the storm groups was then analysed, with the range of values for each group shown below.

	West-Southwest	South-Southwest	West-Northwest
pH	3.81-4.95	4.30-5.10	4.47-4.50
Acidity (mg/l)	2.54-11.17	1.94-4.84	3.21-6.05
Rainfall (in.)	0.39-1.83	0.95-3.53	0.16-1.45
Product (AcidityxRainfall)	1.48-9.09	2.65-6.85	0.97-4.65

It can be seen from this data that precipitation from storms originating in the west-southwest group had the lowest range of pH values. This was the only group to have rainfall pH less than 4, with the lowest recorded value being 3.81. No precipitation events from this group had a pH above 5.00. Precipitation from the group of storms originating in the south often had pH values above 5.0 and there were no values less than 4.30. Both storms originating in the west-northwest had pH values near 4.5.

Acidity values for the three storm categories closely followed the pattern of pH values. Precipitation from storms originating in the west, west-southwest had a wide range of values, with a maximum value of 11.17 mg/l. This value was almost twice as high as the maximum for either of the other two groups. The lowest value recorded was 1.94 mg/l for a storm from the south, south-west.

In order to evaluate a storm's potential effects on the three rivers, the amount of rainfall was multiplied by the amount of acidity in the rainfall. This product was used to compare the relative potential of each storm to effect the river's chemistry. It can be seen that a storm from the west, west-southwest had the highest product of any storm. The lowest value was from the west-northwest group. This storm had moderately high acidity, but the small amount of precipitation associated with it produced a small value for the acidity-rainfall product.

The highest product value in each group was produced by a storm that did not have the highest rainfall acidity. The high value in the west, west-southwest group was due to a storm with the second highest rainfall acidity, 5.51 mg/l associated with a rainfall of 1.65 inches, the most acidic storm, with 11.17 mg/l acidity, had a lower product since only 0.66 inches of precipitation came out of the storm. The group of storms from the south, south-southwest had a highest product value of 6.85 produced by a storm with the lowest acidity, 1.94 mg/l. A very heavy rainfall, 3.53 inches, was responsible for this high product value. Similarly, the high product value for the west, northwest group was also produced by a high rainfall, 1.41 inches combined with a relatively low acidity of 3.21 mg/l. This suggests that the amount of rainfall is equally as important as the acidity of the precipitation when evaluating the storm's effects on the river's chemistry.

5-2 Analysis of River Impacts

Each precipitation event was responsible for changing some parameter of river chemistry. The precipitation and its associated runoff caused changes in the pH, alkalinity, and/or acidity of each of the rivers to some extent. The three rivers all showed the same trend in response to a particular storm, but differed in the magnitude of the effects due to differences in streamflow, watershed size, and chemical composition, before the precipitation event.

The magnitude of the impact of precipitation upon river chemistry is reflected in the product of precipitation acidity and amount of rainfall. Those storms with a relatively high product produced the greatest changes in river chemistry, with pH and alkalinity decreasing and acidity increasing. Storms which had a low product caused very little or no change in the chemistry of the rivers.

As mentioned, storms from the west generally were more acidic and therefore had a higher product than equal size storms originating in he south or northwest. A large amount of precipitation due to a storm originating in the west would cause a significant impact on the river. Storms with small amounts of acidity and no strong acid component also cause a significant impact when the amount of precipitation is very high. These situations were observed frequently, when river pH would drop, alkalinity would decrease to very low values (<1 mg/l), and acidity would rise due to the passing of a storm.

The magnitude of the impact did not rest solely on the amount of precipitation and the acidity of that precipitation. Many factors influenced the way a river would respond to a particular storm; duration between precipitation events, dry deposition during that period, acidity and amount of precipitation from a previous storm, amount of flow in the river before the storm, and the amount of runoff reaching the river were all factors that influenced river chemistry and the river's response to a particular precipitation event.

5-3 Group Analysis - South to South-Southwest Group

Three storms were designated to be from this group, the storms of October 12, 1983, November 15, 1983, and April 24, 1984. The first of these three precipitation events produced unique changes in river chemistry which will be discussed later. The other two storms produced an impact upon the rivers that was expected and explained using the known data.

The storm which struck Rhode Island on November 15, 1983 (Table 4-4) had approached from the south-southwest and was of heavy intensity and long duration. Although the storm had a relatively high pH of 5.10 and no strong acid component, the 3.53 inches of rain associated with this storm caused the intensity-acidity product to be high at 6.85 and all three rivers showed significant changes in water chemistry. Although acidity in the rainfall was low, the large amount of rainfall and its associated runoff produced these chemistry changes.

Prior to the storm's arrival, river flow was very low due to the drier than normal summer, (four consecutive dry months from June through September) with Wood, Beaver, and Usquepaug rivers having discharges of 37, 3.0, and 42.0 cfs respectively. This large amount of precipitation caused the rivers to reach peak flows of 228, 35, and 158 cfs respectively, this large volume of water added to the rivers over a short period, peak flow being reached in approximately 1 day at Wood and Beaver rivers, 2 days at Usquepaug river, caused alkalinity and pH to drop markedly in all three rivers. Acidity showed approximately a 25% and 37% increase in the Wood and Usquepaug rivers, but approximately a 154% increase, (7 mg/l) in the Beaver river. This could be due to the flushing of the swampy area located upstream from the sampling site, with the more acidic water washing out of the swamp and flowing downstream. Any acidic dry deposition accumulated during the dry days before this storm would also have been washed into the rivers by the high amounts of runoff and contributed to the impacts upon the rivers.

The storm of April 24, 1984 (Table 4-11) was of a moderate pH of 4.30 and an acidity of 4.84 mg/l. Strong acid component was 2.67×10^{-5}N and 1.02 inches of rain fall. This produced an intensity-acidity product of 4.94, just slightly higher than average. This produced slight changes in the water chemistry of the three rivers.

Beaver river showed changes in chemistry that were consistent through all parameters. Alkalinity decreased by 29% (1.50 mg/l) while acidity increased by the same amount and pH decreased from 5.75 to 5.57. Flow was 19.0 cfs, just slightly below average discharge of 20.5 cfs. Peak flow occurred within 22 hours and reached a maximum discharge of 28 cubic feet per second.

Usquepaug river responded to the storm in the same way as the Beaver river, but to a lesser degree. Alkalinity dropped 1.78 mg/l (20%) while acidity only increased 0.30 mg/l (5.1%) and pH decreased from 5.94 to 5.74. Flow peaked approximately two days after the storm, rising to 145 cfs from 115 cfs. Wood river showed the same trends but again to a lesser degree than either of the other two rivers. Alkalinity showed no change, acidity increased 1.02 mg/l (25%) and pH decreased from 6.10 to 5.93. No flow data was available.

The impacts of this storm were fairly well buffered by the dilution of the rainfall by the relatively high springtime discharge. A dry period of eight days prior to the storm could have contributed acid in dry deposition that was subsequently carried to the rivers by runoff, but the high flow in the rivers appears to balance this effect. The two larger watersheds were effected the least and took twice as long to reach peak flow as the small watershed.

5-4 Group Analysis-West-Northwest Group

Two storms approached New England from the northwesterly direction, the storm of November 28, 1983 (Table 4-5) and the storm of May 23, 1984 (Table 4-13). The two precipitations were similar in that pH was 4.50 and 4.47 and their strong acid coponent was 2.84×10^{-5} N and 3.96×10^{-5} N, respectively. The two events showed differing total acidity values of 3.21 mg/l in November and 6.05 mg/l in May. Storm size and the events before the storms were the most important factors distinguishing the two storms and their impacts upon river chemistry.

The storm of November 28, 1983 was relatively large with 1.41 inches of rain falling in the area. All three rivers showed a peak in flow approximately one day after the storm's arrival. However, this storm arrived just three days after a Thanksgiving Day storm of 4.66 iches which had already significantly increased river discharges. The Wood, Beaver, and Usquepaug rivers had risen from below average discharges to peak flows of 245, 56, and 247 cfs respectively. The passing of this large storm on November 25th had already caused great impacts on all three rivers.

The Wood river had maintained an alkalinity of 6.45 mg/l when the storm of November 28th passed, being reduced to 1.43 mg/l (a decrease of

78%). Acidity increased from 9.69 to 12.76 mg/l (32% increase). It is impossible to discern if these changes are due to the storm of November 28 or delayed runoff from the previous large storm.

The Beaver river was already greatly impacted from the previous storm when the storm of November 28th arrived. Alkalinity was an extremely low 0.96 mg/l, pH was 5.49 and acidity was a high 12.52 mg/l. These values were further impacted to 0 mg/l (100% day), 5.0, and 14.18 mg/l (13% rise) respectively after the passing of this storm.

The Usquepaug river was also impacted by the storm of November 25th. Alkalinity was very low at 1.91 mg/l, pH was 5.23 and acidity was 15.12 mg/l. The arrival of the second storm added to the impacts, reducing alkalinity to 0.96 mg/l (49% drop) pH to 5.19, while acidity remained constant at 15.12 mg/l.

This storm event clearly shows that the volume of flow in the river at the time of the storm's arrival greatly affected its ability to receive acidic rainfall. The previous storm had already reduced nearly all of the rivers buffering capacity, while the high flow diluted the effects of the following storm. Clearly, the combination of both events signifncantly altered the chemistry in all three rivers.

While the storm of May 23, 1984 also followed closely behind a previous storm, this storm had little or no effect on the rivers due to its small rainfall of 0.16 inches. All three rivers showed no increase in flow rate due to the storm.

Wood and Usquepaug rivers showed no changes in river chemistry with pH, alkalinity, and acidity remaining the same as before the storm. The large watersheds and discharges of these two rivers do not apear to be impacted by a rainfall of this size.

The Beaver river, being much smaller in size, did show a decrease (21%) in alkalinity and a small increase (8%) in acidity, pH remained constant. Although river discharge did not increase, it appears that even small amounts of precipitation can cause a change in river chemistry with a river of this size.

5-5 Group Analysis-West-Southwest Group

Five storm events were determined to originate from this area. Of these, four produced impacts upon the rivers that were expected while one storm, that of November 3, 1983 (Table 4-3) produced unexpected results which will be discussed separately.

The first of these four storms to approach New England was that of February 28, 1984 (Table 4-8). This was the only storm to approach from a west-southwest direction and was the only storm in the group to contain no strong acid component. Although it had low acidity, the amount of rainfall, 1.13 inches, caused the intensity-acidity product to be high at 4.65 and the water quality of all three rivers was adversely impacted.

Wood river was impacted the least, with pH dropping from 5.65 to 5.51, alkalinity declining from 4.86 to 2.70 mg/l (44% reduction) and acidity increasing from 4.36 to 5.64 mg/l (29%).

Beaver river showed an increase in acidity of 5.38 to 6.66 mg/l (24% increase) as pH dropped to 5.12 from 5.61. Alkalinity decreased from an already low 3.51 mg/l to 1.35 mg/l (62% decrease).

Usquepaug river showed the greatest changes in river chemistry. Although pH decreased from 5.75 to 5.54 and acidity only increased from 6.15 to 6.92 mg/l (13%), the alkalinity of the river dropped from 5.67 to 1.89 mg/l (a 67% decrease). Runoff may have contributed to the decline in alkalinity, with four days of dry weather possibly depositing dry fallout in the area.

The storm of March 22, 1984 (Table 4-9) produced impacts that were relatively small due to the smaller amount of rainfall associated with this storm, 0.39 inches. This storm was from the west and did show a strong acid component, but the intensity-acidity product remained low due to the low rainfall. Each of the three rivers displayed a minor decrease in pH and alkalinity with a corresponding increase in acidity.

The precipitation event with the highest intensity-acidity product was on April 4, 1984 with a value of 9.09. This storm combined a large strong acid component with 1.65 inches of rainfall and five days of dry deposition resulting in significant impacts in all three rivers.

Wood river had a drop in pH from 5.90 to 5.22. Alkalinity was nearly depleted in the river dropping from 4.86 to 0.82 mg/l (83%) while acidity jumped from 5.13 to 8.78 mg/l (71%). No flow data was available for this period.

Beaver river was impacted greatly by this storm. Peak flow occurred 26 hours after the storm's arrival, with discharge increasing from 30 to 76 cfs. Alkalinity in this river also was reduced, from 4.86 to 0.62 mg/l (87% decrease) and pH dropped from 5.90 to 5.02. This is a very low pH for a stream headwater. Acidity also rose to a high value of 9.45 mg/l, up from 5.13 mg/l (an 84% increase).

Usquepaug river followed this same pattern with pH declining from 5.72 to 5.36, alkalinity reaching 0.82 mg/l from 5.94 mg/l, (86%) and acidity increasing from 6.41 to 9.79 mg/l (53%). River flow more than doubled reaching peak flow approximately two days after the storm's onset.

The last storm of this group was on May 3, 1984 (Table 4-12) and produced changes in river chemistry that were moderate and as expected. A strong acid component was again present in the 0.97 inches of rain that fell. A long dry period of nine days may have contributed much acidity in the form of dry deposition and also resulted in a lowering of flow in all three rivers.

The Wood river peaked 24 hours after the storm began, increasing flow from 100 to 168 cfs. Acidity increased from 4.10 to 5.13 mg/l (25% rise) and pH only decreased from 6.08 to 5.97. Alkalinity was depressed from 7.76 to 4.73 mg/l (39% decrease)

Beaver river showed a similar impact as that of Wood river. Peak flow occurred 20 hours after storm onset and increased flow from 13.5 to 22.4 cfs. Alkalinity showed the greatest change, being reduced from 6.41 to 4.73 mg/l (26% drop). Acidity increased less than 1.0 mg/l, from 5.38 to 6.15 mg/l (14%) and pH dropped from 5.86 to 5.67.

The Usquepaug river showed nearly no change in pH, dropping only from 6.06 to 6.04. Alkalinity before the storm was high, 10.13 mg/l and was reduced to 7.18 mg/l by the storm (a 29% drop). Acidity increased from 5.89 to 6.66 mg/l (13%). This river peaked approximately two days after the storm began, with flow increasing from 92.3 to 120 cfs.

5-6 Group Analysis-Special Storm Series January 10, 1984 - February 3, 1984

During this period five individual precipitation events occurred (Table 4-7). The first two of these storms were snow storms with subfreezing temperatures throughout the period. The third storm brought rain, but some snow still remained on the ground. The fourth storm was a mixture of rain and snow which contributed more snow to that already present on the ground. The last storm was a large rainstorm which washed all of the snowpack away. This combination of precipitation events makes the impacts of each storm upon water chemistry individually indistinguishable. Therefore this group of storms was treated as a complete hydrological unit, with the total overall impact upon water chemistry analyzed.

While the impacts from each storm could not be dealt with individually, the precipitation resulting from each storm was recorded. Of the five storms, three were from the west, west-southwest group, one was from the south, and one was a combination of a storm from the west and a storm from the south. Acidity of the precipitation did not show a strong correlation with the direction the storm travelled. More important was the type of precipitation resulting from the storm. The three storm events which produced snow all had a consistently large strong acid component ranging between 5.49×10^{-5} N and 5.58×10^{-5} N. Both of the rainstorms had strong acid components of 2.20×10^{-5}N and 2.87×10^{-5}N. The pH of the precipitation was consistent with this pattern, with snowstorms ranging 4.10 to 4.32 and rainstorms 4.60 to 4.65. Acidity ranges were 5.59 to 6.05 mg/l in snow and 3.02 to 4.05 mg/l for the rain. This would suggest that the snow is a more efficient scavenger of acidic precursors from the atmosphere than the rainfall.

The impacts of the combined storms caused changes in river chemistry which fluctuated with the runoff associated with a particular event. Water quality parameters changed little throughout the first two snowstorms and subfreezing temperatures, as most of the acidic precipitation was tied up in the snowpack. After the passing of the third storm, causing some of this snowpack to melt and runoff to the rivers increased, changes in river chemistry were observed.

The Wood river had maintained a high alkalinity of 6.38 mg/l until this rainstorm of January 24 and the combined runoff reduced alkalinity by 33% to 4.25 mg/l. Acidity increased 7% to 5.40 mg/l. The pH showed little change, rising slightly from 5.80 to 5.86. The river began to recover after this storm and did not appear to be adversely affected by the rain/snow combination of January 30. The final rainfall of February 3 and the total combined runoff did cause significant impacts. Alkalinity dropped from 7.76 mg/l before this storm to 2.03 mg/l 3 days after the storm a decrease of 74% pH dropped from 6.60 to 5.91 during this period while acidity actually decreased 39% from 6.75 to 4.10 mg/l. By February 10th the river chemistry had recovered to values near that before the storm series began.

The Beaver river showed a pattern similar to that of Wood river. Alkalinity was 5.53 mg/l before this series began, dropping to 2.98 mg/l after receiving the combined runoff of three storms, a decrease of 46%. Acidity showed an increase of 64%, rising from 5.76 mg/l to 9.45 mg/l. The river also showed a small recovery after this storm and did not exhibit adverse impacts from the January 30th storm. The final rainstorm of February 3 and total runoff combined to depress alkalinity 68%, from 6.41 to 2.03 mg/l. Acidity rose from 5.13 to 8.20 mg/l, an increase of 60%, pH fell from 6.26 to 5.58. Recovery could again be seen by February 10.

The Usquepaug river was slower to respond to the impacts of the runoff, but showed the same trends as the other rivers. Alkalinity dropped 23%, from 5.53 to 4.25 mg/l after the storm of January 24 has caused a portion of the snowpack to melt. Acidity rose from 7.56 to 8.55 mg/l, an increase of 13%. The river then showed a period of recovery until the final storm of February 3 and the total melt of the snowpack significantly affected river chemistry. Alkalinity decreased to 3.38 from 8.10 mg/l, a drop of 53%. Acidity also increased, rising from 6.92 to 8.20 mg/l, an increase of 19%, pH also declined from 6.23 to 5.63

during this period. pH and alkalinity had shown a recovery by February 10 while acidity had continued to rise.

Flow data for all three rivers show a similar pattern. The snowstorms of January 10 and 18 did not increase the discharge of the rivers at all, with flow decreasing throughout the period. The rain of January 24 and the partial melting of the snowpack did cause streamflow to rise. This peak was followed by a steady decline in discharge until the large rainfall of February 3 and the total melting of the snowpack caused river flow to rise significantly. Peak flow occurred approximately two days after the storm's onset in all three rivers and then gradually declined.

5-7 Unique Response of River Water Quality

There were two storms in this study that produced some unique changes of water chemistry in one or more of the three watershed areas. The storm of October 12, 1983 (Table 4-1) gave 1.05 inch of rainfall. No strong acid component was found in the precipitation. Despite its moderate size and relatively low acidity, the rainfall brought significant changes of pH, acidity, as well alkalinity in Wood River and Beaver River. In Wood River alkalinity dropped from 11.84 mg/l to 0 mg/l and acidity changed from 2.22 to 21.09 mg/l representing almost 10-fold increase. Consequently pH dropped from 6.44 to 4.29, which was the most significant pH drop in the entire year of study. Similarly significant drop of alkalinity from 11.08 to 3.44 mg/l and increase of acidity from 1.11 to 12.21 mg/l (11-fold increase) were observed for the Beaver River although pH drop from 6.45 to 6.31 was less drastic. Sufficient alkalinity remained to prevent a further drop of pH. The drastic changes of water chemistry in these two rivers were unexpected from the moderate size and acidity of the storm.

The study area and the state of Rhode Island as a whole was experiencing a long drought period prior to the October 12 storm. There were 5 months of very dry weather from May through September. One storm in October 2 produced 0.68 inches of rainfall, but no data was taken. the October 12 storm was the first one in this study. The very long drought period resulted in extremely low flows in all three rivers. The October 12 storm washed out significant amount of dry acid deposition accumulated in the watersheds and some acid accumulated in the swampy areas as well. This was a unique situation, producing drastic changes in alkalinity and acidity not to be witnessed again throughout the entire study period.

The response of the Usquepaug River water to the October 12 storm, however, was quite different. The river water, although had its acidity increased from 1.11 to 12.21 mg/l had only a slight drop of alkalinity (from 19 to 13.18 mg/l) and pH (from 6.45 to 6.31). Through contact with the owner of the Hollis Tucker Turff farm, it was learned that lime was applied in an amount of 1 1/2 to 2 tons/acre in late July 1983. The turf farm is located immediately upstream from the sampling station of the Usquepaug River. The possible inclusion of lime in the runoff or groundwater connecting to Usquepaug River explains why the alkalinity remained relatively high while the other two rivers had their alkalinity reduced significantly.

A small storm occurred on November 3-4 (Table 4-3). It moved in from the west-southwest direction and carried a high acid concentration. The strong acid component 1.59×10^{-4}N was the highest found in all storms that were studied in one year. It also carried significant amount of weak acids. The amount of rainfall that occurred was uncertain as the data was missing. However the insignificant amount of increase of the river flows in all three rivers indicated that the rainfall was very small. As a result alkalinity and pH drop was insignificant. Similarily the acidity increase was negligible. It is obvious than even a highly acidic rainfall would have little impact in rivers if the amount of rainfall is very small.

5-8 Recovery

As expected the river having the most severe impact of its water quality due to acid precipitation also took a longer period of time for recovery.

In any storm event, the most severe impact on the water quality generally occurred soon after the river flow peaked. The time from the peak flow to the time when the water resumed its pre-storm quality was defined as the time of recovery. Based on storm size and acidity and other factors discussed previously in this chapter, the time of recovery for the three watersheds is listed below:

Wood River	18 1/2	to 140 hours
Beaver River	1	to 117
Usquepaug River	10	to 128

It can be seen that some large storms could impact the water quality for 5 days or longer while small storms had only a brief period of impact of several hours only. The information could be useful to individuals or agencies studying the ecology or the recreational value of these three rivers.

6. CONCLUSIONS

1. In general storms coming to Rhode Island from west-southwest direction carried more acid and precipitation from them had the lowest pH. Storms from south-southwest were the least acidic and storms from west-northwest were in between. Rainfall pH as low as 3.81 and strong acid component at a concentration of 1.59×10^{-4}N were recorded in storms from the west-southwest direction.
2. Rhode Island has very low alkalinity fresh waters. Many storms with high acidity have reduced the river water alkalinity to less than 1 mg/l and in one extreme case to 0 mg/l. The acidity in the river water increased by as much as eleven fold. The lowest pH recorded for Wood River during one storm was 4.29.
3. The degree of impact on river water quality is not merely a function of the acidity of the storm only. Other important factors are the size of the storm; the accumulated amount of dry acid deposition on land prior to the storm event; the river flow prior to the storm event; and the land use pattern in the area. A very acidic precipitation from a small storm may not impact the river water quality as much as a large storm with only moderate amount of acidity. A long drought period or several snow storms in subfreezing whether preceeding a rainfall may result in a significant impact of water quality because of the large accumulation of dry acidic deposition in the area. A high pre-storm river flow may dilute the acidic rain runoff, thus minimizing the impact. Agricultural use of lime in the area may significantly neutralize the impact also.
4. A drop of half of a pH unit could take place in approximately 1/2 day. Depending on the amount of acid and other factors presented

previously, the impact on river water quality may last longer than 5 days from the on-set of the maximum impact to the time of complete water quality recovery.

5. For a better understanding of the acid deposition on river water quality, future studies should include the characterization of groundwater interconnecting the river flow and the seasonal variation of impounded surface water quality in the area including reservoirs, bogs, and swamps.

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8. ACKNOWLEDGEMENT

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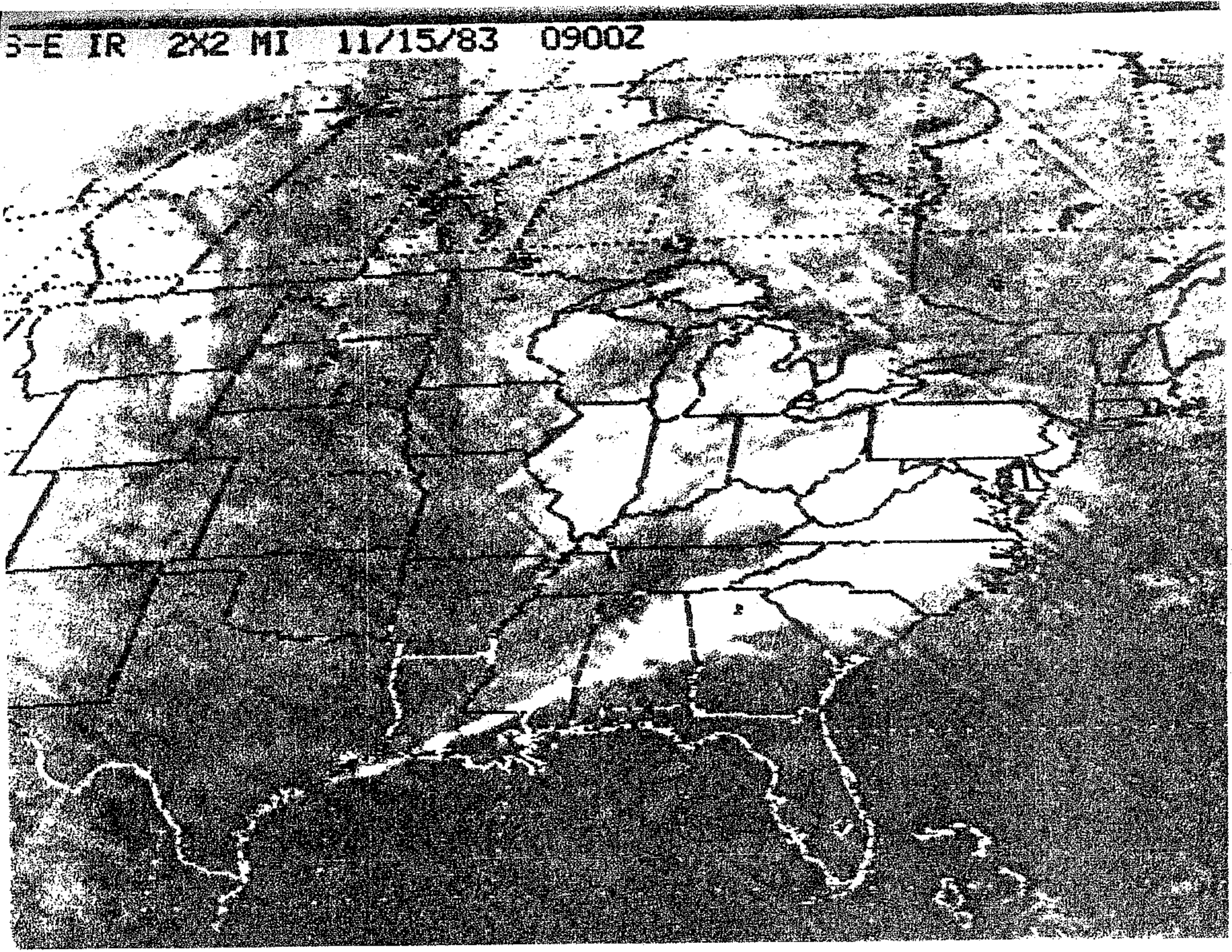
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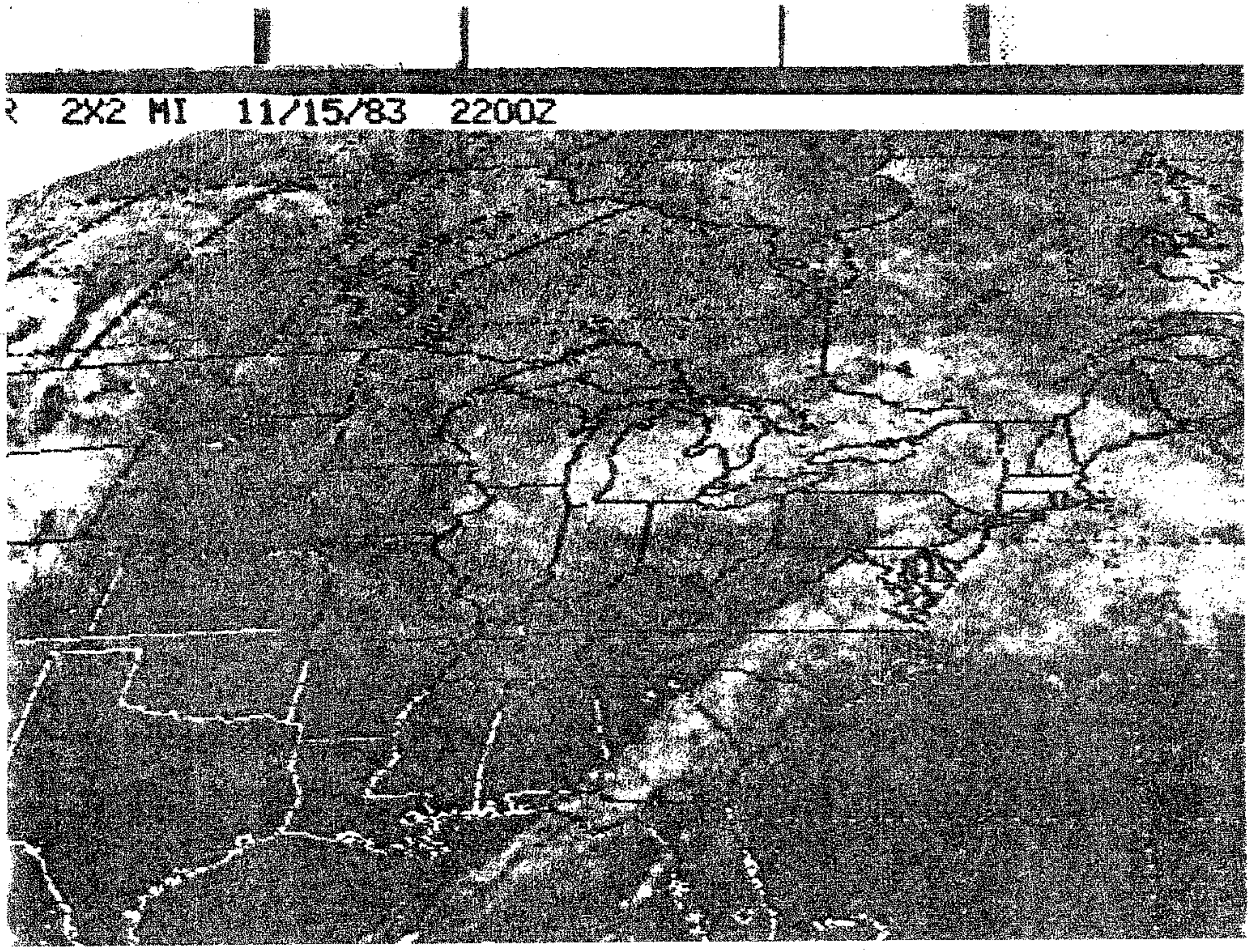
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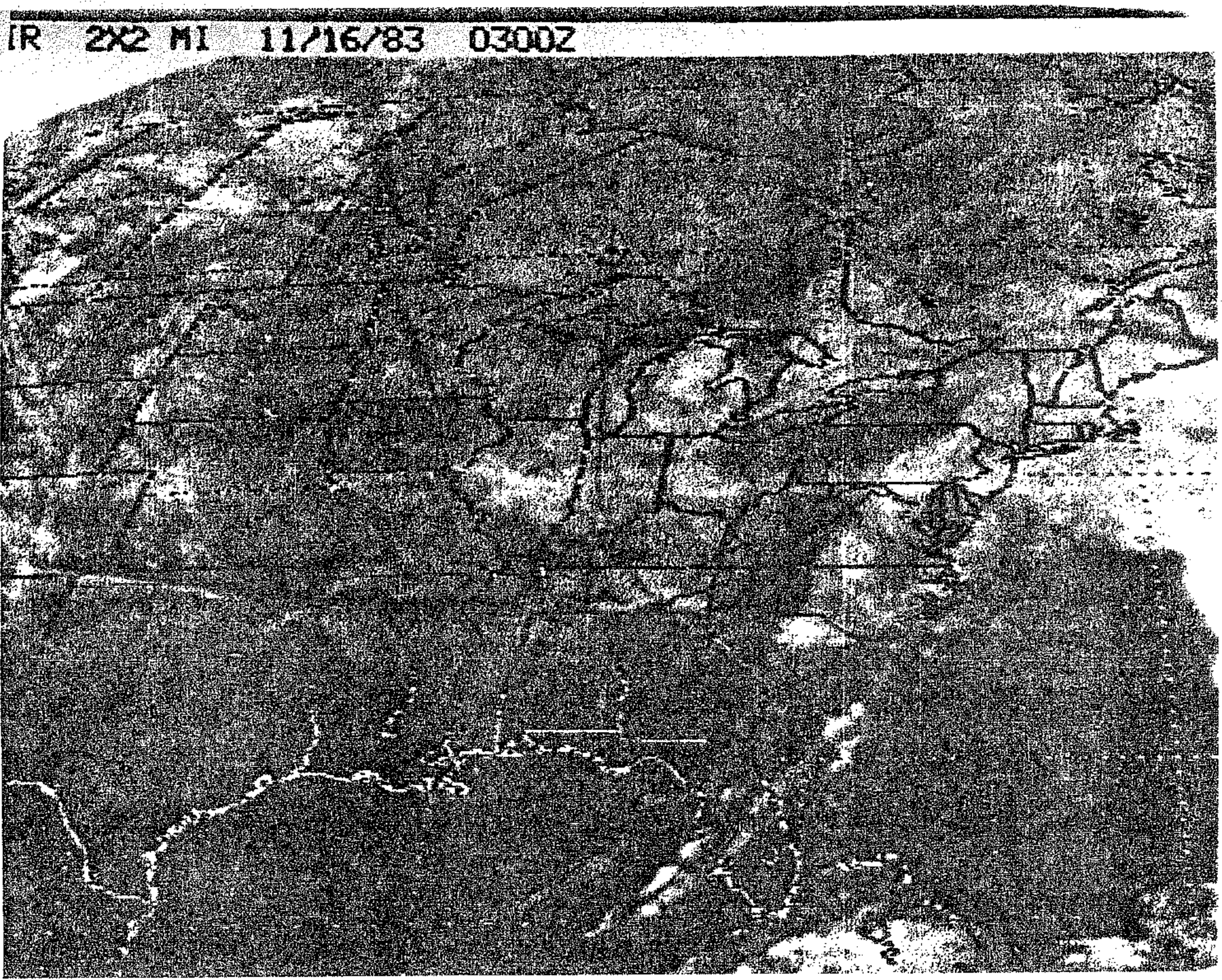
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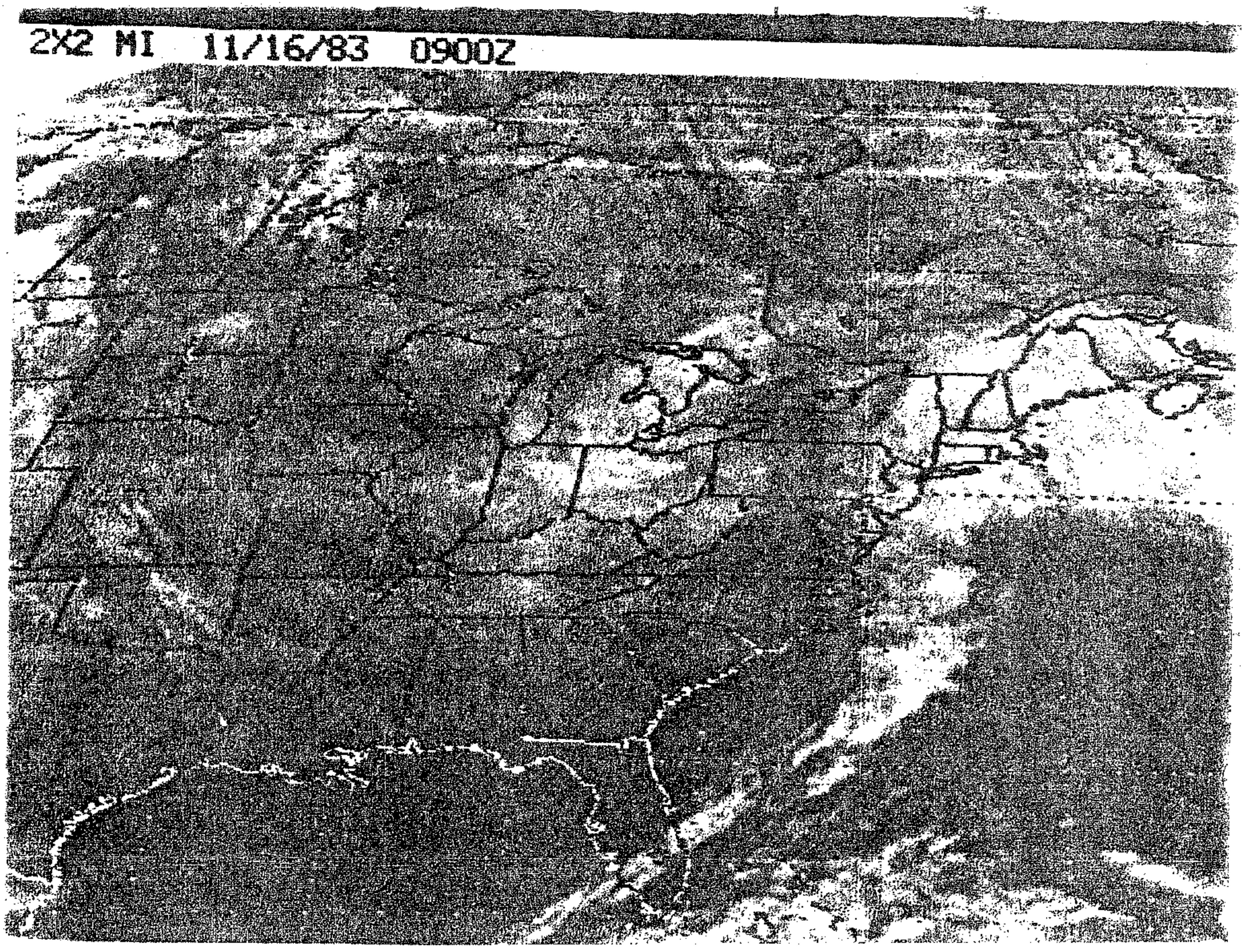
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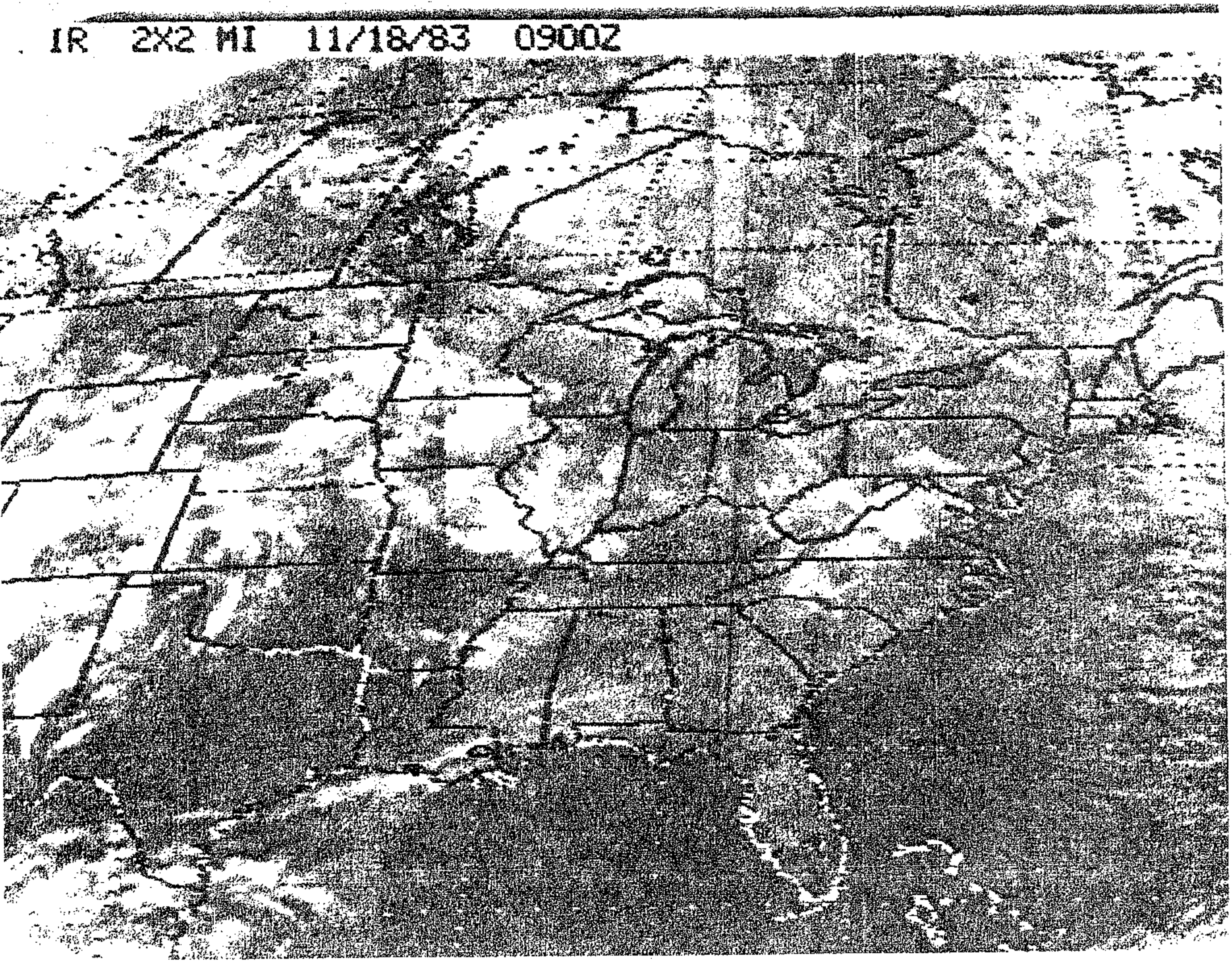
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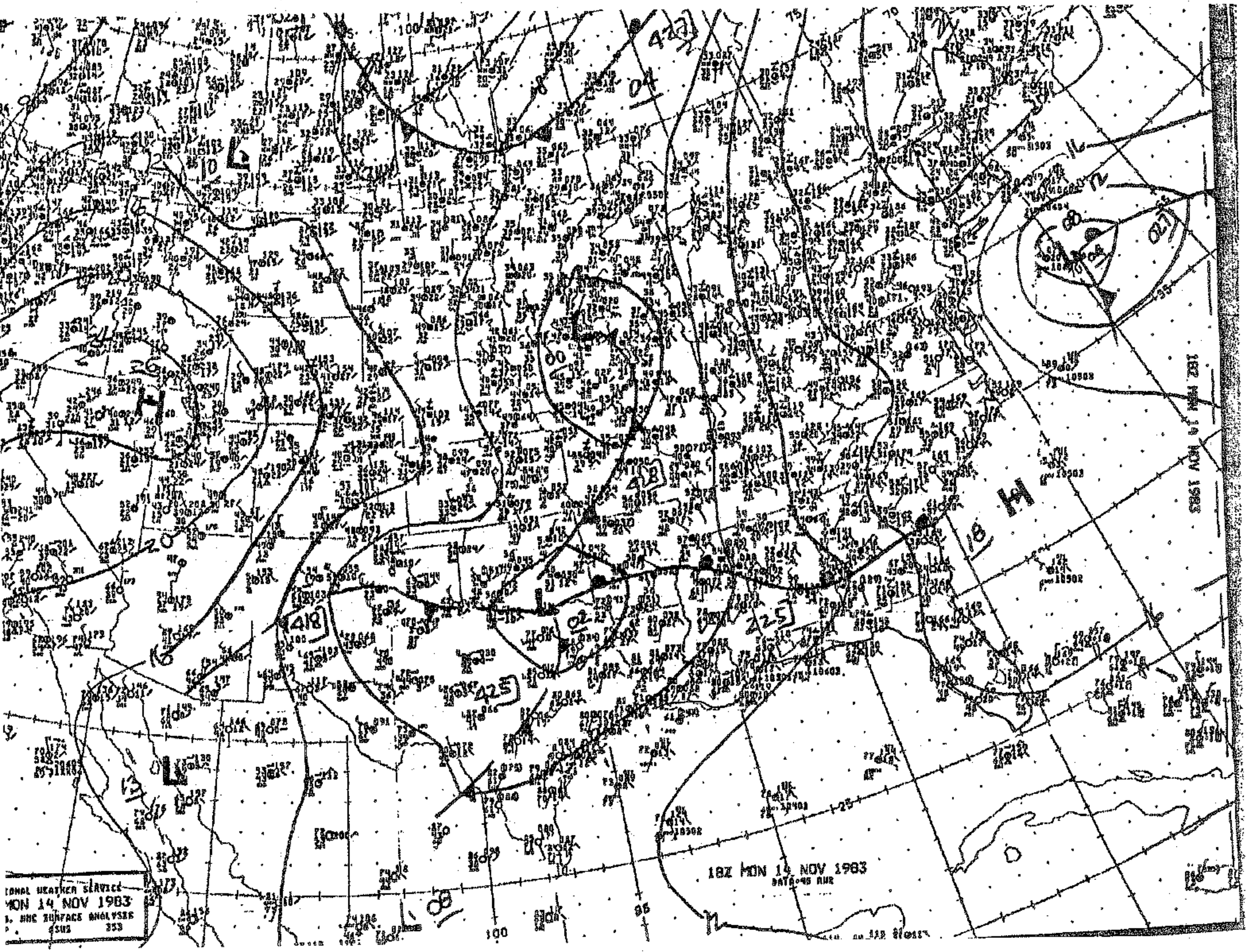
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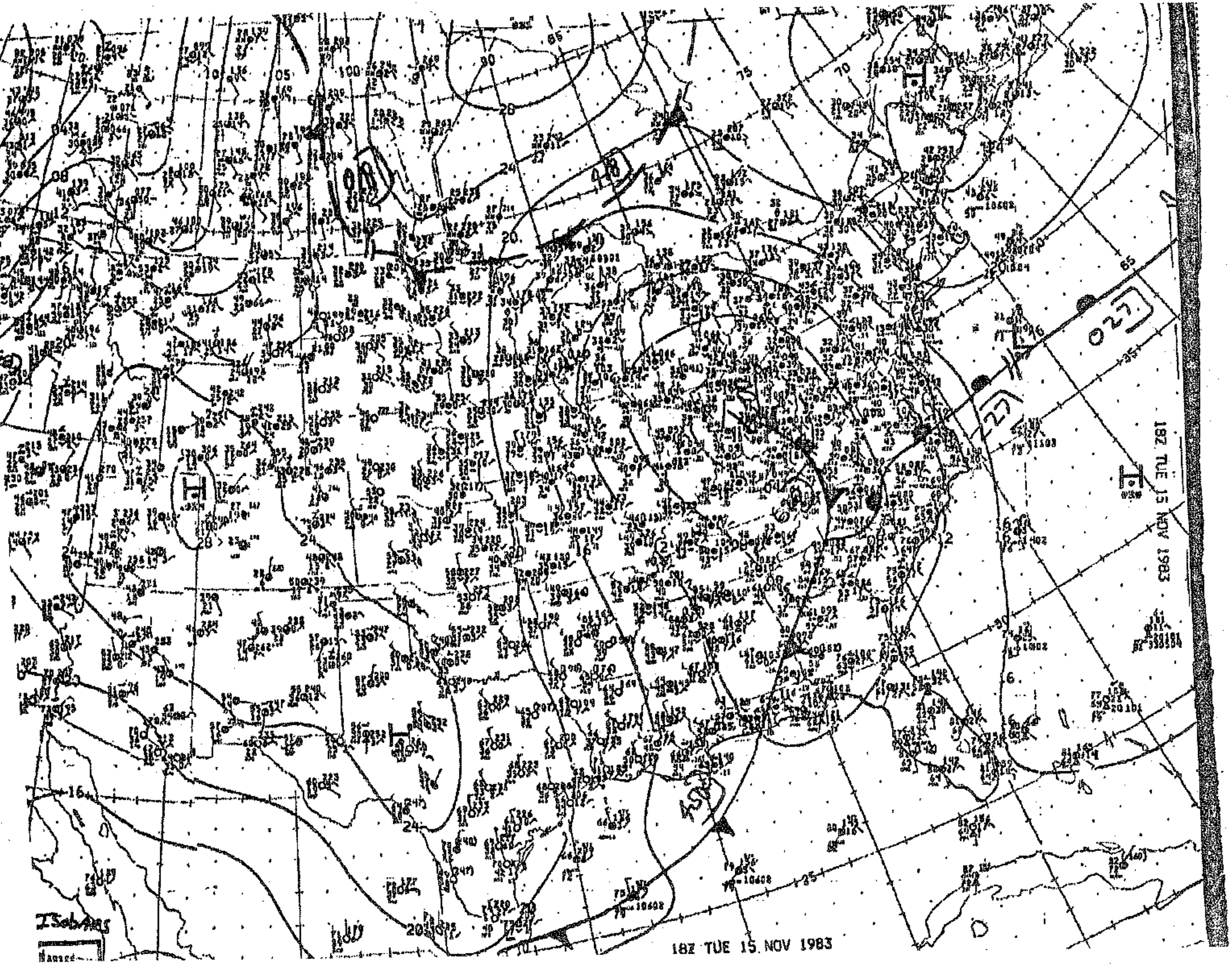

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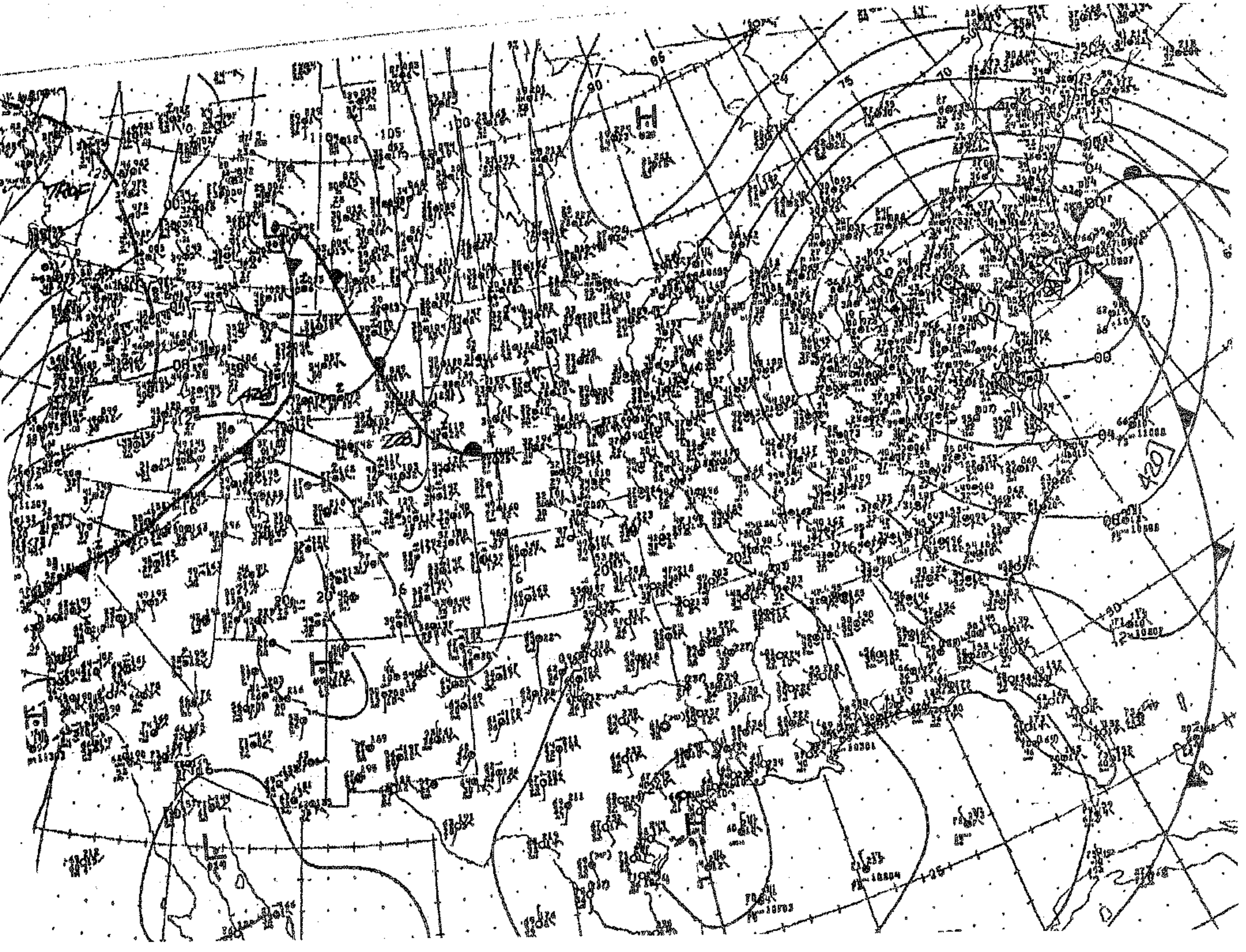

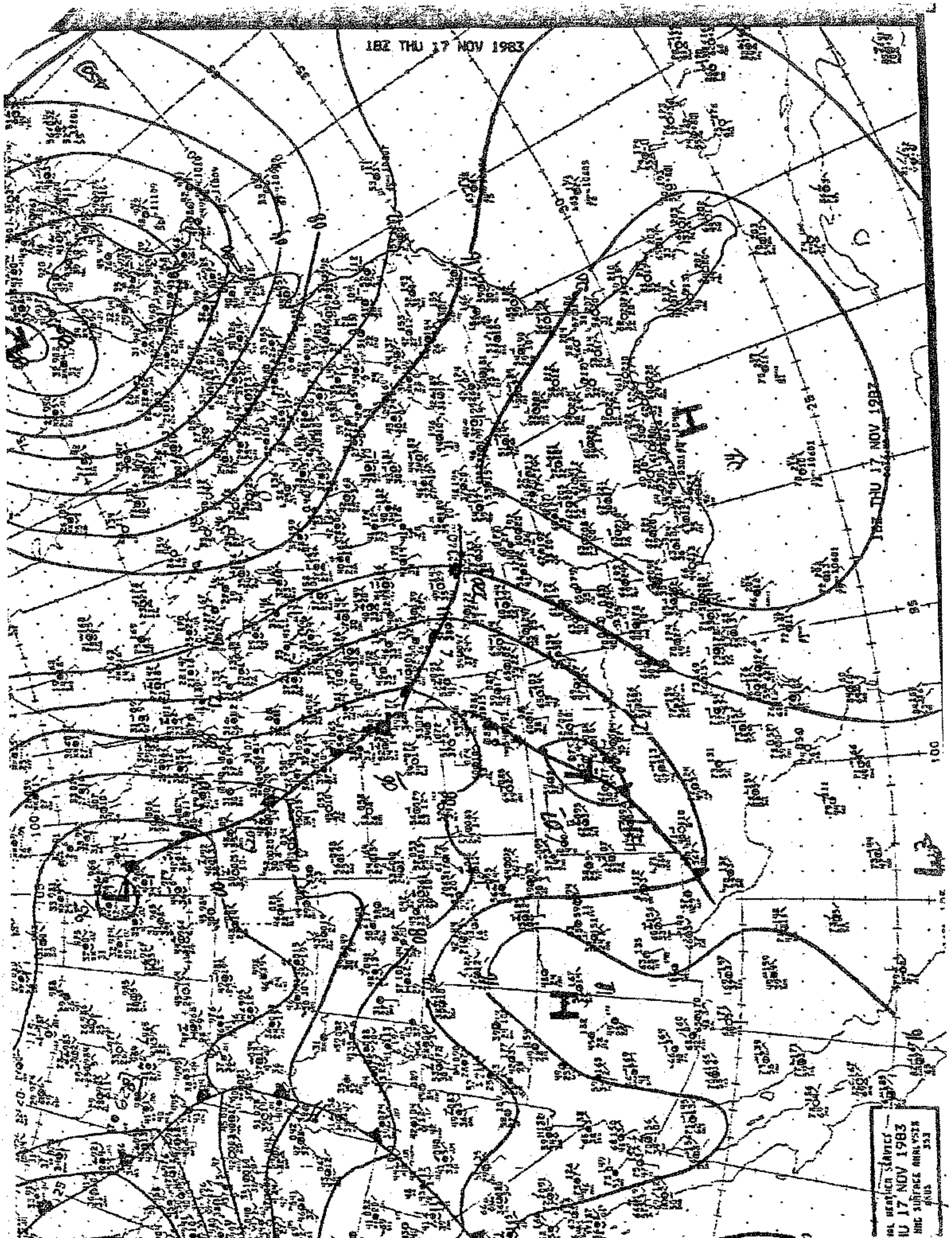
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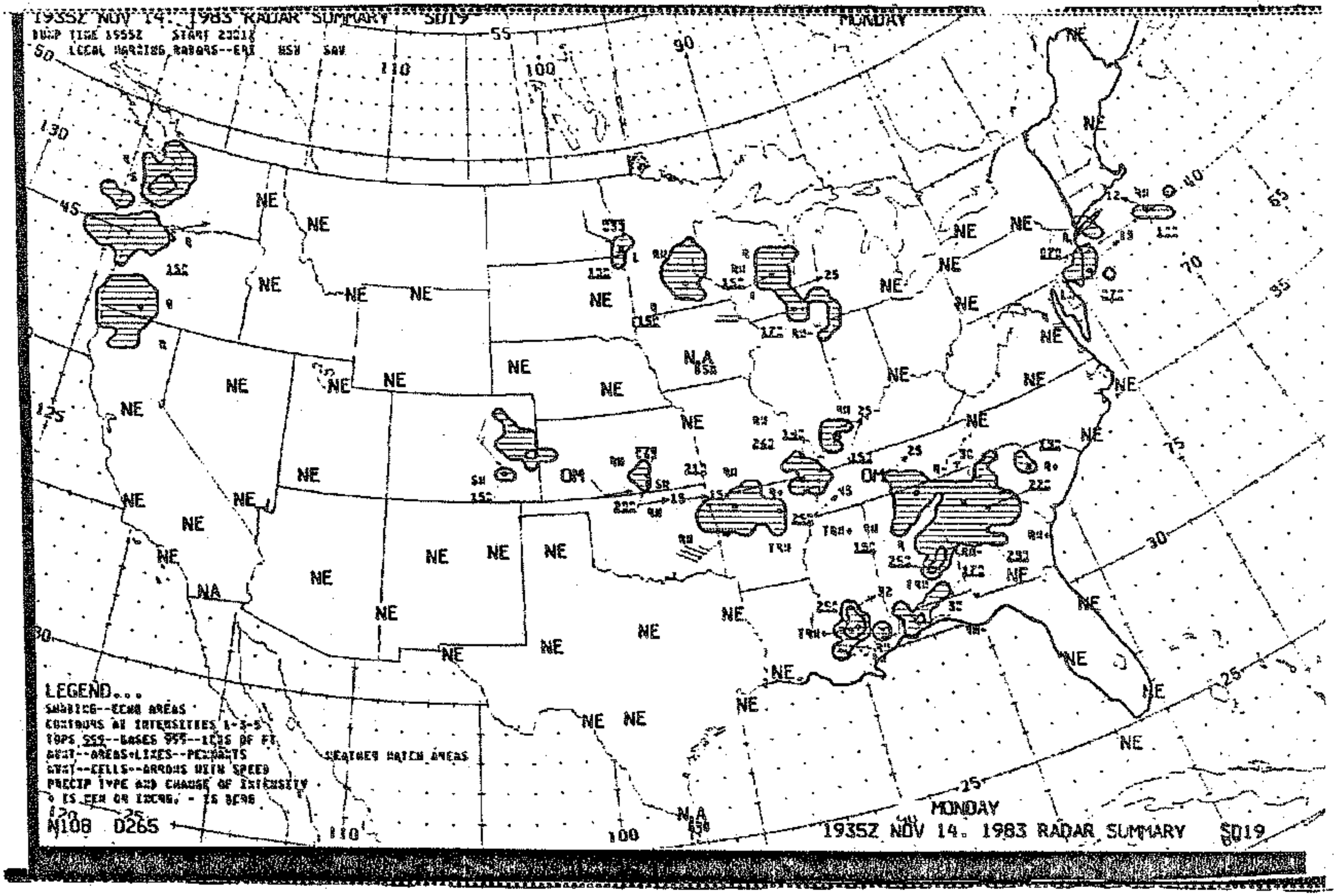
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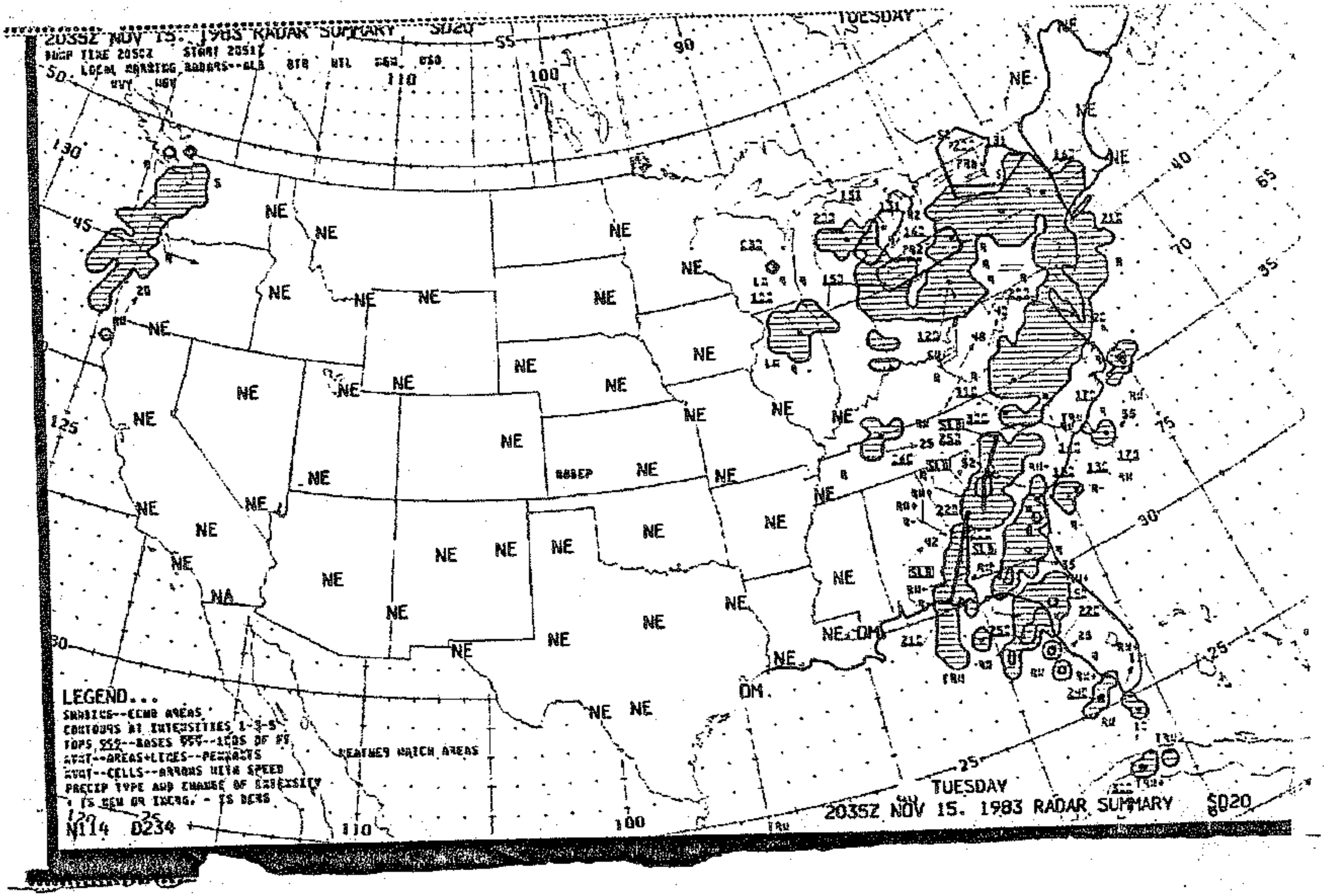
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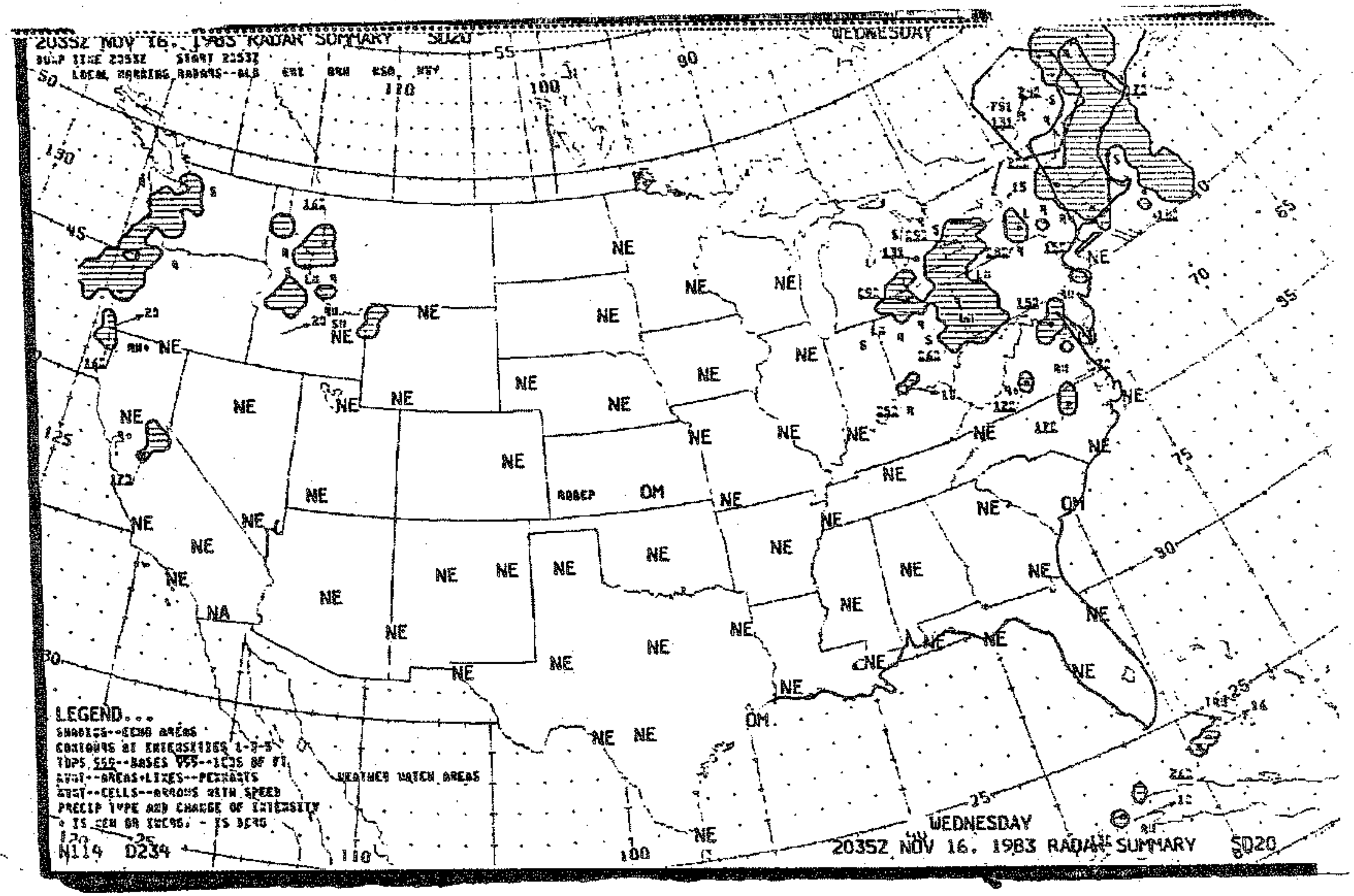
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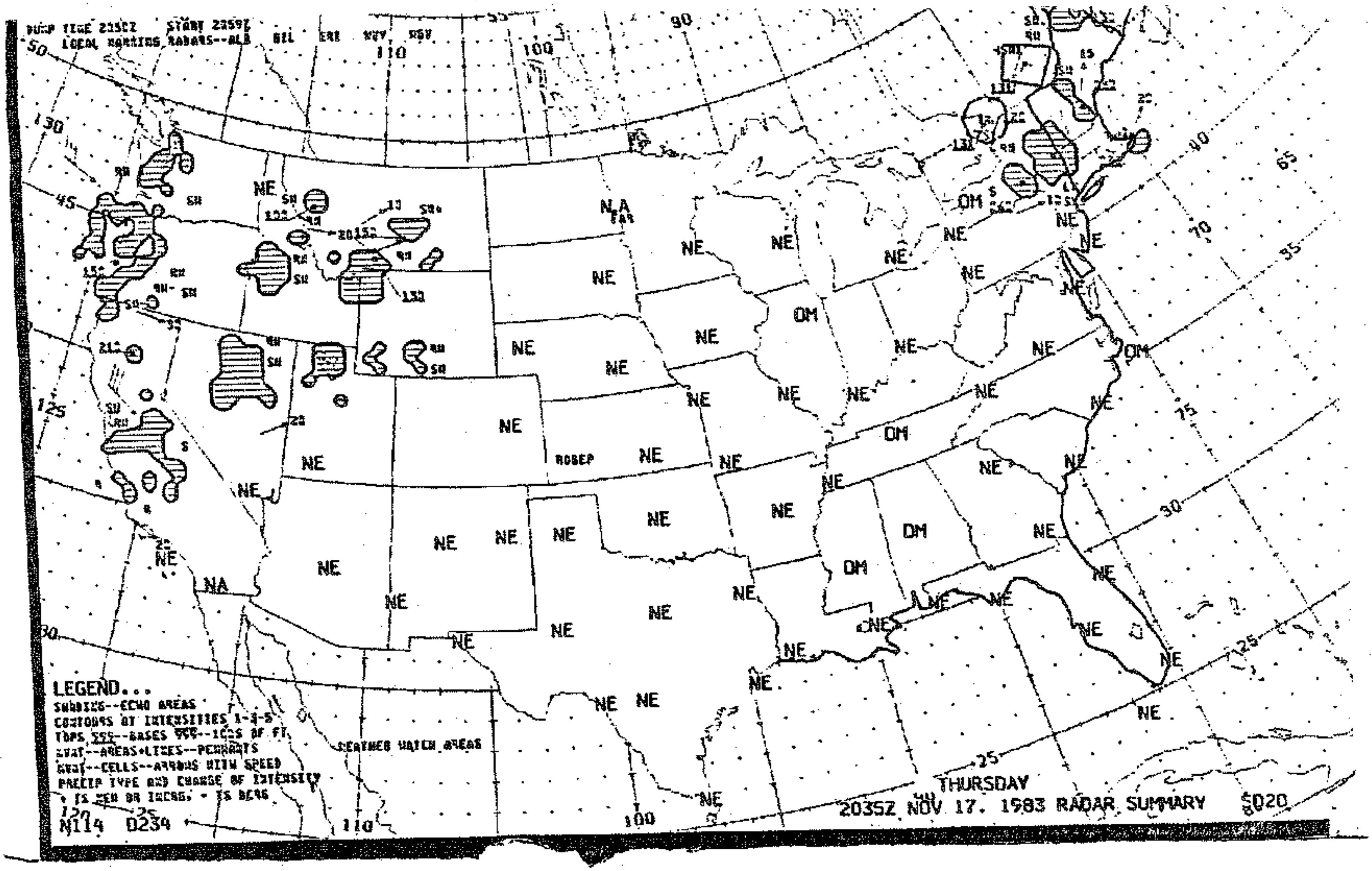
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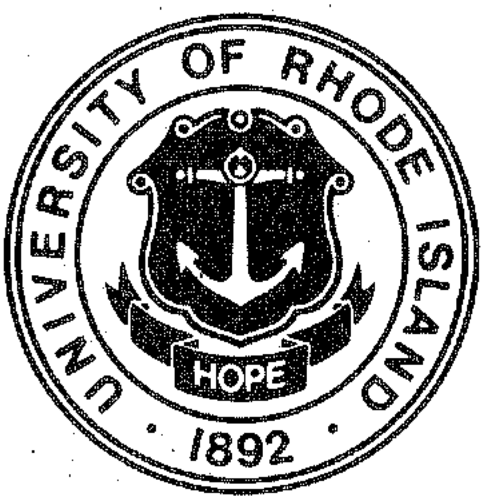
RHODE ISLAND
WATER RESOURCES CENTER



ANNUAL PROGRAM REPORT FY-1983

by

Calvin P.C. Poon, Director

WATER RESOURCES CENTER
UNIVERSITY OF RHODE ISLAND
KINGSTON, RI

Annual Program Report
Fiscal Year 1983
(Annual Report Number 19)

Calvin P.C. Poon, Director

September 1984

The research on which this report is based was financed in part by the United States Department of the Interior as authorized by the Water Research and Development Act of 1978 (P.L. 95-467).

DISCLAIMER

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Jay F. Sperry	Assistant Professor of Microbiology
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RHODE ISLAND WATER RESOURCES CENTER

DIRECTOR'S STATEMENT
FY-1983

Current Situation

The former director, Dr. Daniel W. Urish, left the University of Rhode Island in July 1983. I was appointed as the director of the Center in August with Professor Robert Goff serving as the acting director in between time. At the present time, the Center continues operation with a half time secretary and a 45-percent time director. The Center is contemplating to include in future programs more technology transfer activities at which time a full time secretary or an additional staff will be required.

Current and Anticipated State Water Problems

Water of high quality is an abundant resource in Rhode Island. Many steps have been taken to meet water demands and to protect water quality. These include acquisition of sites for development of both surface and groundwater source, enactment of legislation protecting groundwater aquifers from hazards, controlling soil erosion and sedimentation, development of wastewater treatment facilities, and instituting a wastewater pretreatment program to protect public treatment works. However several problems surface recently which help to identify some of the critical needs in the State of Rhode Island.

One critical need is the formulation of comprehensive and definitive policies, providing a common framework for the activities of all concerned with the essential functions of water supply and wastewater treatment. The policies should provide a set of guiding principles so that agencies could coordinate their works without cross-purposes and duplicating efforts. The recent Governor's conferences on water policy, November 1983 and June 1984, began to address some of the relevant policy issues. Studies on supply and demand management; delivery system; as well as planning and institutional needs are critical.

Since a significant portion of the state population is served by groundwater, hazardous waste related groundwater problem is of critical concern. Agricultural chemicals including fertilizers (e.g. nitrate) and pesticide (e.g. Temik in potato farms), salts from road salting practices, solvents used for home septic tank-leaching field cleaning, toxic matter in landfill leachates, and gasoline leakage from storage tanks are continuing problems in Rhode Island.

For comprehensive planning of water resources, a large data base is required. Easy access to the same data base from various agencies is essential. There is a need consequently for a data information system for fast retrieval of information by various users according to each individual's format and need.

Individual sewage disposal systems, primarily in the form of septic tank and leaching field, serve more than 30 percent of the state population. System failure, which is not uncommon, often lead to surface or groundwater contamination. Some engineering solutions to this problem in preventing system failure or rejuvenating a failed system in a most cost-effective way are required.

Price for water supply and wastewater discharge at the present time is on a declining block rate scheme. As new and costly facilities are added and rapid increase of operation- and - maintenance cost occur, customers are facing alarmingly high water and wastewater bills. A new pricing scheme should be investigated taking into considerations of equity and other intervening variables such as water conservation, elasticity, and change of economic base in the region, etc.

Current Research

There are altogether five projects in the FY-1983 Cooperative Program. Project 374202 (University of Rhode Island Water Resources Center Number A-079-RI) develops a resonance Raman method for detecting and identifying bacteria. The time-resolved fluorescence spectra of several types of bacteria at various emission wavelengths suggest the determination of fluorescence lifetimes as an effective means of bacterial identification.

Project 374203 (A-080-RI) investigates the potential of using chemical nitrification inhibitors to delay or minimize the oxidation of fertilizer NH4+ to NO_3^-, thus minimizing the nitrate problem in groundwaters. No evidence indicates that nitrification inhibitors can reduce nitrogen leaching from a turfgrass sod. Downward migration of NO_3^- from sod is found to be insignificant. This project will be carried into the FY-1984 program for one more year. Porous plate lysimeters will be used and nitrogren budgets for various fertilized plots will be constructed to give a quantitative estimate of nitrogen mobility.

Project 374204 (A-081-RI) examines the acidity and acid components of precipitations which reveal a good correlation between high acidity and storms from the west-southwest direction. Acid precipitations significantly impact the water quality of rural headwaters. Factors affecting the degree of impact and the rate of recovery are investigated.

Project 374205 (A-082-RI) uses a historical precipitation record to establish reference storms and pollutant loading rates which are in turn used for determining the storm water overflow abatement alternatives using a quasi-continuous approach and the STORM WATER MANAGEMENT MODEL.

Project 374207 (A-083-RI) uses a new method of measuring nitrification rates with 15_N radioisotope and indicates that in an urban water downstream from a wastewater treatment outfall the low nitrification rates do not exert a large oxygen demand. The annual nitrogenous oxygen demand is compared with the annual carbonaceous oxygen demand of the river.

Cooperation with State and Regional Agencies

There is a close working relationship between the Rhode Island Water Resources Center and the Rhode Island Department of Environmental Management (RIDEM). The team of principal investigations in project 374204 studying acid precipitation is made up of personnel from the University of Rhode Island and RIDEM. The USGS Subdistrict Office in Rhode Island has also provided flow data and other information as well as consultations to this project. Project 374205 on Storm Water Overflow Management has the principal investigator work closely with both the RIDEM and engineers from the Narragansett Bay Water Quality Commission. The work also goes hand in hand with the Graduate School of Oceanography at the University of Rhode Island which handles the chemical analyses of the stormwater quality for this project.

This center also has initiated a plan to work with the Narragansett Bay Water Quality Commission in the newly established industrial waste pretreatment program. There is a need to establish a monitoring program dictated by the nature of the pretreatment program.

The New England Water Resources Center Directors have met in August 21-22 in Connecticut to discuss present and future efforts in program coordination and regional program approach. A follow-up meeting on the same subject for mroe detail discussion and planning is scheduled for late September 1984.

RHODE ISLAND WATER RESOURCES CENTER
INDIVIDUAL PROJECT ANNUAL REPORTS
FY-1983

374202 (A0-079-RI)	Rapid Detection and Identification of Bacteria in Sewage and Natural Waters by Means of Time-Resolved Laser Spectroscopies.	Nelson and Sperry
374203 (A-080-RI)	The Effectiveness of Nitrification Inhibitors in Reducing Nitrate Contamination of Groundwater from Turfgrass Fertilization	Hull
374204 (A-081-RI)	Source of Acid Prepipitation and its Effects on Water Quality	Poon, Wright and North
374205 (A-082-RI)	Evaluation of Combined Sewer Overflow Management Strategies through Pipe Network Computer Simulation	Wright
374206 (A-083-RI)	The Role of Nitrification in Contributing to Low Oxygen Conditions in an Urban Waterway	Nixon

Project #374202

Title: Rapid Detetion and Identification of Bacteria in Sewage and Natural Waters by Means of Time-Resolved Laser Spectroscopies

Nelson, W.H. and Sperry, J.F., Rhode Island, University of, Kingston, Rhode Island 02881, Departments of Chemistry and Microbiology

Synopsis of Project

The objective of this project has been the development of a sensitive method of rapid bacterial detection and identification using resonance Raman and time-resolved fluorescence spectroscopies. A substantial number of bacterial types have been studied by both spectroscopic methods.

Raman studies have been accomplished using a conventional spectrometer at URI with 488 nm excitation, a micro-Raman spectrometer at Spex, Inc., at Edison, N.J., and a U.V. pulsed Raman spectrometer at MIT. Findings have shown that Raman spectra will be of greatest use if obtained with excitation in the 220-280 nm range. There is a strong likelihood of success in efforts to identify bacteria on the basis of purine and pyrimidine base resonance Raman spectra excited at 257 nm. Attempts to use dye labels as Raman probes in the visible range have failed due to fluorescence interference.

Time-resolved fluorescence studies have involved the use of instruments at URI and at U. Conn. Single-expotential time-resolved fluorescence spectra have been obtained for several organisms which show different time-resolved spectra. More precise experiments with picosecond resolution equipment at U. Conn. show that bacteria have many fluorescent components which can be used to characterize the organisms. The extent to which cultural conditions affect the fluorescence lifetimes and intensities has not yet been satisfactorialy assessed, but work is underway.

We conclude that both resonance Raman and time-resolved fluorescence spectroscopies have excellent potential as techniques for rapid microbial detection and identification. However, a substantial number of important hurdles must be overcome before a major effort can be made to develop practical analytical methods. These include a need to catalog more completely the various fluorescence contributions of bacteria using a time-resolved fluorescence spectrometer of high resolution. We also need to obtain complete resonance Raman spectra in the region 220-280 nm for a substantial number of organisms to see if differences in spectra accurately reflect differences in known purine and pyrimidine compositions of bacterial D.N.A. Sensitivity is excellent. We have shown that detailed spectra can be obtained from only a few organisms observed under the microscope.

Publications produced as a result of this project:

1. The Rapid Identification of Bacteria Using Time-Resolved Fluorescence and Fluorescence Excitation Spectral Methods, S.K. Brahma, M.P. Baek, R.K. Force, and W.H. Nelson, Applied Spectroscopy (accepted 1984).
2. The Detection and Identification of Bacteria by Resonance Raman and Time-Resolved Fluorescence Spectroscopies, W.H. Nelson (to be submitted).

REPORT OF PROGRESS

Water Resources Project 1983-84

TITLE: The Effectiveness of Nitrification Inhibitors in Reducing Nitrate Contamination of Ground Water from Turfgrass Fertilization.

INVESTIGATOR: Richard J. Hull, Professor of Plant Science

FUNDING: $14,659.00

SYNOPSIS OF PROJECT:

Purpose and Objectives:

When ammonium-N (NH_4^+) is applied as a fertilizer to well drained soils o moderate pH, it is rapidly oxidized by the soil bacteria *Nitrosomonas* and *Nitrobacter* to nitrate-N (NO_3^-). This nitrification of NH_4^+ to NO_3^- makes NO_3^- the principal nitrogen form available to plants regardless of the form applied as fertilizer. Because NO_3^- is highly mobile within the soil profile i is readily leached from the plant root zone into the subsoil horizons where it is free to continue downward into the water table. Crops that receive heavy fertilizer applications, e.g. potatoes, corn, and turf sod, all have the poten of contributing NO_3^- to ground water supplies. This is especially likely in light well drained soils which are prevalent in southern New England and throug out the Northeastern states.

This investigation is exploring the potential of using chemical nitrification inhibitors to retard the conversion of fertilizer NH_4^+ to NO_3^- when applie to establish turf. This should retain nitrogen within the root zone for a longer time and increase the opportunity for nitrogen utilization by the turfgrass plants. Delaying the oxidation of NH_4^+ to NO_3^- should also slow the rate of NO_3^- migration into the subsoil and from there to ground water. In addition, the microbial reduction of NO_3^- to nitrogen gas (N_2), which can occu during times when the soil is excessively wet, will also be retarded if fertilizer nitrogen is retained in the NH_4^+ form.

The specific objectives of this research are as follows:

1. Determine the extent to which nitrification of fertilizer NH_4^+ can be modified by the application of nitrification inhibitors to established turf.
2. Determine the influence of fertilizer-N application rates on the action of nitrification inhibitors applied to established turf.
3. Determine the influence of fertilizer composition (complete vrs. nitrogen alone) on the effectiveness of nitrification inhibitors applied to turf.
4. Determine the influence of nitrification inhibitors and the fertilizer factors cited above on the NO_3^- content of the soil solution in the turf root zone and at a depth beneath the root zone (60 cm).
5. Compare nitrogen recovery by turfgrass as influenced by the presence of a nitrification inhibitor and fertilizer composition and rate.
6. Evaluate turfgrass performance (visual quality scores) as influenced by nitrification inhibitors and fertility variables.
7. Construct a nitrogen budget for turf, with nitrification inhibitors as a variable, accounting for all nitrogen additions, losses, and that retainec by the grass plants.
8. An objective implicit in this investigation is an evaluation of methods for obtaining soil solution samples from established turf that truly reflect the NO_3^- and NH_4^+ content of that solution from which turfgrass roots obtain their nutrition.

Methods and Procedures:

A set of "Baron" Kentucky bluegrass (Poa pratensis L.) field plots established in 1976 were utilized for this study. Twelve fertility treatments had been imposed on this land since 1970. They consisted of three rates: 12-2-4, 24-4-8 and 48-8-16g N-P-K per square meter. These rates were applied in four combination of nutrients: N alone, N + P, N + K had N + P + K. Fertilizer applications were split between April and November except for the 48 g N treatment which received 9.6 g/m^2 in April and November and 4.8 g/m^2 during eac treatment which received intervening month. These 12 treatments were replicated four times in a split-plot design with nutrient combinations comprising the main plots and fertilizer rates the subplots.

On 2 May 1983, half of each plot (a 1.8 x 4.9 meter area per plot) was treated with the nitrification inhibitor terrazole (5-ethoxy-3-trichloromethyl-1,2-4-thiadizole) at 2 Kg active ingredient per hectare. A 5% granular formulation provided by Olin Corp. was applied using a conventional drop spreader and watered in with 12 mm of irrigation. The first fertilizer application for the season was applied on 10 May 1983. All N was applied as urea or diammoniu phosphate, P as super phosphate or diammonium phosphate, and K as muriate of potash (KCl). The normal May nitrogen application to the 48 g/m^2 plots was made on 9 June 1983.

On 6 October 1983, the same plots that had received terrazole in the sprin were sprayed with 0.5 Kg/ha of nitrapyrin (2-chloro-6-trichloromethyl pyridine) This also was incorporated into the sod with irrigation water applied within 15 minutes of spraying. The nitrapyrin treatment was repeated at a 1.5 Kg/ha rate on 6 June 1984. A liquid formulation (N Serve 2E) was mixed with urea granules and applied with the urea using a drop spreader. Within 30 minutes of nitrapyrin treatment, irrigation commenced and 12 mm of water were applied. The urea was applied at 1 Kg/ha to the entire plot area.

In June 1983, suction lysimeters were inserted into each plot receiving N alone and the complete N-P-K fertilizer, total of 48 plots. The lysimeters were placed at a 20 cm depth to sample soil solution from within the root zone. In September 1983, an additional set of 48 lysimeters were inserted in the same plots to a depth of 60 cm to sample soil solution below the root zone.

Each week throughout the 1983 growing season and for most of the 1984 season, each plot was mowed at a 3.8 cm height. All clippings from a 0.5 x 3 meter area of each plot were harvested just prior to regular mowing. All clippings were removed from the plot area. Harvested clippings were oven dried at 70°C, ground in a Wiley mill to pass a 40 mesh sieve, and stored in glass snap-cap vials at room temperature. Tissue samples (200 mg) were subjected to microkjeldahl digestion and analyzed for total nitrogen, now as NH_4^+, using the salicylate-hypochlorite spectrophotometric method.

Soil solution samples recovered from the suction lysimeters were assayed for NO_3^- using a NO_3^- electrode and for NH_4^+ using the salicylate-hypochlorite method. During the 1984 season, soil samples were taken from the N-P-K plots, NO_3 was extracted with water and NH_4^+ with 2M KCl and the extracts assayed for NO_3^- and NH_4^+. These analyses were used to corroborate the results obtained from lysimeter solution samples.

Plots were evaluated for turf quality and assigned a quality score (9 = excellent turf, 1 = dead turf or bare soil).

Principal Findings:

Nitrification inhibitors did not influence the concentration of free NO_3^- or NH_4^+ within the root zone of Kentucky bluegrass turf (Tables 1 and 2). Suction lysimeters did not prove reliable as a source of soil solution samples resulting in missing data from many plots. The NO_3^- and NH_4^+ extracted from soil samples taken from the root zone tended to confirm the results from lysimeter samples (Table 2). Nitrate was always more abundant than NH_4^+ on occasion exceeding 100 mg per liter of soil solution. These values may be somewhat exaggerated due to the effect of interfering anions on the NO_3^- electrode. This error is being reduced by adding silver salts to remove interfering anions and by comparing the analyses of selected samples with that obtained by using a Cd-Cu reduction column and assaying for nitrite.

Soil solution samples obtained from suction lysimeters did reveal the impac of fertilizer applications (Table 3). The fertilizer application of 17 October was reflected in higher NO_3^- and NH_4^+ concentrations in soil solutions taken on 22 and 27 October. The 48 g N/m^2 rate did not show a marked increase because those plots had received 4.8 g N/m^2 each month throughout the growing season. Again missing lysimeter samples makes critical comparisons between nitrapyrin treatments difficult. Although the differences were not significant, a trend toward lower NO_3^- and NH_4^+ in soil solutions sampled from plots receiving N-P-K rather than N alone was evident (Table 4).

Soil solutions sampled at a 60 cm depth, below the turf root zone, contained much less NO_3^- than samples taken in the root zone (Table 5). Neither fertilizer rate nor nitrapyrin application appeared to influence soil solution NO_3^- content within subsoil horizons. A trend toward higher values from the plots receiving the highest fertilizer rates is suggested. These data indicate that NO_3^- migration from heavily fertilized turf results in soil solutions exceeding 10 ppm only occasionally. These data are preliminary and many more samples must be analyzed before a clear pattern will be shown.

Nitrification inhibitors had no significant effect on clipping yields harvested from the experimental plots in 1983 (Table 6). A suggestion of slightly higher yields following inhibitor application can be seen except on those dates following a fertilizer application, 17 May and 31 October. This trend receives indirect support when the impact of fertilizer composition on clipping yields is considered (Table 7). On all dates except those following a fertilizer application, clipping yields were higher from plots receiving N-P-K than from plots receiving N alone. While this fertility effect was highly significant, it was offset temporarily by the application of nitrogen fertilizer. The similar response of the nitrification data to fertilizer additions is at least curious.

The effect of nitrapyrin on the nitrogen content of turfgrass leaf tissue was also inconclusive (Table 8). Only in late September, before the application of nitrapyrin and almost five months after the terrazole treatment, did the heavily fertilized inhibitor treated grass exhibit an elevated nitrogen content. Again, a trend is apparent in that almost every grass sample taken from an inhibitor treated plot contained more nitrogen than its companion sample from an untreated plot. This difference, however, was significant in only one case. Obviously a larger number of comparisons extending over a greater portion of the growing season are required to evaluate critically the impact of nitrification inhibitors on the nitrogen use efficiency of turfgrasses.

Conclusions and Continuing Investigations:

The application of nitrification inhibitors to established Kentucky bluegrass turf did little to delay the oxidation of fertilizer-NH_4^+ to NO_3^-. While suggestions of effect were noted, even leaf tissue analysis which is the most highly integrated data collected failed to show an unambiguous response. While the soil solution within the root zone of heavily fertilized grass contained over 100 mg NO_3^- per liter, this high solution concentration did not extend below the root zone. There NO_3^- levels rarely exceeded 10 mg/liter. No evidence was obtained which would indicate that nitrification inhibitors can reduce nitrogen leaching from a turfgrass sod. This might result from the apparent lack of significant downward migration of NO_3^- from sod.

These results and conclusions are preliminary. Much data remains to be analyzed and many tissue and soil solution samples have not been assayed. The apparent interference of unknown anions with the NO_3^- electrode and resulting exaggerated NO_3^- values must be resolved or an alternative method of analysis employed. The suction lysimeters while relatively inexpensive and easy to install proved to be unreliable. Under favorable conditions, only 75% of the 20-cm. lysimeters ever yielded solution samples. The 60-cm. lysimete tended to perform more dependably. An alternative porous plate lysimeter which can quantitatively capture all gravitational water within a 15-cm diameter soil column will be tested under turf conditions. This device will also provide soi solution samples which are suitable for assaying mobile nutrient content.

Incorporation of the nitrification inhibitors into the soil beneath an established turf sod is difficult. Washing the chemical into the soil with irrigation water may not be effective for a volatile material which can be adsorbed into surface organic residues. The more water soluble and less volatile dicyandiamide will be evaluated if a source of supply can be located.

The data collected in this investigation along with climatological records of precipitation and evaporation will be used to construct nitrogen budgets for the variously fertilized plots. From this, a quantitative estimate of nitrogen mobility and utilization by turfgrasses will be obtained.

Publications:

No publications have resulted from the first year of this investigation.

Table 1. Nitrapyrin effect on NO_3^- and NH_4^+ content of soil solution taken from the turf root zone.

Inhibitor treatment	29 Sept.		22 Oct.**		27 Oct.	
	NO_3^-	NH_4^+	NO_3^-	NH_4^+	NO_3^-	NH_4^+
			mg/liter			
Nitrapyrin*	19.8	0.09	52.9	0.56	97.2	0.60
Control	67.8	0.11	63.9	0.73	108.6	0.60

*Nitrapyrin applied 6 Oct. 1983.

**Fertilizer applied 17 Oct. 1983, all plots received nitrogen.

Table 2. Nitrapyrin effect on extractable NO_3^- and NH_4^+ from soil sampled to a depth of 20 cm.

Inhibitor treatment	11 June		19 June		26 June		2 July	
	NO_3^-	NH_4^+	NO_3^-	NH_4^+	NO_3^-	NH_4^+	NO_3^-	NH_4^-
				ug/g dry soil				
Nitrapyrin*	35.8	5.9	31.3	5.1	19.1	4.7	16.1	12.4
Control	39.1	5.4	32.0	5.4	18.3	4.1	14.2	11.5

*Nitrapyrin applied 6 June 1984 with 4.8 g Urea-N/m^2.

Table 3. Nitrapyrin and fertilizer effects on the NO_3^- and NH_4^+ content of soil solution taken from the turf root zone.

Fertilizer		Inhibitor treatment	29 Sept.		22 Oct.		27 Oct.	
Content	Rate		NO_3^-	NH_4^+	NO_3^-	NH_4^+	NO_3^-	NH_4^+
	g/m^2				mg/liter			
N	12**	+*	0.8 b[†]	0.06	0.5 b	0.6 d	-	-
		-	9.2 b	0.19	35.2 b	0.53 bcd	49.5 c	0.60 abc
	24	+	-	-	-	-	63.0 c	-
		-	7.3 b	0.07	37.0	0.74 abc	75.3 c	0.55 abc
	48	+	105.5 b	0.13	51.0 ab	-	178.0 ab	0.42 bc
		-	390.8 a	0.10	173.5 a	1.11 a	253.5 a	1.00 a
N-P-K	12-2-4	+	6.8 b	0.12	13.0 b	0.40 cd	10.8 c	0.15 c
		-	2.2 b	0.10	7.5 b	0.36 cd	14.2 c	0.20 c
	24-4-8	+	6.7 b	0.05	39.0 b	0.85 abc	104.9 bc	0.86 ab
		-	1.0 b	0.08	39.0 b	0.66 abc	77.8 c	0.54 abc
	48-8-16	+	51.0 b	0.14	125.8 ab	1.00 ab	231.2 a	1.00 a
		-	123.3 b	0.14	118.0 ab	1.00 ab	251.3 a	1.00 a

*Nitrapyrin applied 6 Oct. 1983.

**Fertilizer applied 17 Oct. 1983, all plots received N increment.

[†] Means in a column followed by the same letter are not different at the 0.05% confidence level according to Duncan's Multiple Range Test.

Table 4. Fertilizer composition effect on the NO_3^- and NH_4^+ content of soil solution taken from the turf root zone.

Fertilizer Content*	29 Sept.		22 Oct.		27 Oct.	
	NO_3^-	NH_4^+	NO_3^-	NH_4^+	NO_3^-	NH_4^+
			mg/liter			
N	73.0	0.11	73.1	0.74	119.2	0.65
N-P-K	29.4	0.09	49.4	0.64	97.5	0.58

*Fertilizer-N applied to all plots 17 Oct. 1983.

Table 5. Fertilizer rate and nitrapyrin effects on the NO_3^- content of soil solution below the turf root zone.

Fertilizer Rate	Inhibitor treatment	7 Jan. 84	4 July 84	4 Aug. 84
12-2-4	Nitrapyrin*	1.49	0.72	0.91
	Control	1.50	0.43	0.27
24-4-8	Nitrapyrin	2.15	0.46	0.45
	Control	2.14	2.00	0.41
48-8-16	Nitrapyrin	17.01	1.91	2.00
	Control	6.67	0.54	0.52

*Nitrapyrin applied 6 Oct. 1983 and 6 June 1984.

Table 6. Nitrification inhibitor effects on clipping yields of Kentucky bluegrass turf.

Inhibitor treatment	17 May	25 May	1 June	10 June
		g/m^2		
Terrazole*	14.5	24.0	14.8	10.2
Control	14.6	23.2	14.4	9.9
	23 Sept.	30 Sept.	31 Oct.	1 Dec.
Nitrapyrin*	12.0	5.2	5.3	4.6
Control	10.7	4.9	6.6	3.7

*Terrazole applied 2 May 1983, Nitrapyrin applied 6 Oct. 1983.

Table 7. Fertilizer composition effects on clipping yields of Kentucky bluegrass turf.

Fertilizer content	17 May	25 May	1 June	10 June
N	12.3 a*	20.3 b	12.6 b	8.8 b
N-P-K	16.8 a	27.0 a	16.6 a	11.3 a
	23 Sept.	30 Sept.	31 Oct.	1 Dec.
N	9.6 b	4.2 b	6.1 a	2.7 b
N-P-K	13.1 a	5.9 a	5.8 a	5.6 a

*Means in a column for each date followed by the same letter are not significant at the 0.05 confidence level according to Duncan's multiple range test.

Table 8. Nitrapyrin and fertilizer rate effects on the nitrogen content of Kentucky bluegrass leaf clippings.

Fertilizer rate	Nitrapyrin treatment	30 Sept. 83	31 Oct. 83	1 Dec. 83
12-2-4	+*	32.6 c**	36.0 ab	34.8 a
	-	32.1 c	33.8 b	31.0 a
24-4-8	+	40.7 ab	30.9 b	39.3 a
	-	36.9 bc	34.4 ab	36.0 a
48-8-16	+	44.9 a	46.0 a	37.6 a
	-	35.4 bc	39.8 ab	36.4 a

*Nitrapyrin applied 6 October 1983.

**Means in a column followed by the same letter are not significant at the 0.05 confidence level according to Duncan's multiple range test.

SYNOPSIS

Project No. 374204

Project Title: Source of Acid Precipitation and Its Effects on Water Quality

Investigators:
Calvin P.C. Poon, University of Rhode Island
Thomas Wright, Rhode Island Dept. of Environmental Management
Michael North, Rhode Island Dept. of Environmental Management

Project Objectives:

1. Correlating the amount of acid in precipitations to the direction of storms in 1983-1984. The result is useful to show if storms passing through the industrial mid-western states carry more acids than storms from other directions.
2. Determining the year around wate quality, including the buffering capacity, of three rural rivers. The head waters in rural areas are free of contaminants from urban areas. Consequently the effects of acid deposition due to long range transport from out of the state can be better demonstrated.
3. Quantifying the short term effect of acid deposition on the quality of headwaters of streams in the rural area. Short term effects can be drastic and may have a greater impact on water use.

Project Procedure:

Three streams were selected for the study, namely Wood, Beaver, and Usquepaug. The headwaters of these three rivers are in the rural area with class A high water quality, free from contaminants generated in urban areas.

Storm paths were identified using sequential meteorological maps including satellite photos, precipitation radar scans and pressure system maps (NMC surface analysis). Precipitations were collected. Samples were titrated for acidity determination. The acid components were quantified by using the Gran plot method.

River samples wre collected before, during, and after each storm event. Chemical analyses of the river samples showed the sequential changes of the water quality, reflecting the impact of storm acidity on these rivers as well as the time period of recovery.

PROJECT FINDINGS AND THEIR SIGNIFICANCE

1. Storms from the west-southwest direction coming to Rhode Island carry more acids than those from the south-southwest or north-northwest directions. This implies that storms originated from or passing through the industrial mid-western states would impact Rhode Island waters more than storms from southern states or from Canada.
2. Although a storm carrying more acidity has a bigger impact on river waters, a large storm, even containing less acidity, could impact the river water quality to the same degree or even more.
3. It was found in many storms that the alkalinity of the water in the three rural rivers studied was reduced to less than 1.0 mg/l. In one instance, the river water alkalinity was reduced to zero.
4. Some storms caused a drop of one-half pH unit and an increase of 11 folds of acidity in the river water within half a day period. The recovery however was gradual. A complete recovery could take longer than 5 days.
5. Other than the size of the strom and its acidity content, the amount of dry acid deposition accumulated in the watershed prior to the

storm would affect the water quality to a great degree. Consequently a storm at the end of a long dry period could impact the water quality significantly even though the storm may carry little acidity.

6. The impact of acid precipitation on river water quality could be influenced by the existing rate of flow of the river. A high existing flow could dilute the acidity and consequently minimize the impact.
7. The land use pattern could also affect the degree of impact on water quality by acid precipitation. Agricultural activities that use lime could mask the effect of acid precipitation as the chemical applied could neutralize the acidity.

Conclusions:

Although storms from the west-southwest direction in general carry more acidity, storms from other directions may impact river water quality in Rhode Island to the same degree or even more if they are large storms. The rivers in this study, similar to other Rhode Island Rivers, are very low in alkalinity. Acid deposition has significant impact on the water chemistry with the alkalinity at times reduced to less than 1.0 mg/l. The significant drop of alkalinity and reduction of pH by half a unit within half a day are drastic changes. The recovery period however can be 5 days or longer.

Presentation and Publication:

The findings of part of this study were presented at the Northeast State Acid Precipitation Symposium, March 27-28, 1984, Boston. A paper is being prepared for publication.

Project No. - 374205

Project Title - Evaluation of Combined Sewer Overflow Management
Strategies Through Pipe Network Simulation

Principal Investigator: Raymond M. Wright
Civil and Environmental Engineering
University of Rhode Island

SYNOPSIS

Purpose and Objective

Combined sewer overflows (CSOs) severely degrade surface water quality in Rhode Island. The abatement options being considered suggest two or three satellite facilities providing the equivalent of primary treatment with disinfection. In response to the need for more detailed investigation and the development of a system-wide strategy a 502 acre section in the southeast corner of the collection system was selected for study and application of a non-conventional modeling approach.

This study evaluates reduction of the frequency and volume of overflow events through optimizing the use of available local interceptor capacity. Intercepted flow would be conducted to the site of a regional facility downstream of the study area. Analysis of the transport system beyond the boundaries of the study site are not included in this study. The concomitant reduction in pollution loads to the local receiving waters from these modifications are determined. The goal is to achieve maximum wastewater transport with a minimum of structural modification.

Through field investigations CSO hydraulics and water quality characteristics were detemined. Data were developed to calibrate and verify the Stormwater Management Model (SWMM). SWMM was used in conjunction with a non-conventional, quasi-continuous modeling framework. This approach combined the detail of storm event simulation with long term continuous prediction for evaluation of CSO abatement scenarios. This modeling framework was suggested as an alternative to continuous simulation by SWMM but has not been evaluated. It was an objective of this study to attempt verification. Following the validation procedure the quasi-continuous approach was to be applied for ranking of the CSO abatement scenarios by comparison of predicted reduction in pollutant loads.

Methods and Procedures

Field investigations were initiated to obtain quantity measurements and flow proportional quality samples. Rainfall data were continually recorded on-site. Data were developed for calibration and verification of SWMM.

The quasi-continuous framework was based on selected reference storms. From historical precipitation records individual storms based on a five hour dry interval between events were characterized by peak rainfall intensity and total rainfall. Nominal frequency curves were developed and five target frequencies were selected to provide a representative distribution along the curve. The average duration of an event from the record was used with peak rainfall intensity and total rainfall to select the reference rainfall events from the historical record. The reference storms were used as input to the model. The results were used to develop pollutant load response curves. These curves were generated using both peak rainfall intensity and total rainfall volume.

To determine if quasi-continuous simulation was a valid means of predicting annual loading a direct comparison was made to conventional continuous SWMM. SWMM was run in the continuous mode for a dry, wet and average precipitation year. Quasi-continuous simulation was completed using the reference storms and appropriate antecedant dry periods for each year. Annual loadings at the subcatchment inlets were compared for both techniques and for both peak rainfall intensity and total rainfall.

Application of the quasi-continuous method to the study system was performed for three abatement options and the baseline condition. The options are: (1) system as it currently exists; (2) relocation of slots, thereby, optimizing the use of current slot capacities; (3) increased slot capacity to approximately 80 percent of available local interceptor capacity; (4) increased slot capacity to 100 percent of available local interceptor capacity. Options 2, 3 and 4 require structural modification to relocate and modify the current slot arrangement. In keeping with the objective of minimum structural modification, no alterations to the local interceptors is proposed.

Principal Findings and Their Significance

Calibration of quantity routines for one CSO was accomplished by final adjustment of the subcatchment width. The model was validated using three independent and dissimilar storms. The average absolute difference of measured and predicted volumes and peak overflows was 7.1 percent and 7.9 percent, respectively. The technique used to develop model coefficients for the single CSO were employed to determine coefficients for the 4 remaining CSO's in the system.

Quality calibration criteria required ratio of the sum of predicted (P) and measured (M) pollutant loadings equal to 1.0. This was achieved by adjustement of the fraction of dust and dirt associated with a particular pollutant. Quality routines were considered calibrated when a

P/M ratio of 0.98 was reached. As with quantity simulation the techniques used to develop quality coefficients for the single CSO were employed in the other CSO's.

Reference storm selection was based on peak rainfall intensity, total rainfall and effective rainfall duration. Nominal frequency curves were generated for both peak rainfall intensity and total rainfall and five frequencies were selected ranging from 22/year to 1/10 year.

The results of the comparison between the two modeling techniques indicate the quasi-continuous modeling framework is a valid alternative to the more costly conventional continuous simulation, especially for years of average precipitation. Also, peak rainfall intensity provides a better validation than total rainfall. Percent differences in the predicted loadings for the two techniques using peak rainfall intensity were below 3.5 percent for the three water quality parameters evaluated.

Each abatement option was simulated with the verified SWMM program under average rainfall conditions. Pollutant load response curves for peak rainfall intensity were generated for each water quality parameter. The loadings were forcasted by the quasi-continuous modeling approach. Option 2 provides reductions approaching primary treatment levels. Options 3 and 4 exceed primary treatment levels with option 4 approaching reduction equivalent to secondary treatment. The rank of the options according to load reduction is 4, 3 and 2.

Conclusions

The conclusions based on this study include:

1. Quantity Simulation by SWMM for CSO 053 was successfully calibrated and verified. The average percent difference of the 4 storms used for calibration and verification was 7.9 for peak overflow and 7.1 for total overflow volume.
2. The quasi-continuous simulation, which combines event simulation with historical rainfall records, is a viable alternative to conventional continuous simulation.
3. Peak rainfall intensity provides a more accurate verification of quasi-continuous than total rainfall, and as a result it should be used when developing load response curves.
4. Optimization of the collection system through the modification and relocation of slot structures provides local annual pollutant reductions to the Woonasquatucket River that approach secondary treatment levels.

Statement of Cooperation

The authors would like to acknowledge the Narragansett Bay Water Quality District Commission for Supplying a National Weather Service rainfall data tape and allowing access to the collection system. The city of Providence Department of Public Works for aiding in the location of pertinent historical records. Finally, the Postal Service for allowing the placement of a rain gage on the roof of the Olneyville branch post office.

Publication

Mulhare, M.J., and Wright, R.M., "Evaluation of CSO Abatement Strategies Through a Quasi-Continuous Simulation," Proceedings 1984 International Symposium on Urban Hydrology, Hydraulics and Sediment Control, University of Kentucky, UKY BU135, July, 1984, pp. 223-228.

SYNOPSIS

PROJECT NUMBER: 374206

PROJECT TITLE: The Role of Nitrification in Contributing to Low Oxygen Conditions in an Urban Waterway

INVESTIGATORS: Scott W. Nixon and Veronica M. Berounsky
Graduate School of Oceanography
University of Rhode Island
Kingston,RI 02881

PURPOSE AND OBJECTIVES OF THE PROJECT

Urban rivers usually have high inputs of organic matter, nutrients and bacteria which combine to exert a demand on the oxygen content of the river. As a result, the development of anoxic or near anoxic conditions has become a major environmental problem of urban waterways. Fish, bivalves, and other aquatic organisms require oxygen to live. When little or no oxygen is available, these organisms may die or stop reproducing, resulting in an absence of fish or macrofauna or at least a decrease in species diversity.

The Providence River is fed by six other rivers which drain a densely populated residential and industrial watershed. The river itself flows through Providence, R.I., a city of 157,000 people and many varied industries. Along its passage the river collects the outflow from three of the state's largest sewage treatment facilities and 65 combined storm-sewer overflows. The tributaries of the Providence River annually discharge approximately 1190 x 10^6 m^3 of water into the Providence River, water that has flowed through numerous cities, accumulating residential and industrial runoff, treated sewage effluent and raw sewage discharges.

Previous studies have documented that the Providence River receives high levels of nutrients and other pollutants (MERL 1980; Nixon 1981). Past studies and ongoing projects have shown that low oxygen levels (1-4 mg O_2/l) and even periods of anoxia do occur in the Providence River. The benthos of the river supports only a limited number of opportunistic species. Whole schools of fish, particularly menhaden, die every year in the upper river. The state's Department of Environmental Management sets water quality criteria based on dissolved oxygen levels; much of the upper river has oxygen values of 1-3 mg O_2/l and is classified as suitable only for navigation or industry.

In areas where the ammonia inputs are high, such as the Providence River with over 1200 mmol NH_4^+ m^{-3} yr^{-1} (Nixon 1981), low oxygen areas may be attributable, in part, to nitrification. During nitrification, bacteria oxidize ammonia to nitrite and then to nitrate. As noted by Thomann (1972), "nitrification is an important phenomenon in water quality management because of the significant amount of oxygen that may be utilized during the oxidation of ammonia nitrogen and nitrite nitrogen." By measuring the nitrification rate within the Providence River, we can determine to what extent this process is depleting the oxygen supply of the river. Because of the large ammonia loadings from sewage and rivers, it is possible that enough nitrification is occurring to exert a large oxygen demand and make a significant contribution to the low conditions of the river. We have calculated that the maximum potential annual oxygen requirement for the oxidation of the ammonia loadings to the Providence River is over 600 x 10^6 moles of oxygen. This is comparable to about 70% of the presently measured biological oxygen demand of incoming waters. Although nitrification may significantly affect the oxygen budget of the Providence River, the rate of this process has never actually been measured.

The purpose of this project was to obtain the first measurements of nitrification in the waters of the Providence River at various times over an annual cycle and to develop a quantitative assessment of the importance of oxygen uptake during nitrate formation for the oxygen budget of the river. The results of such measurements are important because they will be the first nitrification measurements in the Providence River, and some of the first actual measurements of nitrification in any river or estuary.

Once the importance of nitrification has been established, several options may be suggested to lessen or eliminate this drain on the dissolved oxygen levels. Possible solutions include setting ammonia limits for sewage effluent (Yake and James 1983) which may be achieved by incorporating nitrification facilities (Bailey et al. 1983) or by increasing the activitated sludge retention time within the sewage treatment plants (Mechalas et al. 1970) so that less ammonia enters the river.

BRIEF EXPLANATION OF METHODS AND PROCEDURES

Rates of nitrification in the Providence River were directly measured by use of the stable isotope, ^{15}N. By measuring the incorporation of the isotope into initially unlabelled nitrogen species, we have been able to quantify the conversion of NH_4^+ to NO_2^- and NO_3^-. In addition, rates of uptake of NH_4^+ and NO_3^- by phytoplankton were also measured.

For each experiment, a mixed-depth (surface, 3m, 9m and 13m) river water sample was obtained by pump from the Gulf Oil Dock in East Providence, RI. Water samples were taken in the dark in September 1983, January 1984 and May 1984. At the laboratory, the river water was siphoned into ~ 2.75 liter incubation bottles that were either clear, covered with screening to allow ~10% light through or opaque. Half the bottles were innoculated with $^{15}NH_4^+$, half with $^{15}NO_3^-$ and incubated for 3-12 hours in an outdoor flowing-water tank. After each incubation was terminated, subsamples of river water were filtered and frozen for later analysis of particulate nitrogen, ammonium, nitrite and nitrate.

From each subsample, a species of nitrogen was isolated, then converted to nitrogen gas, the form of nitrogen which can be analyzed via the mass spectrometer. Nitrite was separated by conversion of the nitrogen to an azo dye complex (Schell, 1978; McCarthy et al, 1984). The method used is detailed in the completion report. Nitrate was reduced to nitrite by passage through a cadmium column, then the nitrite was isolated as before. Ammonium was isolated by direct distillation, using the method of Glibert et al (1982). Particulate nitrogen was analyzed from the glass fiber filters through which the river sample had been filtered. The separate nitrogen components were then converted to N_2 gas by a Dumas combustion procedure (Fiedler and Proksch, 1975).

The gaseous sample was run in a dual beam mode on a Micromass 602-D mass spectrometer located at the Graduate School of Oceanography at the University of Rhode Island. Isotope measurements were expressed as "atom% ^{15}N" (by convention of nitrogen stable isotope work) which is the percent of nitrogen (^{14}N plus ^{15}N) in a sample that is labelled with ^{15}N (Bremner, 1965).

The rate of nitrification (or phytoplankton uptake) is calculated as (Sheppard, 1962):

$$\rho_{21} = \frac{S\,(a_{F2} - a_{I2})}{(t_F - t_I)\,a_1}$$

where: 1 = the initially labelled (source) pool of nitrogen
2 = the receiving pool of nitrogen
S = concentration of a nitrogen species in the sample
a = atom% ^{15}N of the sample
t = incubation time

(More details are provided in the completion report.)

PRINCIPAL FINDINGS AND THEIR SIGNIFICANCE

The incorporation of tracer material was detected in the originally unlabelled products of nitrification, NO_2^- and NO_3^- thus documenting that nitrification is occurring in the Providence River. However, the rates calculated (Table 3) were lower than expected from estimates of NH_4^+ input to the river or from the MERL study conducted in conjunction with this study or from studies by other investigators (McCarthy et al. 1984).

From the graph of NH_4^+ concentration vs NO_{2+3}^- production in the MERL tanks (Figure 12), expected net nitrification rates were about 0.4 - 0.5 µmol liter^{-1} d^{-1} for the fall (18 uM = ambient NH_4^+) and rates of about 0.5 to 0.6 for the winter (22 uM = ambient NH_4^+). McCarthy and colleagues (1984) found rates of NH_4^+ oxidized to NO_2^- to be generally between 0 and 12 µmol liter^{-1} d^{-1} during a destratification event at the mouth of the York River and rates of NH_4^+ oxidized to NO_3^- to be between 0 and 20 umol liter^{-1} d^{-1} in Chesapeake Bay.

In this study, the fall maximum net nitrification rate was 0.020 umol liter^{-1} d^{-1} while the winter had slightly higher rates and a maximum of 0.040 µmol liter^{-1} d^{-1}. (Spring samples were taken but have not been analyzed yet.) There were occasions of a net loss of NO_{2+3}^- in both fall and winter. In a few cases the atom % ^{15}N was not significantly different between the initial bottle and a final bottle, causing deceptive rates, but there was always a significant increase between the two shade or the two dark bottles, so a positive rate could be obtained between the short and the long incubations.

This slow initial increase in NO_{2+3}^- suggests that the nitrifiers exhibited a lag period. If this is in response to the water being pumped from depth and handled, more time should be allowed for the sample to acclimate before the experiment is started. A laboratory study of nitrifying bacteria isolated from sea-surface films did find a lag period in cultures of ammonia oxidizers (Horrigan et al. 1981). Another possibility is that the nitrification rate is not constant but increases over time. A time-series experiment with incubations ranging from 1 hour to 12 hours was done, but the samples have not yet been analyzed.

There were no apparent differences in rates between partial light and no light incubations. This was unexpected since several studies found nitrifiers to be light inhibited (Olsen 1981; Horrigan et al. 1981). However, one study (McCarthy et al. 1984) noted that nitrification did not seem to follow a diel cycle.

From analysis of the particulate nitrogen fraction, rates of phytoplankton uptake of NH_4^+ or NO_3^- were measured. Rates of NH_4^+ uptake (Table 4) were of approximately the same magnitude as those found in previous studies in similar waters (Furnas 1984); McCarthy et al. 1984). The effect of light was evident in the fall and spring; shaded and clear bottles had much higher rates than the dark bottles. Uptake rates of NH_4^+ exhibited the expected seasonal trend: highest in the spring (probably due to the usual phytoplankton bloom), next highest in the fall (a smaller fall phytoplankton bloom is usually found in Narragansett Bay) and all winter rates were low and similar (regardless of light level). The spring concentrations of particulate organic nitrogen per sample were about twice as high as those found during the fall or winter, demonstrating the strong relationship between phytoplankton blooms and high spring rates of NH_4^+ uptake.

The small measurements of NO_3^- uptake (Table 5) found in this study support the conclusion drawn in other studies: when NH_4^+ levels are high, there is very little or no uptake of NO_3^- (MacIsaac et al. 1979; Furnas 1983; McCarthy et al. 1977; Pennock 1983; Maestrini et al. 1982). Rates measured were about two orders of magnitude lower than those for NH_4^+ uptake, with no net uptake of NO_3^- in the winter. Spring rates of NO_3^- uptake were highest, possibly due to the large phytoplankton bloom causing utilization of both NH_4^+ and NO_3^-.

In order to understand nitrification rates better, inorganic nitrogen uptake rates must also be measured (or known) because the various rates are related. Fall rates of net nitrification are slower than rates of NO_{2+3}^- uptake, suggesting that the NO_3^- produced by gross nitrification is (comparatively) quickly taken up by the phytoplankton, causing the nitrification rate to appear lower. Evidence for this theory is the relatively low concentrations of NO_{2+3}^- in the water during the fall experiment ($\sim$5 µM). In the winter, there is no NO_3^- uptake; net nitrification is more similar to gross nitrification, as seen by the higher rates and the products of nitrification are allowed to accumulate, as seen by the higher ambient levels of NO_{2+3}^- ($\sim$28 uM). Also, as stated previously, high ambient NH_4^+ levels result in low rates of NO_{2+3}^- uptake suggesting that high NH_4^+ concentrations should be directly related to high nitrification rates. Such a relationship was found in the concurrent study of nitrification in the MERL tanks (see Appendix I).

Rates of nitrate reduction (plus nitrate uptake) were calculated from the nitrate-spiked bottles for the fall and winter (Table 6). Rates were erratic and the NH_4^+ and NO_2^- analyses on the samples (not yet completed) are needed in order to substantiate them.

An objective of this project was to examine the affect of nitrification on the oxygen levels of the Providence River. The process of nitrification requires 4 moles of oxygen for each mole of NH_4^+ that is oxidized to NO_3^- (see Equation 1). Using the maximum rate that was measured, 0.04 µmol $liter^{-1}$ d^{-1}, and accounting for the volume of the river (1.3×10^8 m^3), about 8×10^6 mole of oxygen could be utilized annually be net nitrification:

$$0.04\ \mu mol\ liter^{-1}\ d^{-1} \cdot (4\ oxygen/\ 1\ NH_4^+) \cdot (365\ d/yr)$$
$$(1\ mole/10^6\ \mu mol) \cdot (1000\ liter/m^3) \cdot (1.3 \times 10^8\ m^3)$$
$$= 7.6 \times 10^6\ mol\ oxygen/yr.$$

In order to put this number in perspective, the carbonaceous biological oxygen demand of the Providence River was determined to be about 918×10^6 mol oxygen/yr (Governor's Task Force 1980). Thus, if the maximum net nitrification rate yet measured in the Providence River were maintained for an annual cycle, it appears that the O_2 consumption of this process would be ~ 1% of the total demand of the river. Thus it appears that nitrification within the Providence River, particularly near Field's Point, is probably not consuming much oxygen and there may be no need to change sewage treatment plant management strategies in order to remove NH_4^+ from the effluent.

Since the nitrification rates measured in the Providence River were lower than expected, five possible circumstances are suggested and are presented below. The first is a problem discussed previously, the possibility of an initial lag or slow period of nitrification. If measurements were made during this period, they would appear low. This problem can be verified by a time-series experiment, such an experiment has been run, but results are not available yet. A second possibility is that recovery from photoinhibition is incomplete, causing the bacteria in the euphotic zone of the river to be very inactive at all times. The mixed depth water samples used in this study may be combining active deep water nitrifiers with non-active surface bacteria. This possibility could be examined by measuring separately the rates for different water depths. A third possibility is that the oxygen levels are too low to allow the bacteria to nitrify. This was not likely a problem since experiments have shown that the oxidation of nitrite to nitrate is inhibited at oxygen concentrations below 3 mg O_2/l and the oxidation of ammonia to nitrite is inhibited below 1 mg O_2/l (Helder and DeVries 1983). Other studies have shown that a nitrite bacterium (Nitrosomonas sp.) is active at oxygen levels from saturation to 1 mg O_2/l and to 2 mg O_2/l for a nitrate bacterium (Nitrobacter sp.) (Rheinheimer 1980). Though such low levels occur in the Providence River, during these experiments neither the sample water obtained nor the incubated samples ever had oxygen values below 4 mg O_2 liter^{-1} (Fall $\geqq$ 5 mg O_2 liter^{-1}, Winter $\geqq$ 11, Spring $\geqq$ 8). The fourth possibility is that the concentration of the nitrifier population is low compared to similar systems. Bacterial counts of nitrifiers have not been done on Providence River water samples, but this could be remedied by either direct counts or an immunofluorescent assay (Ward 1982). A decline in the nitrifier population occurred concurrently with a zone of nitrification inhibition in the Delaware River near Philadelphia and it was noted that the environment near the Philadelphia N.E. Sewage Treatment Plant Facility was not conducive to rapid growth of nitrifying bacteria (Tiedman et al. 1981). A study of nitrification in the Passaic River (NJ) also found areas of lower nitrifier population densities than expected which was attributed to the settling out of cells from the water column (Finstein et al. 1977). If nitrifier counts are low, this may be due to the fifth possibility.

The last possibility, and a probable one, is that something in the water is inhibiting nitrification. Sewage and runoff flows contain more than nutrients. Various components known to be discharged into the Providence River--metals, oil, chlorine, dissolved organic matter and other unidentified substances--may inhibit nitrification through either chemical reactions or physical complexing. Such inhibitions would not be seen in the MERL study, where only nutrients were added. An experiment that may address this problem has been run, an ^{15}N experiment similar to that run in the Providence river but using nutrient-enriched water from the MERL tanks. Results are not yet available. When the MERL samples are analyzed we may better understand why nitrification rates are low in the Providence River.

But another question remains. There are high levels of NO_3^- (and at times NO_2^-) in the Providence River. If these nutrients are not produced by nitrification in the river, where are they coming from? The most logical possibility is that NO_2^- and NO_3^- are flowing into the Providence River from its tributaries and the runoff they receive. This possibility could be examined by undertaking a transect study in which nitrification experiments would be run on water from the Blackstone and Seekonk Rivers and compared with the rates found in the present study.

CONCLUSIONS

1. By use of ^{15}N stable isotopes the process of nitrification was found to occur in the Providence River (RI) during the fall and winter. Maximum measured rates were 0.020 umol liter^{-1} d^{-1} in September 1983 and 0.040 umol liter^{-1} d^{-1} in January 1984 and most rates were of this same order of magnitude. Winter rates were slightly higher than fall rates. There were no apparent differences in rates between partial light and no light incubations.

2. These preliminary rates were at least an order of magnitude lower than expected from comparisons with previous studies. The reason for the low rate is presently unknown, but possibilities include (1) the incubations included a lag period of little or low nitrification activity, (2) light inhibition of upper water nitrifiers masks the activity of deep water nitrifiers, (3) the concentration of nitrifying bacteria in the river is low, and (4) a substance in the river water inhibits or masks nitrification.

3. The preliminary data indicate that nitrification is probably not exerting a large oxygen demand on the system. The annual nitrogenous oxygen demand appears comparable to about 1% of the annual carbonaceous oxygen demand of the river. This suggests that a nitrification facility at the Field's Point Sewage Treatment Plant may not be needed.

4. Methods for measuring nitrification rates with ^{15}N are not yet well-defined. This report presents a discussion and examination of present methods and calculations.

5. During all three experiments, uptake of NH_4^+ (ambient concentrations = 18-39 uM) was much higher than uptake of NO_3^- (ambient concentrations = 4-28 uM). Uptake of NO_3^- was minimal in spring and fall and non-existent in winter. These results agree with studies by other investigators.

6. Phytoplankton uptake rates exhibited a seasonal trend; spring rates were higher than fall rates and winter rates were lowest, stressing the relationship between uptake and phytoplankton blooms. The effect of light was evident, there was more uptake in the full and partial sunlight incubated bottles than in the dark bottles.

7. A concurrent study of nitrification in four Narragansett Bay mesocosms during a nutrient-enrichment experiment found significant rates of nitrification when NH_4^+ concentrations were similar to those found in the Providence River. Rates of net NO_2^- production were 10 to 1000 times higher than those found in open ocean systems, indicating the imortance of nitrification to estuarine and riverine systems. The main difference between the mesocosms and the Providence River experiments is that the mesocosms were enriched only with inorganic nutrients, suggesting that another substance in the river inhibits nitrification.

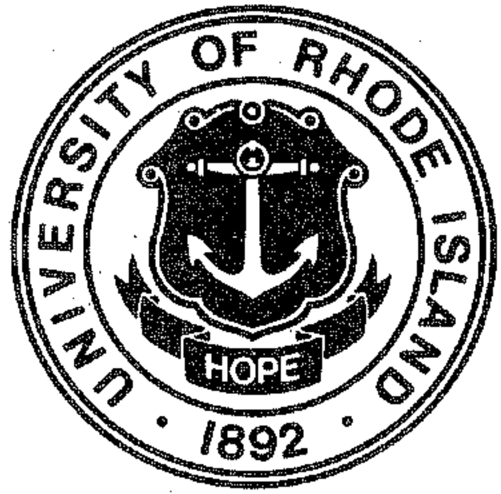
8. Because it does not appear that much NO_2^- and NO_3^- are being produced in the Providence River by nitrification, these nutrients are probably flowing in from the tributaries. Measurements of nitrification rates in the Blackstone and Seekonk Rivers are needed to examine this possibility.

PUBLICATIONS PRODUCED FROM THIS PROJECT

Berounsky, V.M. and S.W.Nixon, in press, Eutrophication and the rate of net nitrification in a coastal marine ecosystem. Estuarine, Coastal and Shelf Science.

RHODE ISLAND
WATER RESOURCES CENTER

EIGHTEENTH ANNUAL REPORT



DANIEL W. URISH DIRECTOR

JANUARY 1983

WATER RESOURCES CENTER

UNIVERSITY OF RHODE ISLAND
KINGSTON, R.I.

ANNUAL PROGRAM REPORT
FISCAL YEAR 1982
(Annual Report Number 18)

DANIEL W. URISH DIRECTOR

JANUARY 1983

The work upon which this report is based was supported in part by funds provided by the Office of Water Research and Technology, U.S. Department of the Interior, Washington, D.C., as authorized by the Water Research and Development Act of 1978. (P.L. 95-467).

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RHODE ISLAND
WATER RESOURCES CENTER
University of Rhode Island

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Bruno M. Vittimberga	Professor of Chemistry
William R. Wright	Associate Professor of Plant and Soil Science

RHODE ISLAND WATER RESOURCES CENTER

DIRECTOR'S STATEMENT

Fiscal Year 1982

Current Situation

The past year has again been one of uncertainty for the Center. Because of an initial lack of funding to continue Center operations through Fiscal Year 1982, the administrative assistant was terminated as of September 30, 1981. This left only the director to run all Center operations until June 1982 when a half time secretary was hired. Funds permiting it is envisioned that the Center will continue minimum operations into FY'1983 with a half time secretary and a one third time director. This will enable continuing project program closeout and minimum administrative operations.

Current and Anticipated State Water Problems

The States major water problems are outlined in the Center's Five Year Research Plan.

Hazardous waste ground water problems remain a critical state concern. The extent of the problems and necessary actions to alleviate or correct present adverse conditions are still unknown. Of particular interest from a research point of view is the possible movement of contaminants through deeper rock strata, an area relatively unexplored at this point.

The effect of individual sewage disposal systems on surface and ground water quality continues to be an important issue, particularly in the coastal areas of Rhode Island. The Coastal Resources Center and the Sea Grant Program have completed a three year coastal pond study which underscores the adverse environmental effect of urban development in coastal areas and concludes that strict land use controls are necessary.

Major water quality problems exist in the upper Narragansett Bay due to extensive urban and industrial pollution. In addition to municipal sewage and storm runoff systems that discharge directly into the Bay, major sources of pollutants appear to be the several rivers that enter after passing through heavily developed regions. Much research and engineering effort must be done to both define and correct the problem.

Current Research

Three projects (A-074-RI, A-075-RI, and A-076-RI) continued into FY'1982 as a part of the Cooperative Program. Project A-074-RI addresses a particularly difficult problem associated with heavy metal contamination in the bottom sediment of upper Narragansett Bay. Project A-075-RI assesses the effectiveness of phosphorus adsorption in the sandy subsoil in Rhode Island and will lead directly to a better estimate of the pollution potential of individual sewage disposal systems. Project A-076-RI address the problem of finding an effective process for removal of chloroform from water with promising results suggested from an ultraviolet-ozone process.

In addition to the three continuing projects, two new projects were initiated for Fiscal Year 1982. The new projects, being supported from Annual Cooperative Program funds are:

1. Research Project A-077-RI by Professors Stanley Barnett and Frank J. DeLuise will look at the practicality of applying a flotation process to jewelry wastes. This process is also being considered both

for manganese removal from industrial user waste water and for municipal water supplies.

2. Research Project A-078-RI with Professor William R. Wright as the principal investigator is directed at determining the fate of heavy metals and nitrogen, derived from toxic sludge landfill leachate, when it is applied to land via irrigation. Data from this study would demonstrate the "living filter" concept for managing leachate from toxic sludge disposal sites.

Cooperation with State and Regional Agencies

The Water Resources Center continues to work closely with the Rhode Island Water Resources Board and the U.S. Geological Survey. To this end several reports were initiated in FY'1982 to provide information to these agencies and other interested parties.

1. An overview of the current status of hazardous waste management in New England.
2. A user's manual for the operation of a modified version of the Pinder-Trescott Groundwater model allowing for continuous aquifer simulation.
3. A survey of procedures for investigating the flow of pollutants through bedrock.

In addition the initiative has been made to work with the Narragansett Bay Water Quality Commission in their efforts to solve the major pollution problems associated with the Upper Narragansett Bay. There is a particular need for river and open channel water quality modeling.

RHODE ISLAND WATER RESOURCES CENTER

INDIVIDUAL PROJECT ANNUAL REPORTS

FISCAL YEAR 1982

A-074-RI	The Recovery and Transport of Heavy Metals by <u>Spartina Aterniflora</u> from Dredging Spoils	Hull
A-075-RI	Phosphate Movement in Laboratory Soil Columns and On-Site Sewage Disposal Systems	Wright and Kelly
A-076-RI	UV-Ozone Process for the Concurrent Decomposition of Halogenated Alkenes and the Disinfection of Water	Poon and Vittimberga
A-077-RI	Scale Up Study of Flotation for Metal Removal and Recovery from Industrial Plating Wastes and Drinking Water Supplies	Barnett and Deluise
A-078-RI	Land Application of Toxic Sludge Landfill Leachate	Wright

Form OW-1
(Rev. 10/80)

ANNUAL REPORT -- ANNUAL COOPERATIVE PROGRAM OR MATCHING FUND PROGRAM PROJECT

OWRT PROJECT NO. A-074-RI

AGREEMENT NO. 14-34-0001- 1142

FCCSET RESEARCH CATEGORY: II LVB or VG

PROJECT TITLE:
The Recovery and Transport of Heavy Metals by *Spartina Alterniflora* from Dredging Soils

NAME AND LOCATION OF UNIVERSITY WHERE PROJECT IS BEING CARRIED OUT:

University of Rhode Island
Kingston, RI 02881

PROJECT BEGAN -- MONTH: 10 ; YEAR: 80

TO BE COMPLETED -- MONTH: 9 ; YEAR: 82

PRINCIPAL INVESTIGATORS	DEGREE	DISCIPLINE
Richard J. Hull	Ph.D.	Plant & Soil Science

STUDENT ASSISTANTS[1]	DEGREE HELD (IF ANY)	DISCIPLINE OR ACADEMIC BACKGROUND
Jodi Shann	M.S.	Plant & Soil Science

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[1] LIST ONLY THOSE STUDENTS SERVING AS RESEARCH ASSISTANTS IN A PROFESSIONAL SENSE. DO NOT INCLUDE HOURLY WAGE EARNERS SUCH AS LAB DISWASHERS HERE BUT INCLUDE THEM IN FORMS OW-2, 3, AND 5. INCLUDE POST-DOCTURAL STUDENTS IF NOT SERVING AS PROFESSIONAL INVESTIGATORS.

NARRATIVE STATEMENTS

(REFER TO THE ATTACHMENT TO THIS FORM OW-1)

OWRT PROJECT NO. A-074-RI

Recovery and Transport of Heavy Metals by *Spartina alterniflora* from Dredging Spoils

Richard J. Hull

Plant and Soil Science

The transport of heavy metals and other toxic substances from marsh sediments to estuarine waters by grasses growing on tidal salt marshes is of concern. The environmental soundness of disposing of contaminated dredging spoil by building tidal marshes near the dredging site depends upon the extent of this biological transport. This research studied the absorption and translocation of heavy metals, Cd and Zn, by the dominant tidal marsh grass *Spartina alterniflora* under field and greenhouse conditions.

PROJECT ACCOMPLISHMENTS

Plant Sediment Interactions

Marshgrass plants and sediments were collected from ten sites in upper Narragansett Bay during the summers of 1980 and 1981. Both plants and sediments were assayed for Cd and Zn and the plant content of Cu, Ni, and Pb was also determined (Tables 1 and 2). Significant variation in metal content was noted between the ten sites. Sediments from the Pawtuxet Cove region (Sites 1, 2 & 7) and Seekonk River at Blackstone Park (Site 6) contained high levels of both Cd and Zn. Plants from these sites also generally exhibited higher metal content (Table 2), however, the correlation between sediment metal content and that recovered in the shoots of plants was often not significant. Zinc normally provided a good correlation between sediment and plant content ($r^2 = 0.91$) while Cd in shoots was best correlated with sediment Zn content ($r^2 = 0.71$). Stepwise regression analyses indicated that metal content in Spartina shoots could best be predicted from sediment analyses when several metals were considered together. This was especially true when Cd, Cu, Ni, and Zn were determined in both sediments and plants and these values subjected to a regression analysis. Cadmium, Cu, and Ni in leaf tissue was best correlated with the extractable sediment content of other metals. This complex interaction involved in metal absorption and transport by Spartina needs further study but our data indicate that predictive models of plant metal content can be developed if most available sediment metals are assayed and sediment physical properties are included in the model.

Absorption and Translocation

Using the radioisotopes cadmium-115m and zinc-65, metal absorption rates and distribution patterns were observed in S. alterniflora using methods of solution depletion and gross radioautography. Root uptake rates measured on the basis of solution depletion or increase in plant content over time did not always provide comparable values (Table 3). Cadmium uptake values did not differ dramatically but Zn absorption was very much less when measured on the basis of Zn recovered in the plant. Adsorption on the surface of culture vessels and excretion from the leaves via salt glands may have contributed to metal loss in these experiments. Based on increases in plant content Cd and Zn absorption by roots averaged 6.1 and 277 μg per gram of plant mass per day respectively. The inclusion of 15 ppt NaCl in the nutrient solution decreased Cd and Zn absorption to 3.3 and 150 μg per gram per day respectively.

Radioautographic analysis indicated that both Cd and Zn were mobile in the xylem and phloem. When the metal was applied in the nutrient solution bathing the roots for five days, less than 25% of the Cd and 45% of the Zn was recovered in the shoots (Table 4). The inclusion of 15 ppt NaCl had no effect on the xylem transport of Cd but the shoot Zn content was reduced to

37% of that recovered in the plants. Application of radioactive metals to the surface of a fully expanded leaf resulted after five days in over 35% of the plant Cd and approximately 15% of the plant Zn were recovered in the roots. The inclusion of 15 ppt NaCl in the nutrient solution had little effect on the basipetal translocation of Cd but Zn movement to roots was almost doubled in the presence of salt.

The presence of salt glands in the leaves of S. alterniflora resulted in salt accumulation on the surface of leaves during these experiments. This salt was washed from the leaves prior to radioautography or radioassay but an analysis of leaf washes revealed the presence of metals. Cadmium release via salt glands was stimulated by the presence of NaCl in the nutrient solution when the metal was introduced to the plant via roots or leaves. Zinc was discharged to the leaf surface independent of NaCl being present in the nutrient solution. The variability in these observations was considerable and it was not possible to estimate the rates of metal excretion onto leaf surfaces. The possibility exists that the low metal content of shoots compared to that of roots (Table 2) may result from the loss of metals via leaf excretion and removal by tidal flood waters or by rain.

WORK REMAINING

The seasonal variation in the correlation between sediment metal content and that of Spartina shoots remains to be determined. Samples were collected from five sites during the summer of 1981. These collections will continue into the autumn and the data will be analyzed during the winter. Detailed root absorption studies investigating the interaction of divalent metals on the uptake process is badly needed. The role of metal excretion by leaf salt glands in maintaining lower metal concentrations in shoots should be quantified and related to metal flux in the estuary. The impact of metal interaction and salinity on the shoot excretion process needs further clarification. With this information, a predictive model of heavy metal content in grass plants growing on contaminated dredged materials can be constructed based upon sediment analyses.

PUBLICATIONS

1. Shann, Jodi R. 1981. The Use of Dredge Spoil in Salt Marsh Creation: Heavy Metal Contaminants and the Cordgrass Spartina alterniflora. M.S. Thesis, University of Rhode Island, Kingston, R.I.
2. Hull, R.J. and J.R. Shann. 1981. Using Dredging Spoils to Build Tidal Marshes. Maritimes 24(3):7-9.

TABLE 1. Metal Concentrations of ten Narragansett Bay marsh sediments.

Site	Metal concentration	
	Cd	Zn
1	0.48 d †	213.33 d
2	1.65 b	1603.33 a
3	1.25 c	356.00 c
4	0.06 e	15.00 ef
5	0.11 e	26.67 ef
6	2.14 a	507.00 b
7	0.51 d	232.67 d
8	0.10 e	48.00 e
9	0.03 e	3.33 f
10	0.02 e	3.67 f

† Values within columns followed by the same letter are not different at alpha level 0.05.

TABLE 2. Metal concentration in plant parts of *Spartina alterniflora* collected around Narragansett Bay, RI.

		Metal Concentration				
Site	Plant part	Zn	Pb	Cu	Ni	Cd
1	Root	135 bcd †	74.5 bcd	31.0 bc	8.00 ab	3.50 ab
	Rhizome	59 efgh	9.0 cd	11.0 bc	1.00 b	1.00 bcd
	Shoot	19 h	0.0 d	2.7 c	1.25 b	0.00 d
2	Root	175 b	288.0 a	174.5 a	1.00 b	2.00 bcd
	Rhizome	67 efgh	20.0 bcd	14.7 bc	0.50 b	0.00 d
	Shoot	114 cde	45.0 bcd	38.2 bc	5.00 ab	3.25 abc
3	Root	87 def	95.5 bc	26.0 bc	2.57 b	1.00 bcd
	Rhizome	17 h	0.0 d	3.7 c	0.50 b	0.00 d
	Shoot	18 h	0.0 d	4.0 c	0.50 b	0.25 cd
4	Root	229 a	81.2 bcd	164.2 a	14.50 a	5.25 a
	Rhizome	60 efgh	0.0 d	18.0 bc	1.50 b	0.50 bcd
	Shoot	61 efgh	0.0 d	4.5 c	0.00 b	0.25 cd
6	Root	153 bc	106.0 b	82.5 b	8.33 ab	6.00 a
	Rhizome	39 fgh	3.5 cd	10.0 bc	1.29 b	1.00 bcd
	Shoot	29 fgh	9.5 cd	4.0 c	1.25 b	0.00 d
9	Root	85 defg	23.5 bcd	20.5 bc	6.00 ab	1.75 bcd
	Rhizome	65 efgh	0.0 d	7.0 bc	3.25 b	0.50 bcd
	Shoot	23 gh	0.0 d	4.2 c	2.50 b	1.00 bcd
10	Root	79 defgh	19.0 bcd	14.2 bc	5.75 ab	1.00 bcd
	Rhizomes	44 fgh	2.0 cd	5.7 c	0.75 b	0.50 bcd
	Shoot	21 h	0.0 d	4.5 c	0.00 b	0.25 cd

† Numbers within columns followed by the same letter are not different at alpha level 0.05.

TABLE 3. Uptake rates and plant content of heavy metal in individual root exposed *Spartina alterniflora* plants.

			Uptake rate		Plant metal content		
Metal	Salinity	Plant	Solution	Plant	Root	Shoot	Total
	ppt		ug g^{-1} day^{-1}		ug		
Cd	0	1	9.28	6.27	36.0	9.6	45.6
		2	4.77	5.88	30.1	3.5	33.6
	15	1	3.05	1.58	8.3	1.8	10.1
		2	5.23	4.97	29.7	4.9	34.6
Zn	0	1	679	260	588	616	1204
		2	542	294	699	206	904
	15	1	1178	166	925	145	1070
		2	512	134	226	112	338

TABLE 4. Percentage distribution of total plant metal in root or shoot exposed *Spartina alterniflora*.

Metal	Exposure	Salinity	Total plant metal		
			Root	Shoot	
				lower	upper
		ppt	%		
Cd	Shoot †	0	35.6 a	44.4 a	20.0 a
		15	36.2 a	45.7 a	18.1 a
	Root ‡	0	76.5 a	23.5 a	
		15	77.0 a	23.0 a	
Zn	Shoot	0	17.2 b	55.3 a	27.5 a
		15	29.1 a	44.8 b	26.1 b
	Root	0	54.5 b	45.5 a	
		15	63.0 a	37.0 b	

† All shoot exposure distributions are mean values of two experiments, with three to five replications of salinity treatments in each.

‡ All root exposure distributions are mean values of four experiments, with three to five replications of salinity treatments in each.

Values within columns, exposures, and metals followed by the same letter are not different at alpha level 0.05.

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ANNUAL REPORT -- ANNUAL COOPERATIVE PROGRAM OR MATCHING FUND PROGRAM PROJECT

OWRT PROJECT NO. A-075-RI

AGREEMENT NO. 14-34-0001- 1142

FCCSET RESEARCH CATEGORY: ____________

PROJECT TITLE:

Phosphate Movement in Laboratory Soil Columns and On-Site Sewage Systems

NAME AND LOCATION OF UNIVERSITY WHERE PROJECT IS BEING CARRIED OUT:

University of Rhode Island
Kingston, RI 02881

PROJECT BEGAN --
MONTH: 10 ; YEAR: 80

TO BE COMPLETED --
MONTH: 9 ; YEAR: 82

PRINCIPAL INVESTIGATORS	DEGREE	DISCIPLINE
William R. Wright	Ph.D.	Plant & Soil Science
William E. Kelly	Ph.D.	Civil & Environmental Engineering

STUDENT ASSISTANTS[1]	DEGREE HELD (IF ANY)	DISCIPLINE OR ACADEMIC BACKGROUND
Charles Galgowski	M.S.	Plant & Soil Science

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NARRATIVE STATEMENTS

(REFER TO THE ATTACHMENT TO THIS FORM OW-1)

PHOSPHATE MOVEMENT FROM ON-SITE SEWAGE DISPOSAL SYSTEMS

W. R. Wright, C. E. Galgowski and W. E. Kelly

OWRT Project No. A-075-RI

The objective of this experiment was to determine the magnitude of phosphorus adsorption in sandy subsoils located around 20 year old cesspools in Rhode Island. Attempts were also made to determine what elements in the soil were responsible for adsorbing P. The goal of the final portion of this study was to calculate what the P-pollution potential of individual sewage disposal systems would be on groundwater and open bodies of water.

Project Accomplishments

One hundred and ten soil samples were obtained at depths ranging from 1 to 3.5 m around eight cesspools more than 20 years old located in outwash sands and gravels in West Kingston, RI. The soil samples were air dried, passed through a 10-mesh sieve, and analyzed for particle-size distribution. The gravels (greater than 10-mesh) were discarded and the finer fractions were analyzed for P.

The magnitude of P adsorption was determined by using the Ammonium Molybdate-Vanadate Method (Page, 1965) which is used by the University of Rhode Island Soil Testing Laboratory. This method extracts the soil with a solution of 0.05 N hydrochloric acid and 0.025 N sulfuric acid and the orthophosphate is determined colorimetrically. The amount of P extracted by this weak acid solution is normally correlated with plant uptake of P. It perhaps does not extract all adsorbed P, however, it was used to estimate the amount of P-adsorption occurring around the cesspools.

The Ammonium Molybdate-Vanadate Method of determining P was run on 110 soil samples gathered from the eight cesspool sites. Table 1 summarizes the concentrations at various locations around the cesspools. Concentrations of P at the base of the cesspools and at 1 m above the base were significantly higher than all other locations. It is important to note, that much of the P remained in the area above the cesspool bottoms and that concentrations of P 1 m below the cesspools were not significantly different than background levels. It can be conservatively estimated, from the Ammonium Molybdate-Vanadate Method, that the glacial outwash subsoils around septic systems in this area of Rhode Island can adsorb at least 100 μg P/g soil (142-41 $\cong$ 100 μg P/g soil).

An attempt was also made to fractionate the samples into several types of P-adsorption utilizing methods described by Jackson (1958). These fractions of P-adsorption are aluminum-phosphate (1 N NH_4Cl extractable P), iron-phosphate (0.1 N NaOH extractable P), calcium-phosphate (0.5 N H_2SO_4 extractable P), occluded iron-phosphate (sodium citrate-sodium dithionite extractable P), occluded aluminum-phosphate (0.5 N neutral NH_4F extractable P following the sodium citrate-sodium dithionite

TABLE 1 - Mean concentrations of extractable phosphorus at various locations around 20-year-old cesspools.

Location	Location Description	Number of Samples	Mean (μg P/g soil)
Above Cesspool	1 m above cesspool bottom and 0.7 m outside cesspool	23	132a[1]
Base of Cesspool	at cesspool bottom and 0.7 m outside cesspool	15	142a
Below Cesspool	1 m below cesspool bottom and 0.7 m outside cesspool	24	68b
Background	1 m above cesspool bottom and 10 m outside cesspool	24	40b
Background	1 m below cesspool bottom and 10 m outside cesspool	24	41b

[1] Values followed by the same letter are not significantly different at the 5% level of probability (Duncan's Multiple Range Test).

step), and organically held P (30 percent hydrogen peroxide and 0.5 N NH_4F extractable P). Each extractable fraction was analyzed for P with a stannous chloride-molybdate colorimetric test. In addition, the free iron and aluminum content of the samples were analyzed by extracting with the sodium citrate-sodium dithionite method (Jackson 1958) followed by atomic adsorption spectrophotometry.

Jackson's method, although quite valuable, is laborious and very time consuming. Numerous testing on three replicates of eight samples began to yield some reproducible results for fractions of aluminum-phosphates, iron-phosphates, calcium-phosphates, and occluded Al-phosphates. However, fractions of occluded iron-phosphates and organic phosphates never yielded very reproducible results. This was unfortunate since the occluded iron-phosphate fractions should be where secondary P-fixation would occur. One of the goals for this experiment was to quantify this long term P-fixation around cesspools which the literature shows has not been extensively explored. Studies of P-fertilization over periods of 20-50 years have shown this secondary P-fixation of occluded forms to be at least several times larger than initial P adsorption.

Table 2 indicates that 60 to 80% of the phosphorus was in the form of Al-P and Fe-P. This emphasizes the importance of these elements in the adsorption of phosphorus. It is interesting to note that the free Fe and Al concentrations approximately doubled near the base of the cesspools when compared to the background soils; therefore it is conceivable that the potential P-adsorption capacity of a soil would increase with additions of sewage effluent.

TABLE 2. Concentrations of free iron and aluminum and various phosphorus fractions in soils at various locations around 20-year-old cesspools.

				Mean P Concentrations				
Location	No. of Samples	Free Fe	Free Al	Al-P	Fe-P	Ca-P	Occluded Al-P	Total P
		μg/g soil						
Base of Cesspool	6	650	32	69(42)[1/]	69(42)	24(15)	2(1)	164
Background	2	320	16	14(33)	12(28)	16(37)	1(2)	43

[1/] Values in paranthesis indicate percentage of total P in that fraction; occluded Fe-P and organic-P are not included in total as a result of methodology difficulties.

The cumulative concentrations of P in Al-P, Fe-P, Ca-P, and occluded Al-P of samples near the cesspools yielded 164 µg/g soil, whereas, background soils contained 43 µg P/g soil. These values agree extremely well with those obtained by the Ammonium-Molybdate-Vanadate method (Table 1), however, occluded Fe-P and organic-P were excluded from these cumulative means. Therefore, perhaps much more P was actually adsorbed than the estimated 100-120 µg P/g soil.

Data obtained by Gotoh and Patrick (1974) and Magdoff, et al. (1974) show that phosphate is adsorbed below the water table as well as above it. Any sufficiently large mass of soil with or without water should be capable of adsorbing P from individual sewage disposal system. The only time it would contribute harmful quantities of P to a body of water would be when the leach field is located in shallow soils overlying bedrock. Therefore, in an attempt to see how long it would take for soils around a leach field over bedrock near open water to become P-saturated, a hypothetical model of a leach field was designed using guidelines from the State of Rhode Island (Department of Environmental Management, 1980). The following assumptions were made for this model:

1) The depth of soil from the middle of the leach field to bedrock equals 1.22 m.
2) The percolation rate equals 7.9 min/cm.
3) The leach field trench is 76.2 cm wide.
4) A family of four generates 1140 liters of sewage effluent/day.

5) A family of four generates 1.8 kg P/year (Sawhney & Hill, 1975).

6) The cross sectional area of soil around the leach field that adsorbs effluent is 3 m wide and 1.22 m deep.

From these assumptions a trench 32 m long is required. Assuming the soil can hold 100 μg P/g soil, it would take 11 years for the soils around the leach field to become P-saturated. Considering that our original P-adsorption of 100 μg P/g soil was a conservative estimate, 11 years may perhaps be a minimum time.

Levels of 0.01 μg P/g water will allow eutrophication of open bodies of fresh water to occur (Fetter 1980). Although this is a small concentration, substantial amounts of P would have to be added to the large volume of water encountered in lakes to reach the eutrophication condition. Although this data shows there might be a pollution problem after 11 years, a unique feature of individual sewage disposal systems might prevent this. Soils around cesspools or leach fields might be able to adsorb much more P than other soils because there is a never ending supply of Fe coming into the field from the household effluent. If the Fe concentration is high enough it could allow P to precipitate and be adsorbed onto soil particles indefinitely. Unfortunately, complications with Jackson's method in this study did not allow the significance of Fe in forming occluded Fe-phosphates to be evaluated.

Application of Research Results

The data gathered in this study suggest that P-pollution of aquifers and open bodies of water by individual sewage disposal systems is rarely a problem. However, in cases where the system is in shallow soils over bedrock near open water, some pollution might occur after 11 years. However, Fe added to the system from the incoming effluent might extend this period indefinitely. More work needs to be done on the importance of this Fe in P-adsorption within on-site sewage disposal systems.

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Form OW-1
(Rev. 10/80)

ANNUAL REPORT -- ANNUAL COOPERATIVE PROGRAM OR MATCHING FUND PROGRAM PROJECT

OWRT PROJECT NO. A-076-RI

AGREEMENT NO. 14-34-0001- 1142

FCCSET RESEARCH CATEGORY: ____

PROJECT TITLE:

UV-Ozone Process for the Concurrent Decomposition of Halogenated Alkenes and the Disinfection of Water

NAME AND LOCATION OF UNIVERSITY WHERE PROJECT IS BEING CARRIED OUT:

University of Rhode Island
Kingston, RI 02881

PROJECT BEGAN --
MONTH: 10 ; YEAR: 80

TO BE COMPLETED --
MONTH: 9 ; YEAR: 82

PRINCIPAL INVESTIGATORS	DEGREE	DISCIPLINE
Calvin P.C. Poon	Ph.D.	Civil & Environmental Engineering
Bruno M. Vittimberga	Ph.D.	Chemistry

STUDENT ASSISTANTS[1]	DEGREE HELD (IF ANY)	DISCIPLINE OR ACADEMIC BACKGROUND
Thomas Reynolds	B.S.	Chemistry

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NARRATIVE STATEMENTS
(REFER TO THE ATTACHMENT TO THIS FORM OW-1)

Summary Report
A-076-RI, Water Resources Office

UV-Ozone Process for the Concurrent Decomposition of Halogenated Alkenes and Alkanes and the Disinfection of Water

by Calvin P. C. Poon, Civil and Enviroinmental Engineering
Bruno M. Vittinberga, Chemistry

PROJECT ACCOMPLISHMENT

A new Perkin-Elmer Sigma 3B gas chromatograph equipped with an electron capture detector was used for the analysis of individual species of trihalomethanes in the experiment. The liquid/liquid extraction procedure outlined in the Federal Register, Vol. 44, No. 231, Rules and Regulations, Thursday, Nov. 29, 1979; pgs 68683-68636 was followed.

A reservoir holding two liters of distilled water was spiked with a standard solution. From the reservoir, the spiked solution was pumped into the photochemical column reactor for experiment (Figure 1).

Four sets of experiments were conducted as follows:

UV treatment
Ozone treatment
Air purging
UV-Ozone combined treatment

The UV laump was warmed up 30 minutes before each experiment. If ozone was used. the ozonator was turned on to provide at least a two-hour warmup time. An initial sample was taken directly from the reservoir and periodic samples, including a zero-time sample, were taken from the reactor. Samples taken were refrigerated 24 to 48 hours prior to extraction and GC analysis. Refrigeration was found absolutely necessary for UV exposed samples because sample temperatures rose above the boiling point of the extraction solvent (Pentane, 36.1°C). Ozone, when used, was analyzed for its initial and final concentrations in solution following standard methods (p. 399, 15th ed. 1980). Ozone input rate in mg/min was also determined by measuring the ozone trapped in a potassium iodide solution over a given period of time. The rate of flow of ozone was identical to the air flow rate used in air purging experiments.

Regardless of the method of treatment, a plot of the logarithmic concentration ratio ($\ln C/C_o$) versus time yielded a straight line, indicating a first order removal kinetic for the concentrations of trihalomethane chemicals used in the experiments. Chloroform concentration ranged from 199 to 312 μg/l and bromodichloromethane from 15.3 to 48.6 μg/l simulating their respective concentrations found in drinking water supplies in various cities and towns in United States. The slope of such a plot represents the removal rate expressed in (1/minute). The experimental results and calculated removal rates are summarized in Table 1.

Air purging or air stripping was found to be very effective in removing both $CHCl_3$ and CHB_rCl_2, either individually or combined. With an air flow rate of 0.4 l/min in a reactor with 1.3 l of working liquid volume, only 90 to 120 minutes were required to remove 96 to 99 percent of these two compounds. Effluents with extremely low concentration of either one or both of these two compounds were obtained consistently. Table 1 indicates that $CHCl_3$ was stripped at a faster rate than CHB_rCl_2.

Treatment with UV exposure alone with 13.8 watt power input and 15,800 μW/cm^2 intensity was found to be comparatively ineffective for $CHCl_3$, although CHB_rCl_2 removal was as efficient or better than that with air purging. The removal rate for $CHCl_3$ was so slow that even at 150 minutes the effluent still contained $CHCl_3$ at a concentration greater than the acceptable limit for drinking water. Since $CHCl_3$ does not appreciably absorb in the UV region, the low photolysis result was expected.

Ozone treatment was as effective as air purging. The percent removal for CHB_rCl_2 was only slightly below than that in air purging. The effluent concentration for both $CHCl_3$ and CHB_rCl_2 was also slightly higher (still exceptionally good quality) only because the initial concentration was higher and the time of treatment was shorter. Ozone treatment provides trihalomethane removal with oxidation as well as purging. The fact that ozone treatment was comparable but not better than air purging indicates the latter to be more cost effective.

When UV was combined with ozone, the advantage of applying the process for trihalomethane removal was apparent. The removal of either compound alone or both together was much higher than the ozone treatment process. In fact the removal was much higher than the combination of the individual removals by ozone and by UV. It is feasible that the excited state of the oxygen atom reacts with water to give hydroxyl radicals (-29 kcal/mole). Some of which recombine to form H_2O_2 while others bring about chain reaction with the hydroxyl radical as the active species primarily responsible for the oxidation of $CHCl_3$ and CHB_rCl_2.

In the UV-Ozone experiments, 100 percent kill of coliform was consistently obtained, indicating that the UV-ozone is an extremely effective process in water disinfection.

APPLICATION OF RESEARCH RESULTS

The result of this project work suggests that UV-ozone process has a high potential of field application in the removal of trihalomethane compounds from drinking water supplies. It could also be used in place of the chlorination disinfection process commonly practiced in the United States. UV-ozone will disinfect drinking water supply effectively, does not form trihalomethane species and remove trihalomethane species that are present in water coming into the water treatment plant.

Form OW-1
(Rev. 10/80)

ANNUAL REPORT -- ANNUAL COOPERATIVE PROGRAM OR MATCHING FUND PROGRAM PROJECT

OWRT PROJECT NO. A-077

AGREEMENT NO. 14-34-0001- 2142

FCCSET RESEARCH CATEGORY:

PROJECT TITLE:

Scale Up Study of Flotation for Metal Removal and Recovery from Industrial Plating Wastes and Drinking Water Supplies

NAME AND LOCATION OF UNIVERSITY WHERE PROJECT IS BEING CARRIED OUT:

University of Rhode Island
Kingston, RI 02881

PROJECT BEGAN --
MONTH: 10/1/ ; YEAR: 81

TO BE COMPLETED --
MONTH: 9/30 ; YEAR: 83

PRINCIPAL INVESTIGATORS	DEGREE	DISCIPLINE
Dr. Stanley M. Barnett	Ph.D	Chemical Engineering
Prof. Frank J. DeLuise	MS	Mechanical Engineerin & Applied Mathmatics

STUDENT ASSISTANTS[1/]	DEGREE HELD (IF ANY)	DISCIPLINE OR ACADEMIC BACKGROUND
Elliot Nir	B.S.	Chemical Engineering

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NARRATIVE STATEMENTS

(REFER TO THE ATTACHMENT TO THIS FORM OW-1)

Scale-up Study of Flotation for Metal Removal and Recovery from Industrial Plating Wastes

OWRT-Project A-77-RI

Research Objectives

To test a proven method for removal of trace metals in equipment configuration suitable for jewelry industry waste streams.

Research Project Accomplishments

In the early 1970's, a particularly stable foam called a microgas dispersion (MGD) was developed. Here at the University of Rhode Island, countercurrent flotation using MGD has been used to remove organic dyes, manganese, and a mixture of metal ions in both simulated and real wastewater. While countercurrent flotation pilot plants have been shown to be effective and economical in removing metals such as cobalt, copper, lead, zinc and iron by means of various precipitate flotation techniques, many plating facilities have troughs or other horizontal conduits which would make flotation more economically attractive if these existing channels could be adapted for such use. Such a method would be cross-current rather than countercurrent. The purpose of this study was to investigate the feasibility of crosscurrent precipitate flotation using MGD. The metals investigated were copper, nickel and lead.

The most important trend found in the results is that the shorter trough more effectively removes metals by precipitate flotation for a given pH and given flow rates than the longer trough. This can be explained by the fact that for a given flow rate of both contaminant and surfactant solutions, the residence time for both foam and bulk liquid will be about twice as great in the longer trough. This means that the foam used to effect removal has more time to coalesce, resulting in return to the bulk solution of the same metal ions removed earlier.

Thus, any horizontal flotation process should be done over a minimum length to avoid undersired enrichment of the water due to foam breakage.

Removal rates approached the highly favorable results for column flotation of jewelry industry wastes reported earlier.

Application of Research Results

The Manufacturing Jewelers and Silversmiths Association has expressed interest in the project. They have provided contacts within the industry for waste water supplies and are interested in having the work continue. We plan to try an in-plant trial of our unit.

Project Status

The project will continue due to local industrial needs. We plan to optimize the trough system and proceed to an in-plant trial. A completion report for the work up to this point is being submitted.

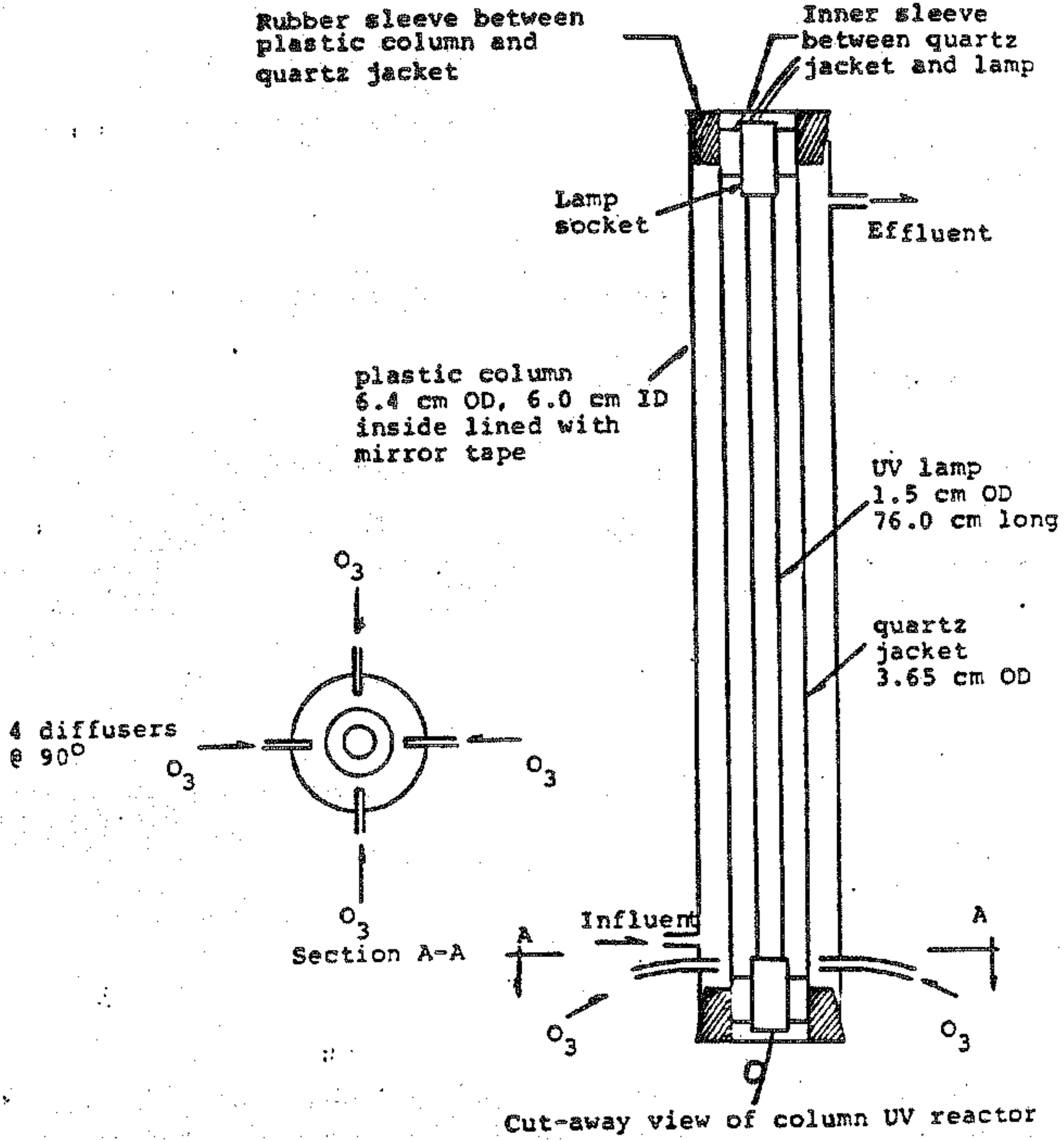
Work Remaining

Continuation of the project will depend upon a source of funds.

Table 1 -- Summary of Results

Method of Treatment	Chemical Compound	Removal Rate min^{-1}	Percent Removal %	Time of Treatment min	Residual* Concentration µg/l
Air Purging	$CHCl_3$	0.057	99	90-120	2
	CHB_rCl_2	0.038	97	90	1.0 to 1.9
	Mixture				
	$CHCl_3$	0.056	99	90-105	1.0 to 3.3
	CHB_rCl_2	0.039	96		1.0
UV	$CHCl_3$	0.0019	27.8	150	111 to 209
	CHB_rCl_2	0.048	97.0	80	1.0 to 1.5
	Mixture				
	$CHCl_3$	0.0014	19.4	150	183
	CHB_rCl_2	0.043	95.6	150	1.0
Ozone	$CHCl_3$	0.053	95.4	60	6 to 18
	CHB_rCl_2	0.042	87.2	50-60	2.9 to 8.1
	Mixture				
	$CHCl_3$	0.054	95.6	60	9 to 12
	CHB_rCl_2	0.039	86.2		2.5 to 3.0
UV and Ozone	$CHCl_3$	0.075	99.0	60	3
	Mixture				
	$CHCl_3$	0.082	95.5	30-60	2 to 16
	CHB_rCl_2	0.098	94.0		1.0

*Allowable residue in drinking water is 100 µg/l total trihalomethane.



Section A-A

Cut-away view of column UV reactor

PHOTOCHEMICAL COLUMN REACTOR

Form OW-1
(Rev. 10/80)

ANNUAL REPORT -- ANNUAL COOPERATIVE PROGRAM OR MATCHING FUND PROGRAM PROJECT

OWRT PROJECT NO. A-078-RI

AGREEMENT NO. 14-34-0001- 2142

FCCSET RESEARCH CATEGORY: ____________

PROJECT TITLE:

Land Application of Toxic Sludge Landfill Leachate

NAME AND LOCATION OF UNIVERSITY WHERE PROJECT IS BEING CARRIED OUT:

University of Rhode Island
Kingston, RI 02881

PROJECT BEGAN --
MONTH: 10/01/ ; YEAR: 81

TO BE COMPLETED --
MONTH: 12/31 ; YEAR: 82

PRINCIPAL INVESTIGATORS	DEGREE	DISCIPLINE
Dr. William R. Wright	Ph.D	Plant & Soil Science

STUDENT ASSISTANTS[1]	DEGREE HELD (IF ANY)	DISCIPLINE OR ACADEMIC BACKGROUND
Holly Brown	BS	Natural Resources (Soil Science)

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NARRATIVE STATEMENTS

(REFER TO THE ATTACHMENT TO THIS FORM OW-1)

Land Application of Toxic Sludge Landfill Leachate

W.R. Wright and H.J. Brown

OWRT Project A-78-RI

Research Objective

The objective of this research was to evaluate the feasibility of applying sewage sludge landfill leachate to a grass crop to attenuate heavy metal contaminants. The effectiveness of such a "living filter" system was assessed by analyzing the concentration of metal ions Cd, Cu, Fe, Ni, Pb and Zn and the total nitrogen content in soil water extracts, soil samples and grass samples collected from experimental plots before, during and after treatment with various rates of sewage sludge landfill leachate.

Project Accomplishments

A miniature landfill, 2m deep x 8m x 1.5m was excavated, lined with 6 ml plastic, equipped with a leachate collection system and filled with primary treated, super chlorinated sewage sludge from South Kingstown's treatment facility. Sludge samples were collected, oven dried and analyzed for total nitrogen using standard Macro Kjeldahl procedures and heavy metals using an atomic absorption spectrophotometer. Landfill leachate was collected weekly, analyzed for N and applied to grass plots at rates of 0, 200, 400 and 600 kg N/ha/yr. Metal concentrations in the leachate were measured monthly.

Experimental plots (16-m^2), seeded with rye grass and edged with 6" wide strips of aluminum, were established in a randomized block design adjacent to the landfill and treated with weekly applications of landfill leachate at various rates. Within each plot, soil samples were collected at depths of 30, 60 and 90 cm, air dried, passed through a 10 mesh sieve and analyzed for N and metals. Suction lysimeters were installed at each of these depths and sampled for soil water extracts on a biweekly basis. The average monthly nitrogen content in soil water extracts is presented in Table 1. The data show that the concentration of nitrogen increased with higher application rates, as well as over time. Also, leachate application rates greater than 200 kg N/ha present a possible problem of nitrate contamination of groundwaters since the N concentration exceeds the minimum safety level of 10 ppm. Average monthly metal ion concentrations, in the same samples, are presented in Table 2. Rye grass from each plot was harvested each month, prior to heading. Grass samples were oven dried; dry weights were recorded and percent yields were determined. Grass samples were analyzed for heavy metals and nitrogen according to standard procedures.

Application of Research Results

Landfill leachates are a serious groundwater pollution threat. Recovering these leachates and passing them through a "living" filter of grass and topsoil may prove to be an environmentally safe means of purifying toxic sludge leachate and thereby reduce the potential of groundwater contamination.

Project Status

This project will continue through November 30, 1982.

Work Remaining

Field data will continue to be collected through November 30, 1982. Accumulated data remains to be statistically analyzed, evaluated, and prepared for publication.

Table 1. Average nitrogen concentration in soil water extracts as affected by leachate application rate and sampling date.

Sampling Date	Leachate rate (kg/ha) 0	 200	 400	 600
	ug/ml			
6/82	3.71	1.26	4.22	2.13
7/82	1.89	0.82	4.36	4.93
8/82	4.39	1.64	21.53	121.80
9/82	3.51	3.73	22.34	132.67
10/82	--	3.15	30.95	117.16

Table 2. Average metal ion concentration in soil water extracts as affected by rate of leachate application and sampling date

Sampling date	Leachate rate	Metal					
		Cd	Cu	Fe	Ni	Pb	Zn
	Kg h/ha	ug/ml					
6/82	0	.016	.028	.023	.006	.04	.017
	200	.031	--	.027	--	.03	--
	400	.021	.017	.300	.018	.06	.013
	600	.036	--	.054	.031	.05	--
7/82	0	--	.013	.010	.015	.01	.051
	200	--	.010	.016	.016	--	.077
	400	--	.027	.156	.036	--	1.37
	600	--	.022	.096	.214	--	.269
8/82	0	.004	.010	.015	.013	.01	.042
	200	.001	.012	.167	.036	--	1.37
	400	.001	.009	.057	.023	--	1.65
	600	.001	.014	.133	.013	.03	.617
9/82	0	.002	.022	.318	.119	.05	.536
	200	.003	.061	.142	.048	.03	.290
	400	.003	.025	.400	.160	.04	.560
	600	.004	.039	.568	.109	.01	.261
10/82	0	.006	.023	.032	.147	.05	.419
	200	.006	.019	.048	.166	.07	.055
	400	.050	.017	.024	.165	.03	.489
	600	.007	.013	.035	.171	.02	.350

ANNUAL REPORT - TRAINING AND EDUCATION ASPECTS OF THE WATER RESEARCH PROGRAM UNDER P.L. 95-467

Name of University:
(or College) University of Rhode Island

SUBMIT THE INFORMATION SPECIFIED BELOW FOR THE UNIVERSITY AT WHICH THE WATER RESOURCES RESEARCH INSTITUTE OR CENTER APPROVED UNDER P.L. 95-467 IS LOCATED, AND FOR OTHER UNIVERSITIES WITH WHICH THE INSTITUTE OR CENTER IS COOPERATING. KEEP THE STATISTICS ON ENROLLMENTS, NUMBER OF STUDENTS GRADUATING, EMPLOYMENT STATUS OF GRADUATES, NEW COURSES, ETC., SEPARATE FOR EACH UNIVERSITY. IT IS RECOGNIZED CERTAIN OF THE REQUESTED DATA ON STUDENTS MAY NOT BE READILY AVAILABLE. IF SO, PROVIDE BEST ESTIMATE FIGURES. IN OW-9, DATA ON STUDENTS ARE REQUESTED ONLY FOR THOSE STUDENTS WHO RECEIVED EMPLOYMENT AS RESEARCH PROJECT OR PROGRAM ASSISTANTS THROUGH THE P.L. 95-467 PROGRAM. IF EXTRA SPACE IS NEEDED, ADD PAGES AND NUMBER EACH CONTINUATION ITEM IN THE ORDER SHOWN BELOW.

A. Number of students receiving employment as research project or program assistants through the P.L. 95-467 program. (Include only those students, both continuing and graduating, paid wholly or in part with P.L. 95-467 funds during the past fiscal year.)

Category of Students	No. by Scientific Discipline or Major Field of Study (Engineering, Biology, Economics, etc. 2/	
	Scientific Discipline of Student	Number
(1) Undergraduates	Arts & Sciences	1

2/ This refers to educational background prior to employment as research assistant on P.L. 95-467 projects--not to departments in which projects are being conducted.

A. (Continued)

Category of Students	No. by Scientific Discipline or Major Field of Study (Engineering, Biology, Economics, etc.) Scientific Discipline of Student	Number
(2) Master's Students	Chemical Engineering	2
	Environmental Engineering	1
	Plant & Soil Science	2
(3) Doctoral Students		
(4) Postdoctoral Students		

B. Employment status of majors in water-related fields who graduated during the school year ending about June and who receive P.L. 95-467 support.

EMPLOYMENT STATUS	CATEGORY OF SCHOOL YEAR GRADUATE BY DEGREE OBTAINED			
	Bachelor's Degree	Master's Degree	Doctoral Degree	Total
1. No. employed in water-related positions in: Total——				
Federal Agencies——	( )	( )	( )	( )
State & Local Agencies——	( )	( )	( )	( )
University or College——	( )	( )	( )	( )
Other – Including private enterprise——	( )	( )	( )	( )
2. No. graduates returning to school for advanced degree——				
3. No. going into military service——				
4. No. unemployed or working in other fields——				
5. No. status unknown——				
6. Totals——	0	0	0	0

C. Type of employment of these school year graduates who received P.L. 95-467 support and who are known to have gone into water-related positions. (Number should agree with total listed under item 1 of the preceding paragraph "B". Graduates enrolled for further course work or training should not be listed here as employed.)

Number of Graduates Engaged in Water-Related Work In:	CATEGORY OF SCHOOL YEAR GRADUATE BY DEGREE OBTAINED			
	Bachelor's Degree	Master's Degree	Doctoral Degree	Total
1A. Federal Agencies:				
a. Primarily Research				
b. Primarily Planning				
c. Primarily Development				
d. Primarily Operations				
e. Primarily Management				
f. Other or not known				
1B. State & Local Agencies:				
a. Primarily Research				
b. Primarily Planning				
c. Primarily Development				
d. Primarily Operations				
e. Primarily Management				
f. Other or not known				
1C. University or College: 3/				
a. Primarily Teaching				
b. Primarily Research				
c. Primarily Research & Teaching				
d. Other or not known				
1D. Other - Including Private Enterprise:				
a. Primarily Research				
b. Primarily Planning				
c. Primarily Development				
d. Primarily Operations				
e. Primarily Management				
f. Other or not known				
Totals	0	0	0	0

Selected summary of above data — from the "Total" column:

Research (1Aa, 1Ba, 1Cb, 1Cc& 1Da) ________

Planning (1Ab, 1Bb & 1Db) ________

Development (1Ac, 1Bc & 1Dc) ________

Operations (1Ad, 1Bd & 1Dd) ________

Management (1Ae, 1Be, & 1De) ________

3/Do not include here students working as research assistants and receiving course credits.

Form OW-5
(Rev. 10/80)

FY 1982 ANNUAL REPORT

SUMMARY SHEET

ANNUAL COOPERATIVE PROGRAM ☒ or MATCHING FUND PROGRAM ☐

(Prepare a Separate Summary Report for each Program and Indicate By ✓ Above)

State Where Institute is Located: Rhode Island

Total Number of Projects Underway, FY 1982: 5

Of these, number completed during FY: 3

Cost Categories and Work Months	Budgeted 1/ Total	Expenditures FY 19 2/ Federal	Non-Federal	Total
A. Salaries and Wages				
Principal Investigator(s) No.: Work-Months:	(33,570.00)	(9682.00)	(19,558.00)	(29,240.00
Other Professional Staff No.: Work-Months:	(25,900.00)	(8905.00)	(0)	(8905.00
Grad. Stu. Assts. & Tech. No.: Work-Months:	(24,500.00)	(22,199.00)	(0)	(22,199.00
Undergrad. Stu. Assts. & Tech. No.: Work-Months:	(3620.00)	(3467.00)	(0)	(3467.00
Non-Stu. Techs. & Others No.: Work-Months:	(11,859.00)	(9068.00)	(0)	(9068.00
Total:	99,449.00	53,321.00	19,558.00	72,879.00
B. Employee Benefits Total:	7921.00		0	0
C. Non-Expendable Property Total:	800.00	424.00	3,341.00	3,765.00
D. Expendable Property Total:	10,094.00	2703.00	0	2703.00
E. Other Cost (specify)	(816.00)	( )	( )	(
	( )	( )	( )	(
	( )	( )	( )	(
Total:	126,654.00	56,448.00	22,899.00	79,347.00
Indirect cost (35% of DC	43262.00		27,771.45	27,771.45
Total Expenditures FY 19 82	169,916.00	56,448.00	50,670.00	$107,118.45

This summary report includes, but is not limited to, the following projects completed during the reported fiscal year (show OWRT project numbers):

OWRT - A-074-RI
OWRT - A-075-RI
OWRT - A-076-RI

1/ Total Federal and Non-Federal amount budgeted as set forth in project budgets (and revisions) submitted and accepted by OWRT.

2/ Actual expenditures, including firm outstanding commitments (or obligations); for example, unliquidated orders for equipment.

RI-A-077
1983

Technical Completion Report

A-077-RI

CROSS-CURRENT FLOTATION FOR METAL REMOVAL FROM PLATING WASTES

by

S.M. Barnett, F.J. DeLuise, E. Nir
Dept. of Chemical Engineering/Dept. of Mechanical Engineering

Submitted to

Office of Water Policy

United States Department of the Interior
Washington, D.C. 20243

The work on which this report is based was supported in part by funds provided by the United States Department of the Interior as authorized under the Water Research and Development Act of 1978.

Rhode Island Water Resources Center
University of Rhode Island
Kingston, R.I. 02881

September, 1983

Selected Water
Resources Abstracts
Input Transaction Form

1. Report No.

2.

3. Accession No.
W

4. Title
CROSS-CURRENT FLOTATION FOR METAL REMOVAL FROM PLATING WASTES,

5. Report Date

6.

8. Performing Organization Report No.

7. Author(s)
Barnett, S.M., DeLuise, F.J., and Nir. E.

10. Project No.
OWRT A-077-RI

9. Organization
Rhode Island University, Kingston, R.I.

11. Contract/Grant No.
13-34-0001-2142

13. Type of Report and Period Covered

12. Sponsoring Organization

15. Supplementary Notes
Water Resources Center Technical Report No. 12, September 1983.
11 p, 3 tab, 11 ref.

16. Abstract

While countercurrent flotation pilot plants have been shown to be effective and economical in removing metals such as cobalt, copper, lead, zinc and iron by means of various precipitate flotation techniques, many plating facilities have troughs or other horizontal conduits which would make flotation more economically attractive if these existing channels could be adapted for such use. The purpose of this study was to investigate the feasibility of crosscurrent precipitate flotation for these troughs. The metals investigated were copper, nickel and lead. The most important trend found in the results is that the shorter trough more effectively removes metals by precipitate flotation for a given pH and given flow rates than the longer trough. Thus, the horizontal flotation process should be done over a minimum length to avoid undersized enrichment of the water due to foam breakage.

17a Descriptors
*Foam separation, *Wastewater treatment, *Metal-finishing wastes, Heavy metals.

17b. Chromium Zinc Nickel Lead

17c COWRR Field & Group
05 D

18 Availability

19. Security Class. (Report)

20. Security Class. (Page)

21. No. of Pages

22. Price

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Washington, D.C. 20240

Abstractor

Institution

CROSS-CURRENT FLOTATION FOR METAL REMOVAL FROM PLATING WASTES

by

S.M. Barnett, F.J. DeLuise, E. Nir

In October, 1982, new federal regulations went into effect which set new limits on the level of heavy metals in the process water discharged by industrial users (1). Among those most significantly affected by the new regulations are the approximately 10,000 plating firms in the U.S. A significant number of these firms will be subject to less stringent contamination levels because they discharge less than 10,000 gal/day, but even for such firms, the flotation process as described below holds considerable promise as a treatment system.

Flotation is an operation in which a solute is removed from solution by being adsorbed at a gas-liquid interface. This interface is usually provided by rising gas bubbles or foams. Surface active agents are often used, since they serve not only to stabilize a foam by increasing surface tension and thus retard bubble coalescence, but, if the surfactant is ionic, the polar (charged) portion of the surfactant molecule can be utilized to attract charged solute particles, be they ions or polar molecules. Several thorough reviews of the types of flotation along with their operation principles can be found in the literature (2-4).

In the early 1970's, a particularly stable foam called a microgas dispersion (MGD) was developed by Felix Sebba (5). The MGD gains its stability because of its double interface. It provides the advantage of a high surface area/volume ratio found with small bubbles, along with the rapid rise velocities of larger ones, since the bubble network rises with the effective diameter of a larger bubble (6). Here at the University of

Rhode Island, countercurrent flotation has been used to remove organic dyes (6), manganese (7), and a mixture of metal ions in both simulated and real wastewater (8). While countercurrent flotation pilot plants have been shown to be effective and economical in removing metals such as cobalt, copper, lead, zinc and iron by means of various precipitate flotation techniques (9-11), many plating facilities already have troughs or other horizontal conduits. It would make flotation more economically attractive if these existing channels could be adapted for such use, and save the cost of a column. Such a method would be cross-current rather than countercurrent. The purpose of this study was to begin to investigate the feasibility of crosscurrent precipitate flotation using MGD. The metals investigated were copper, nickel and lead.

Apparatus

Two troughs were constructed, one six feet long, the other twelve feet in length, made out of two-six foot sections. Both troughs were made of 1/4" thick plexiglas and lined on the inside with 3-ml thick polyethylene. The bottom and side panels were bound together with acrylic glue, and by being bolted to strips of Dexion.^{TM} Sections were sealed on the outside with silicone caulk. The polyethylene lining served to separate the solution from both the caulk and the bolts binding the plexiglas^{TM} to the Dexcon,^{TM} both of which would otherwise have been sources of contamination. In the case of the twelve-foot trough, the two sections were joined by reinforcing them with two one-foot long strips of plexiglas, one on each side of the bottom panels. the side panels were caulked on the outside to prevent leakage, even though the polyethylene already served this purpose. To facilitate flow, the troughs were tilted 1/2" from horizontal for each six feet of length. At the effluent end of each trough was a sampling tube, located about 2" above the bottom of the end plate.

The contaminant solution was held in a 110-gallon tank, with flow controlled by a valve. When opened, the valve allowed solution to flow down an 18 ft. tall, 1-ft ID vertical column, which served as a conduit from the tank to the trough. Flow through the column could be regulated by a PVC valve at the bottom. Because the tank was located approximately 20 feet above the trough, no pump was used to move the solution; flow was entirely the result of gravity.

The surfactant used was ethylhexadecyldimethylammonium bromide (EHDA), which was added to distilled water to produce a 300ppm solution. Nitrogen, rather than air, was used as the gas in the dispersion. A pail of cold water was used as a crude heat exchanger, and the foam reservoir was a 2-inch ID, 14 ft. tall column adjacent to the larger column. A venturi-type generator was used, in which the surfactant solution moves from a region of high pressure and low velocity to a point of high velocity and low pressure. Nitrogen enters through a sidearm, and passes through a narrow gap between the male and female parts of a 7/12 ground joint. The dispersion was thus formed, and was recirculated through the generator so that coalescing bubbles would again be broken up. The pump used was a Sears #563.26461) driven by a Sears #113.19706, 1/3 hp motor. Surfactant solution was stored in a 20-liter propylene tank situated above the foam reservoir, and was able to flow from the foam tank into the reservoir solely by gravity.

Analytical Instruments

To determine metal ion concentration, a Perkin-Elmer 5000 Atomic Absorption spectrophotometer was used withbackground correction. The pH meter used was an Onion model 601A Digital IONALYZER.

Procedure

Stock solutions of each of the metals was made by weighing out the proper amount of the nitrate salt of each of the three metals - $Pb\ (NO_3)_2$, $Cu\ (NO_3)_2\ \ 3H_2O$ and $Ni(NO_3)_2\ \ 6H_2O$ - to form one liter of a 2,000ppm solution, using distilled water. For each run, 60-gallons of a dilute contaminated solution to be treated were made by appropriate dilution of the stock solution with tapwater. For most of the runs, the pH of the contaminated solution was adjusted to the range of 910 - 10.0, which according to Ciriello, is the optimum pH range for removal of the metals under investigation. The pH was adjusted with 0.6M NaOH solution.

To start each run, surfactant solution was introduced into the foam reservoir, the N_2 gas was opened up, and the pump to circulate foam through the reservoir was turned on. Foam was allowed to circulate for ten minutes, so that the quality would exceed 50%. (Quality is the percent air entrained in the foam.) While foam quality was building up, the valves leading from the tank and at the bottom of the column were opened up, and contaminant solution filled up the trough. Once the trough was filled and began to overflow, the foam was introduced into the trogh by opening a clamp that held the foam lines leading to the trough shut. There were two foam lines, both secured to the bottom panel. One line introduced foam about six inches from the influent end, the other entering at the midway point. Every five or seven minutes (it varied from run to run), samples were taken of both the infuent and effluent, to be analyzed later. Samples of foam were also taken to ensure that it was of sufficient quality. The runs continued until the takn emptied. After each run, tank and trough were cleaned, first with dilute (.01M) HNO_3, and then with tapwater.

Percent removal was calcuated by the following formula:

$$\% \text{ Removal} = \frac{\text{Initial conc.} - (\text{Final conc./dilution factor})}{\text{Initial concentration}} \times 100$$

Dilution factor would be defined here as inflow divided by outflow, or the contaminant solution flow rate divided by the sum of the contaminant and surfactant solution flow rates. This figure varied markedly over the course of a run for two reasons - 1) adjustments to surfactant solution flow rate had to be made by hand, which offered fair but not strict control, and may have caused the flow rate to vary from the desired 0.3 pm flow rate.2) The rate of flow of aqueous solution, of course, varied, depending on the height of liquid in the tank. Table 1 relates time, liquid level in the tank, and flow from the tank.

Results and Discussion

A chart of flow rate vs. time is shown in table 1. These rates of drainage are well below what would be predicted for drain-rate from a tank through an orifice 1" in diameter at the bottom of the tank. Obviously, in this drainage, the limiting diameter was not the orifice at the bottom of the tank, but rather the diameter of the open valve, which was considerably less, but not measured, and which was situated 18 cm beneath the bottom of the tank.

The removal of metal ions using the twelve foot trough are shown in table 2. Three runs were done using nickel, one at an unadjusted pH of 5.9, the other at pH basic enough so that precipitate flotation of the hydroxide ould be the primary mechanism of removal. While it was considered unliekly that the findings of this investigation would contradict those of Ciriello (8), who found good rates of removal of pH greater than 8, and poor removal at pH less than 7 when using EHDA as a surfactant, it nevertheless merited a second look, because of the effluent could be effectively treated without altering its pH, we save on the cost of a pH control process. For nickel, however, not only was the untreated solution not effectively cleaned, neither was the pH adjusted one. This was probably caused by two factors - 1) the coalescence of most of the foam while the water being treated was still in the trough, 2) some of the precipitate adhered to the lining, and would recontaminate the solution at a later point in time.

Three runs were also made to investigate the removal of copper, one at an unaltered pH, the second and third conducted using a basic solution. Again, the untreated water proved ineffective, indicating that in crosscurrent as well as countercurrent methods, ion flotation using MGDs is not a useful mechanism. One run done at a higher pH produced noticeable removal rates early on, but effectiveness dropped with time, most likely the result of backcontamination.

Table 3 shows the results of flotation using the shorter, six-foot trough. For this series of runs, all contaminant solutions were pH adjusted so as to induce precipitate flotation of the hydroxides. Further, lead was also investigated this time. Removal rates for nickel varied from a low of 20.0% to a high of 55.4%, with an average removal rate of 40.6%. For copper, the average percentage removed was 60.7%, and for lead it was 49.0%. The improved removal rates in the shorter trough are probably due to the shorter residence time of the solution in the trough, which means less time for the foam to drain and coalesce, and less recontamination of solution.

Conclusion:

The most important trend found in the results is that the shorter trough more effectively removes metals by precipitate flotation for a given pH and given flow rates than the longer trough. This can be explained by the fact that for a given flow rates of both contaminant and surfactant solutions, the residence time for both foam and bulk liquid will be about twice as great in the longer trough. This means that the foam used to effect removal has more time to coalesce, resulting in return to the bulk solution of the same metal ions removed earlier. Thus, if any horizontal flotation process should be done over a minimum length to avoid undersired enrichment of the water due to foam breakage. One other mechanism, not investigated here, is the need to separate quickly the foam from the bulk liquid, a process which can largely, but not completely, be done by mechanically skimming foam off the top.

There are numerous other variables which need to be investigated. With removal rates under the conditions used in this investigation averaging about 60% for a short trough, it seems fair to say that these removal rates can probably be improved by experimenting with the following use of chelating agents, increasing the dilution factor, using a different surfactant, or use of an adsorbing colloid such as $FeCl_3$ or alum, Ciriello (8), for example, found greatly improved removal, in some cases reaching 100% by using chitosan as a chelating agent. The desired minimum removal rate is 90%-95%, and this should be possible with further investigation into conditions.

The horizontal process also seems capable of handling greater loads than a vertical process. The trough had a cross-sectional area of 27.5 sq. in., (0.191 ft^2), so at its peak of 1.8 gpm, its volumetric velocity was 9.4 gal/ft^2-min, about three times the typical load per unit cross-sectional area as any vertical flotation setup.

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Table I
Sol'n height, contaminant solution flow rate, and dilution factor as a function of time.

Time after opening valve (min.)	Height of sol'n in tank (cm)	Sol'n flow rate (previous minute)	Dilution factor(*)
1	52.4	1.93 gpm	.960
2	50.8	1.93	.960
3	49.2	1.93	.960
4	47.6	1.93	.960
5	46.0	1.93	.960
6	44.45	1.87	.959
7	42.9	1.87	.959
8	41.35	1.87	.959
9	39.8	1.87	.959
10	38.3	1.81	.958
11		1.81	.958
12	35.3	1.81	.958
13		1.75	.956
14	32.4	1.75	.956
15		1.75	.956
16	29.5	1.75	.956
17		1.69	.955
18	26.7	1.69	.955
19		1.63	.953
20	24.0	1.63	.953
21		1.63	.953
22	21.3	1.63	.953
23		1.57	.951
24	18.7	1.57	.951
25		1.57	.951
26	16.1	1.57	.951
27		1.51	.950
28	13.6	1.51	.950
29		1.45	.948
30	11.2	1.45	.948

(*)Assumes surfactant flow of 0.3 lpm.

Table 2
Metal removal by flotation in twelve-foot trough.

Run #	Metal	pH	Time of sampling	influent	effluent	% Removal
1	Ni	5.9	7	3.978	3.907	1.8
			15	4.011	3.787	5.6
			20	4.108		
2	Cu	5.9	7	4.227	3.815	9.8
			15	3.917	4.823	
			20	3.714	4.811	
3	Cu	8.9	5	2.976	0.907	62.8
			10	3.870	2.327	39.9
			15	3.540	3.082	13.0
4	Ni	9.7	5	3.653	3.801	
			10	3.534	3.452	2.3
			15	3.550	3.334	6.1
5	Cu	9.4	7	3.046	3.169	
			15	3.423	3.438	
			20	sample lost		
6	Ni	9.2	7	3.562	3.140	11.8
			15	3.884	3.626	7.1
			20	3.019	3.130	

Table 3
Metal removal by flotation in six-foot trough

Run #	Metal	pH	Time of Sample	Influent	Effluent	% Removal
1	Ni	8.78	5	2.223	1.760	20.8
			10	2.690	2.153	20.0
			15	2.944	1.524	48.2
			20	2.868	1.447	49.6
2	Cu	8.80	10	2.600	1.085	58.3
			15	3.051	1038	66.0
			20	3.942	0.432	89.0
			25	3.371	0.803	76.2
3	Pb	8.97	10	3.18	1.91	39.9
			15	2.92	2.29	21.6
			20	3.55	2.09	41.1
			25	3.61	1.85	48.8
4	Ni	9.10	10	2.297	1.025	55.4
			20	2.295	1.227	46.5
			30	2.365	1.330	43.8
5	Pb	9.03	10	2.87	0.76	73.5
			20	3.37	1.31	61.1
			30	3.46	1.54	56.4
6	Cu	8.95	10	3.727	2.250	39.6
			20	4.045	1.843	54.4
			30	4.438	2.612	41.1

RHODE ISLAND
WATER RESOURCES CENTER

UNIVERSITY OF RHODE ISLAND
1892

COMPLETION REPORT FY-1983 PROGRAM

RAPID DETECTION AND IDENTIFICATION OF BACTERIA IN SEWAGE AND NATURAL WATERS BY MEANS OF TIME-RESOLVED LASER SPECTROSCOPIES

by

W.H. Nelson and J.F. Sperry

COMPLETION REPORT

RAPID DETECTION AND IDENTIFICATION OF BACTERIA IN SEWAGE AND NATURAL WATERS BY MEANS OF TIME-RESOLVED LASER SPECTROSCOPIES

by

W. H. Nelson and J. F. Sperry

Project No. G867-02

The research on which this report is based was financed in part by the United States Department of the Interior, as authorized by the Water Research and Development Act of 1978 (P.L. 95-467).

Completion Report

Objectives:

The objective of this project has been the investigation of sensitive methods of rapid detection and identification of bacteria. Specifically, we have studied the use of resonance Raman and time-resolved fluorescence spectroscopies.

Related Research:

Previously, we have shown (1) that chromobacteria can be distinguished on the basis of distinctive resonance Raman spectra. Spectra were excited by low-power argon ion laser radiation at 488 nm and are due to the presence of carotenoid pigments. A spectrum of Flavobacterium arborescens is attached (Figure 1). Algae have been studied in similar fashion.

Methods and Procedures:

Using a Raman spectrometer produced commercially by Spex, Inc. were able to laser illuminate and count two types of bacteria under the microscope. Because it was possible to see the laser-excited bacteria while the resonance Raman spectra were being obtained, it was possible to estimate closely the number of bacteria giving rise to a spectrum.

Because of the obvious presence of distinctly different fluorophores in bacteria, we have attempted to assess whether marked differences in fluorescence lifetimes can be used as a means of bacterial investigation. Toward that end, we have studied the fluorescence lifetimes by means of a PRA instrument with 300 ps resolution. In fact, lifetimes between 500 ps and 20 ns could be assessed if no more than three major components were observed at a specific emission wavelength. Emission wavelengths were isolated by means of interferene filters.

Principal Findings and Their Significance:

Spectra attached (Figure 2) of the two types of flavobacteria were the result of scattering from 25-50 organisms. Laser power was low (~5 mw), and moderate background fluorescence was present as interference. Thus, this experiment did not seriously press the potential detection limits. It is clear that the resonance Raman technique can be highly sensitive, and this experiment suggests that both remote detection and detection from mixtures is possible in principle.

In pratice, it is doubted that excitation with visible radiation will allow effective identification of bacteria, simply because most bacteria are not intensely colored and do not give strong resonance Raman spectra in the visible range.

Perhaps a more serious problem is the omnipresent fluorescence due to the cell components or media. A typical bacterial fluorescence emission spectrum is attached. This spectrum of S. epidermidis (Figure 3) excited at 220 nm shows a very broad, relatively featureless bond between 285 and 600 nm due to the contributions of various cell components. On casual examination, problems associated with 285-600 nm resonance Raman excitation are obvious. The fluorescence "background" will obliterate any resonance Raman spectra since the resonance Raman spectra usually are of about the same intensity as the fluorescence, or, an order of magnitude or more, less intense.

The spectrum of S. epidermidis, on the other hand, is even more significant in terms of what it does not show -- fluorescence intensity below 285 nm. This means there should be the possibility of excellent resonance Raman sensitivity associated with cell components which absorb below 285 nm. Since many of the most important cell nucleic acid and protein components absorb in the 255–290 region or lower, it is apparent that a study based on these will be most attractive. Preliminary studies (3,4) of mononucleotides, tyrosine, tryptophan, DNA, and living cells (Figure 4) show that under very low powers, 2 mw, excitation at 257 nm, very intense, characteristic spectra are obtained without any fluorescence interference.

While resonance Raman studies of DNA especially are expected to provide the basis for rapid identification, fluorescence may provide a better means of assessing cell viability. Fluorescence excitation spectra associated with emission in the 450–550 nm range show marked differences between bacteria which are related to the nature of the bacteria, as well as their history (Figure 5).

The time-resolved fluorecence spectra of several organisms have been studied to determine differences characteristic of specific bacteria. The time-resolved spectra of two of these, Staphylococcus epidermidis and Pseudomonas fluorescens, are attached (Figures 6,7). It is notable that P. fluorescens shows only two components emitting beyond 418 nm (at 1.89 and 7.56 ns, respectively), while S. epidermidis shows three components in that same wavelength range of distinctly different lifetimes (844 ps, 3.88 ns, and 11.46 ns), respectively.

In addition, I wish to note that both resonance Raman and time-resolved fluorescence spectra ultimately will be efficiently excited by a pulsed source in the picosecond time domain. The availability of a reliable, strong tunable source would make possible the simultaneous determination of both types of spectra with separate detectors. Then, a single source and instrument potentially could determine the identity, number, and viability of microorganisms. Remote detection remains a definite possibility, although important questions concerning range and sensitivity must be addressed.

Conclusion:

Resonance Raman and time-resolved fluorescence spectroscopies both show promise as means of detecting identifying and studying bacteria. Because of fluorescence interference in the visible region, and because bacteria are easily differentiated on the basis of nucleic acid content, Raman investigation in the regions associated with strong ultraviolet absorption of nucleic acids is most promising.

Time-resolved fluorescence spectra are notably different for different bacteria. This is very likely due to different degrees of quenching of tyrosine and tryptophan in the proteins of these organisms. Additional work is needed to positively identify the bases for the spectral differences. With a rational basis developed to understand the spectral differences, the time-resolved fluorescence technique has great promise for use in rapid bacterial analysis.

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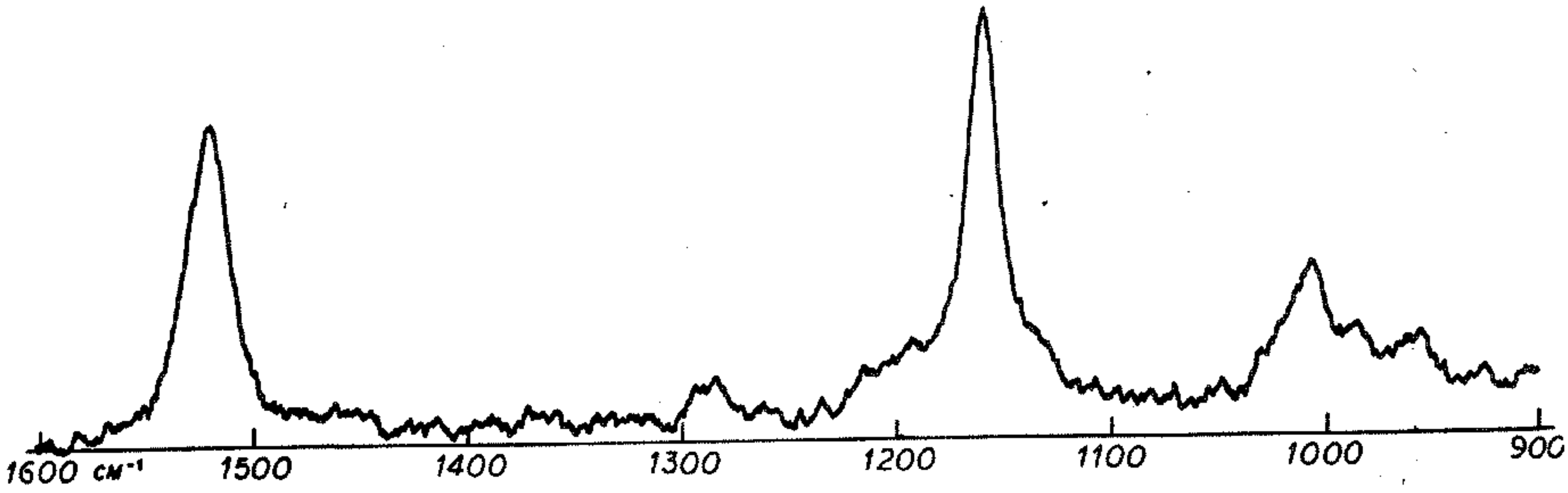
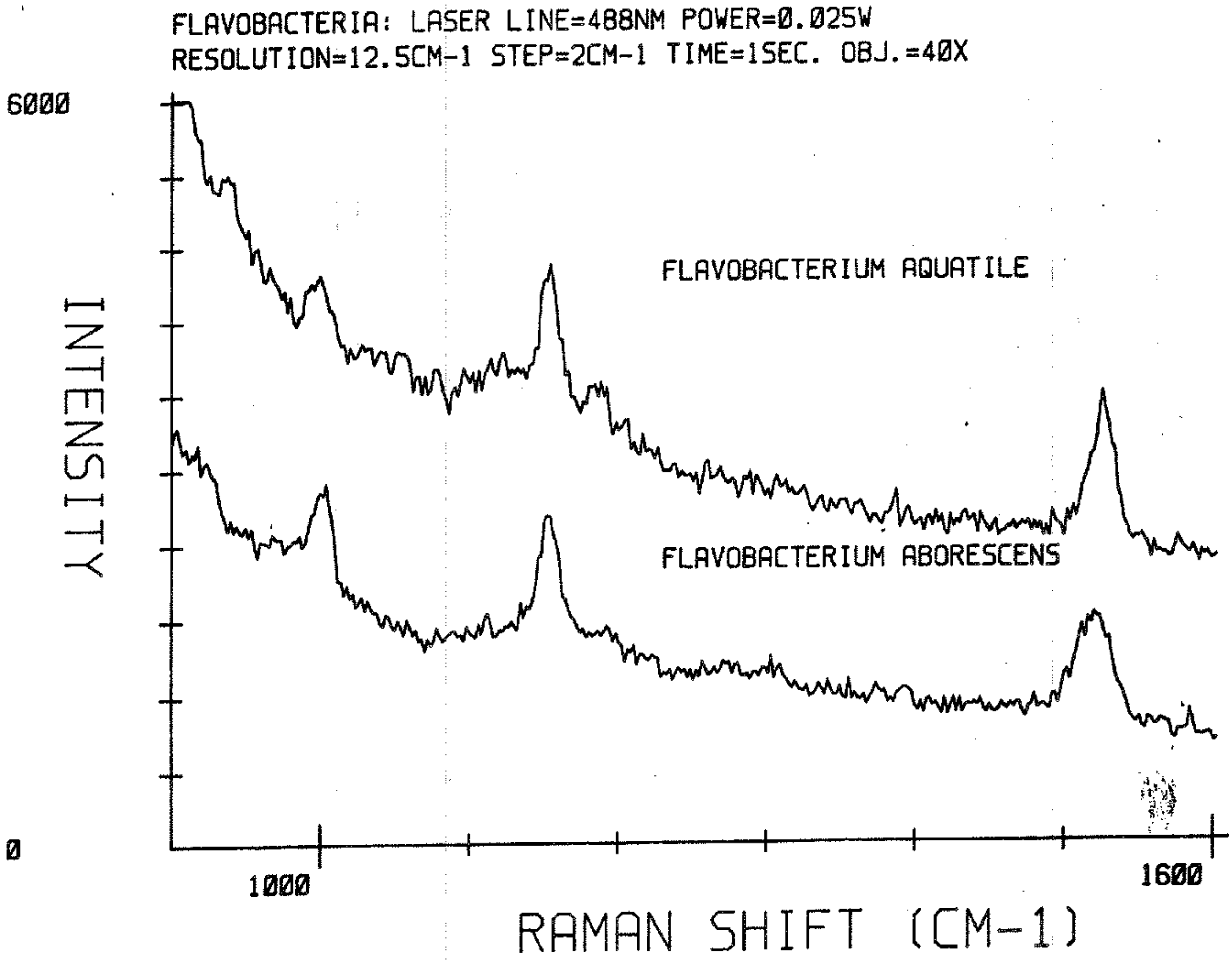


FLAVOBACTERIUM ARBORESCENS

(YELLOW - ORANGE)

Figure 1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6000
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INTENSITY
FLAVOBACTERIUM AQUATILE
FLAVOBACTERIUM ABORESCENS
1000
1600
RAMAN SHIFT (CM-1)

Figure 2

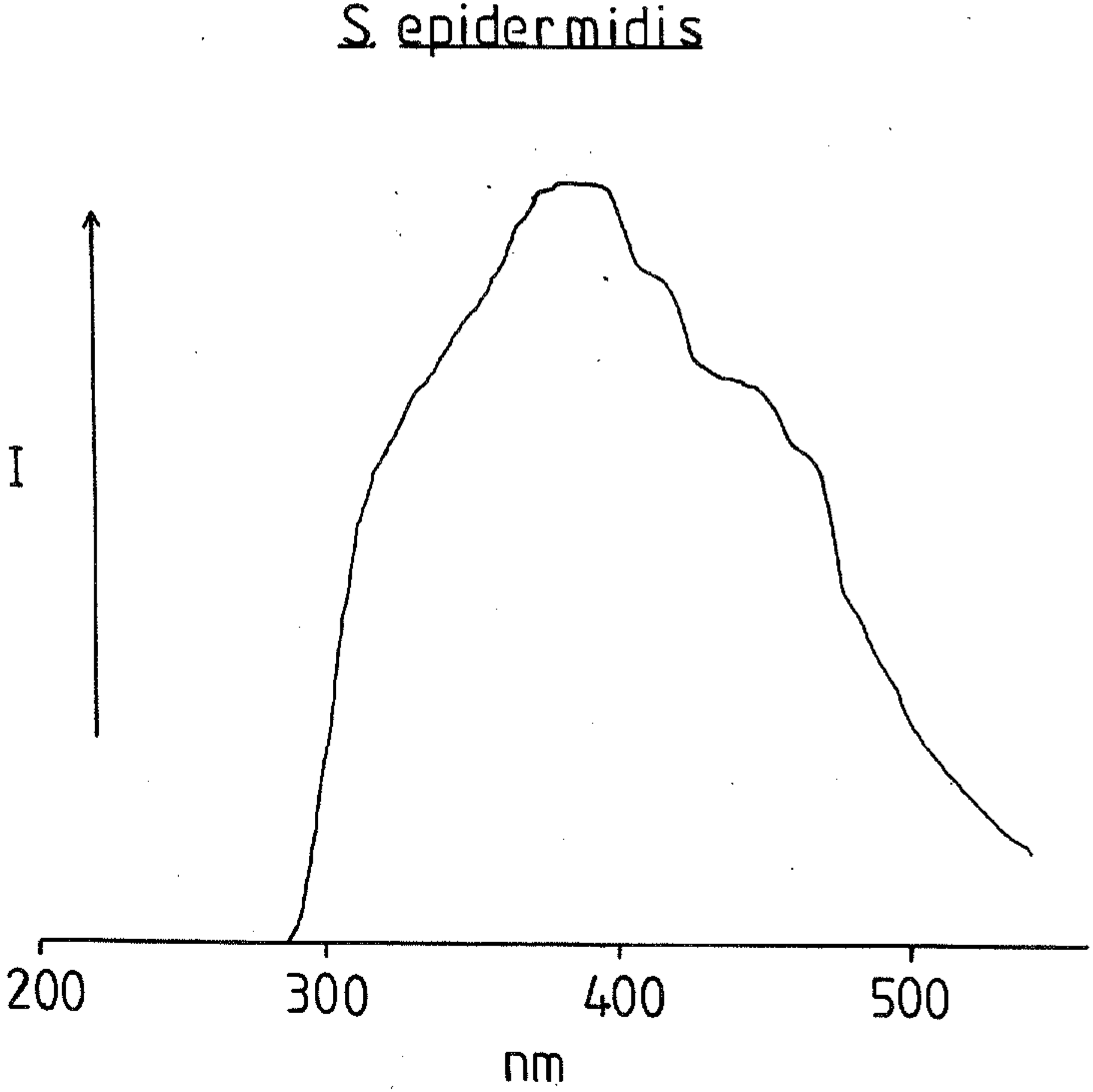
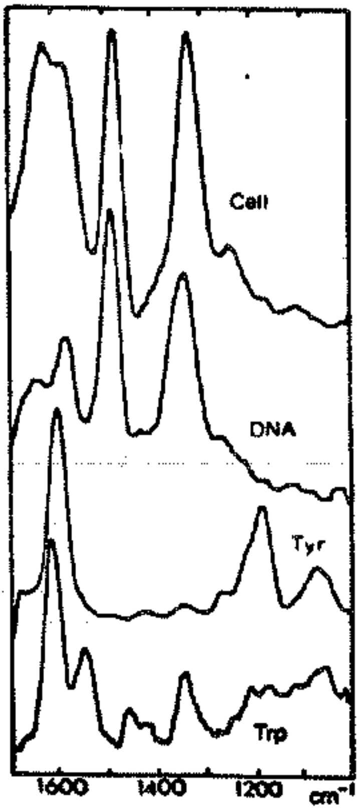
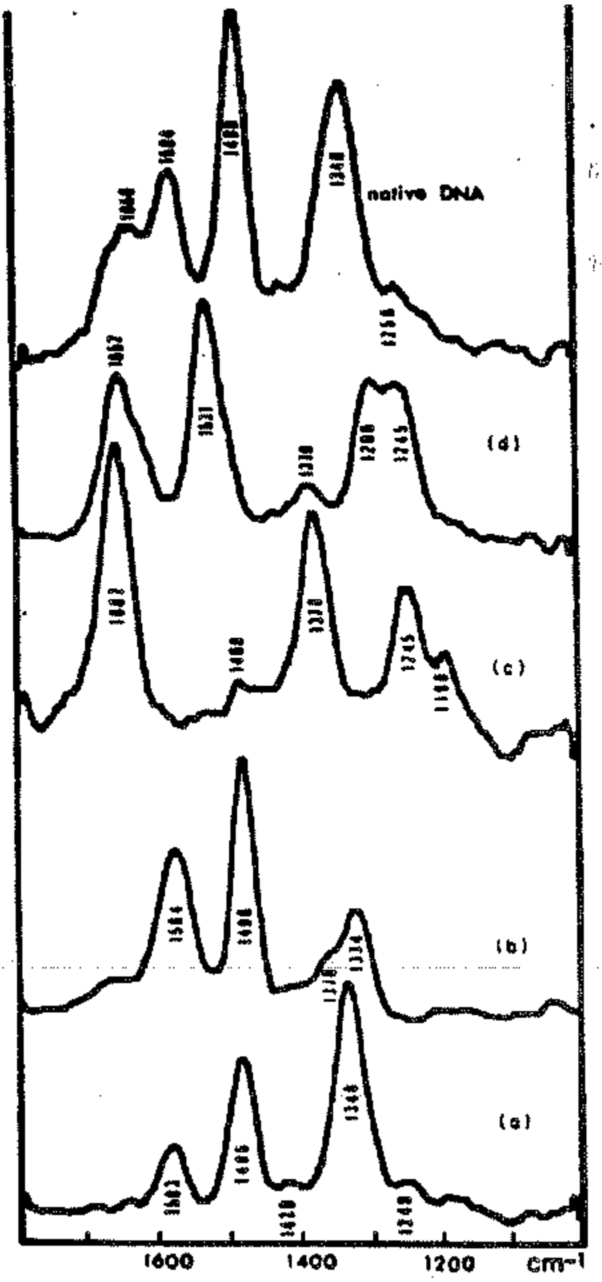


Figure 3



Resonance Raman spectra in the wavenumber shift range of 1000 to 1800 cm^{-1} of *in vitro* DNA 0.1 mol per ml 10^{-2} M NaCl, tyrosine 10^{-3} M pH 7, tryptophane 10^{-3} M pH 7 in neutral aqueous solutions and living cells.



Resonance Raman spectra in the wavenumber shi
range of 1000 to 1800 cm^{-1} of the four mononucleotides i
neutral aqueous solution; 0.1 mg ml^{-1}, λ exc = 257 nm; (a
adenosine monophosphate; (b) guanosine monophosphate; (c
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native DNA in 10^{-2} M NaCl.

Figure 4

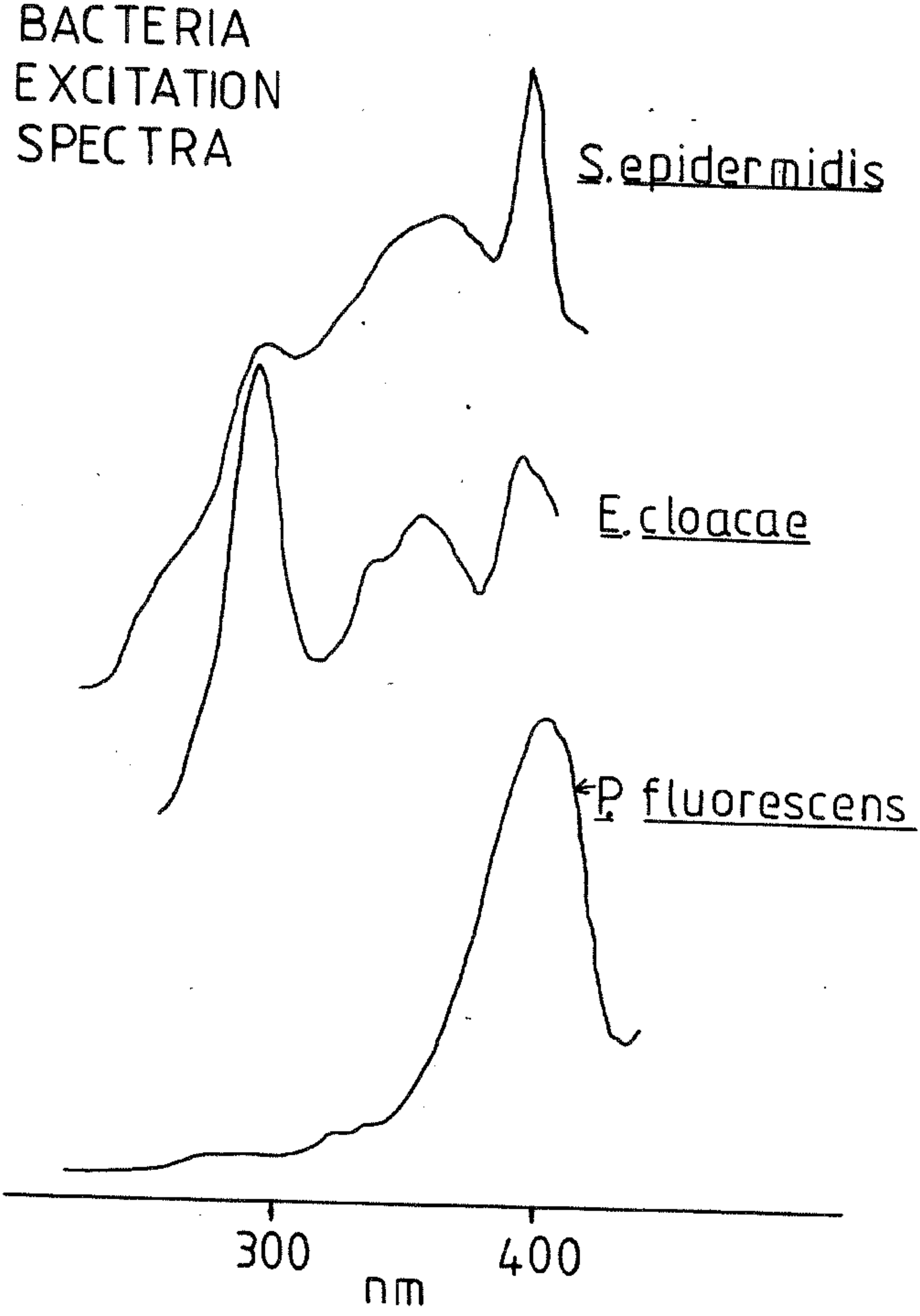
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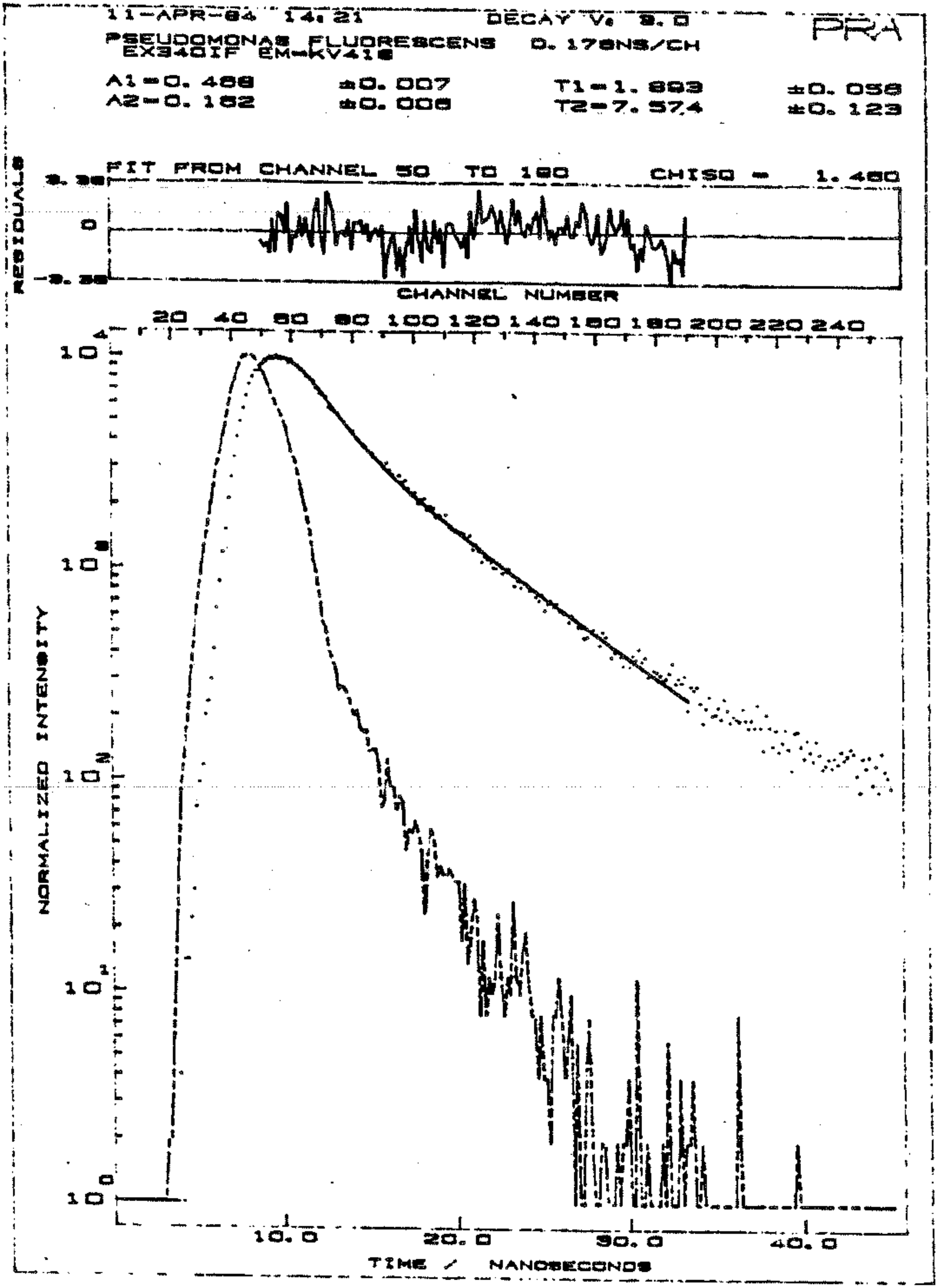
Figure 5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DECAY V. 3.0
PRA
PSEUDOMONAS FLUORESCENS 0.178NS/CH
EX340IF EM-KV418
A1=0.488 ±0.007 T1=1.893 ±0.056
A2=0.162 ±0.006 T2=7.574 ±0.123
FIT FROM CHANNEL 50 TO 180 CHISQ = 1.480
RESIDUALS
3.30
0
-3.30
CHANNEL NUMBER
20 40 60 80 100 120 140 160 180 200 220 240
NORMALIZED INTENSITY
10^4
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10^2
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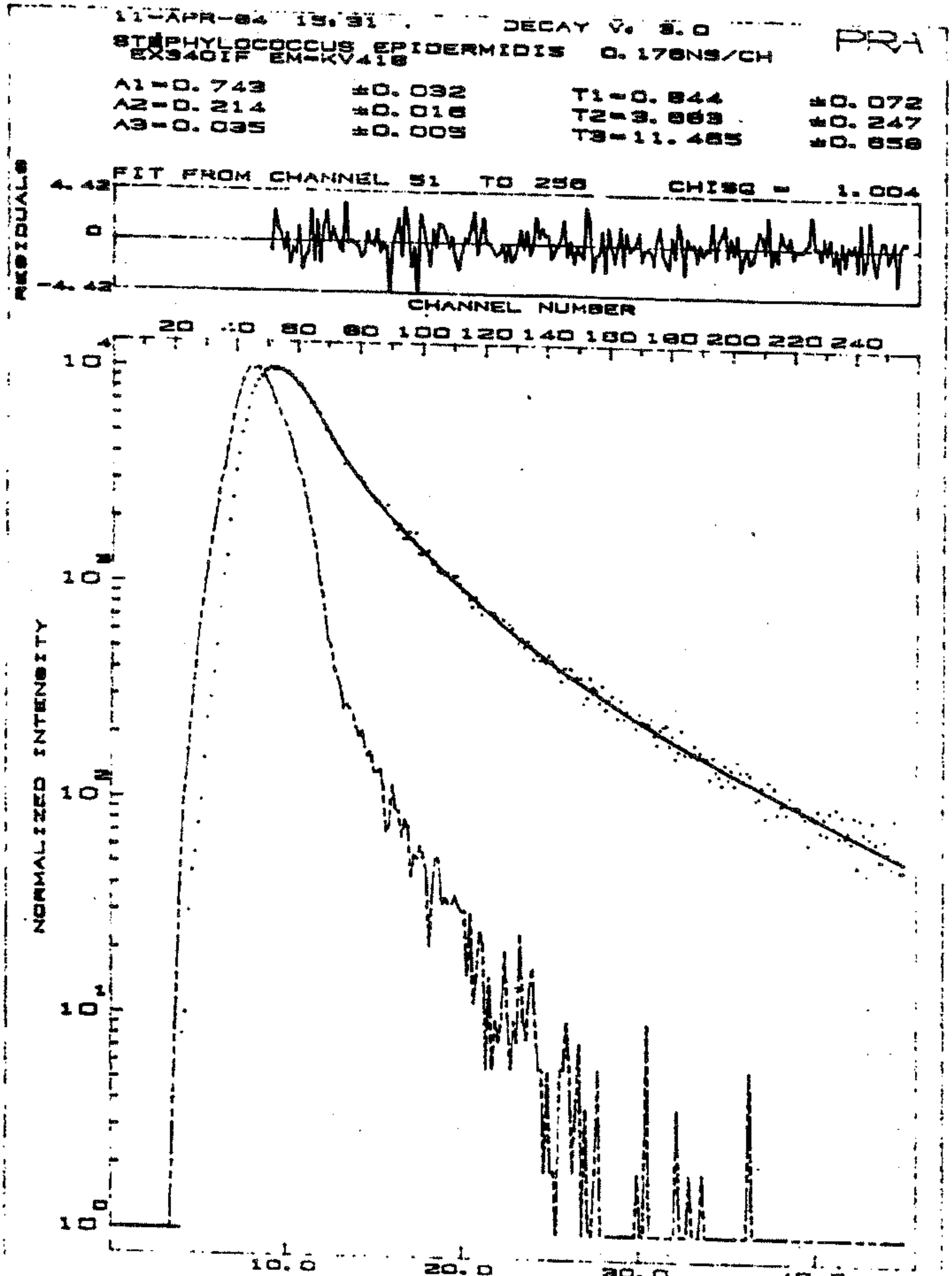
TIME / NANOSECONDS

Figure 6



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STAPHYLOCOCCUS EPIDERMIDIS 0.176NS/CH
EX340IF EM-KV418

A1=0.743 ±0.032 T1=0.844 ±0.072
A2=0.214 ±0.016 T2=3.863 ±0.247
A3=0.035 ±0.005 T3=11.465 ±0.858

FIT FROM CHANNEL 51 TO 256 CHISQ = 1.004

QUASI-CONTINUOUS SIMULATION OF COMBINED SEWER OVERFLOW

BY

MICHAEL JOSEPH MULHARE

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
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1985

QUASI-CONTINUOUS SIMULATION OF CSO

MASTER OF SCIENCE THESIS

OF

MICHAEL JOSEPH MULHARE

APPROVED:

Thesis Committee

Major Professor Raymond M. Wright

Calvin P. C. Poon

A. A. Michel

DEAN OF THE GRADUATE SCHOOL

UNIVERSITY OF RHODE ISLAND

1985

ABSTRACT

Quasi-continuous simulation couples the detail of event simulation with historical rainfall records to predict annual pollutant loadings. This study furthered the advance of this technique by developing a systematic approach for standardization and verification of the quasi-continuous framework. A 28 year rainfall record was used to develop nominal frequency curves for peak rainfall intensity and total rainfall. The historical record was searched for actual storms that represented the frequency curves. These reference storms, in conjunction with a calibrated Stormwater Management Model (SWMM), were used to develop empirical pollutant load response relationships.

Verification of the QCS technique was accomplished by directly comparing the annual pollutant loadings predicted by QCS to those predicted by conventional continuous simulation. The peak rainfall intensity load response curves predict accurately the loadings of continuous SWMM simulation. For the average rainfall year, the loadings predicted using the peak intensity load response curves differed by less than 3.25 percent.

The quasi-continuous technique was used to simulate proposed abatement strategies. Results indicate for an average year of precipitation the optimum use of interceptor capacity through modification and relocation of slot structures provided pollutant load reductions to local receiving waters approaching the equivalent of secondary treatment.

ACKNOWLEDGEMENTS

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INTRODUCTION

During the mid-nineteenth century, municipalities began construction of sewer systems. These early collection networks were designed to transport sanitary and industrial wastes as well as stormwater runoff to the nearest water body. As people became more aware of the health problems associated with this disposal practice and methodologies to stabilize sewage were developed, the construction of centralized wastewater treatment plants began. Interceptor sewers were built to transport the dry weather flow from the existing combined sewers to the treatment facilities. Hydraulic diversion structures, usually slots or weirs, were constructed within the combined sewer. The diversion devices allowed dry weather flow to enter the interceptor, however, during a storm event the capacity of the diversion structures is exceeded and a mixture of stormwater runoff and wastewater is discharged to a receiving water.

The impairment of water quality from combined sewer overflow (CSO) is difficult to predict. The dynamic nature of rainfall events and the random frequency of events produce overflows that can vary significantly in concentration and mass loading of pollutants. In addition, there is little consistency observed when comparing the characteristics of overflow from one drainage basin to another (Colston,1974). However, by comparing average concentrations of CSO, raw sanitary wastewater and stormwater, certain trends can be established. Typically the biochemical oxygen demand (BOD) of CSO is 100 milligrams per liter (mg/l) which is approximately half the concentration of sewage and 3 times the concentration of stormwater runoff. The average suspended solid (SS) concentration for CSO is 400 mg/l. The average concentration of SS found in sewage and runoff are 200 mg/l and 600 mg/l, respectively. CSO and stormwater discharge can induce shockloading to a water body. A rainfall event with an intensity of 1 inch per hour (in/hr) can increase the dry weather flow of a river or stream by 2 orders of magnitude. During a storm event 95 percent of the organic loading to a water body can be attributed to stormwater runoff and CSO (Field and Turkeltaub, 1981).

Nationally there are more than 1300 municipalities, with a population of 54 million people, served by combined sewers. There are over 50,000 miles of combined sewers that discharge through 20,000 outfalls (Field, 1973). Over 15 percent of the stream miles in this country are water quality limited because of CSO and urban runoff. Secondary treatment of point sources will not produce the required receiving water quality necessary to maintain stream classifications in many urban areas (Field and Turkeltaub, 1981).

In the Providence, Rhode Island area there are 65 outfalls that during and following a precipitation event, the hydraulic capacity of the system is exceeded discharging a mixture of urban runoff and untreated sewage to the Providence River and its tributaries, the Moshassuck, Woonsaquatucket, and Blackstone Rivers. These discharges induce water quality problems that include: a) depression of oxygen levels; b) increases in sedimentation, nutrient levels, and turbidity; and c) presence of toxic chemicals and pathogenic organisms. The magnitude of the CSO problem in the Providence area is of such proportion that even with advanced wastewater treatment at existing treatment facilities, water quality would still be severely impaired (Brueckener, 1979).

In considering the needs of the entire state, the development of a CSO management strategy is listed as one of the top water quality priorities (Bureckener, 1979). The economic impact of CSOs is most strongly felt by the shell fishing industry. Some of the most productive shell fishing areas in the country are located in upper Narragansett Bay. These areas are subject to a minimum of 7 days closure after rain events with an accumulation of 0.5 inches or more of rainfall in 24 hours (Figure 1).

In 1977 the Combined Sewer Management Report (CSMR) was completed for the Providence 201 Facilities Plan, (Anderson - Nichols, 1977). In this report specific CSO abatement alternatives are evaluated. The recommended strategy is a concept which involves aggregating the sixty-five overflows into nine districts. Flow-through satellite treatment plants would provide the equivalent of primary treatment and disinfection in each of the districts (Figure 2). In 1979 the present worth cost of the project was set at 188,590,000 dollars.

In the analysis for the CSMR, quality and quantity estimates for CSO and urban runoff were based primarily on other work, (Graber, 1978). These estimates were basic, relying entirely on quality runoff coefficients from the literature and a relatively simple approach to determining runoff/rainfall relationships. This simplistic approach did provide information adequate for that planning stage. It, however, does not approach the current state-of-the-art in hydrologic and water quality stormwater modeling.

In 1980 the Narragansett Bay Water Quality District Commission (NBWQDC) received control of the sewerage collection system and treatment plant from the city of Providence. During the first years of its existence the NBWQDC has modified the earlier recommendations. The current strategy requires the investigation into the feasibility of two or three satellite facilities in place of the nine proposed (Metcalf and Eddy, 1983).

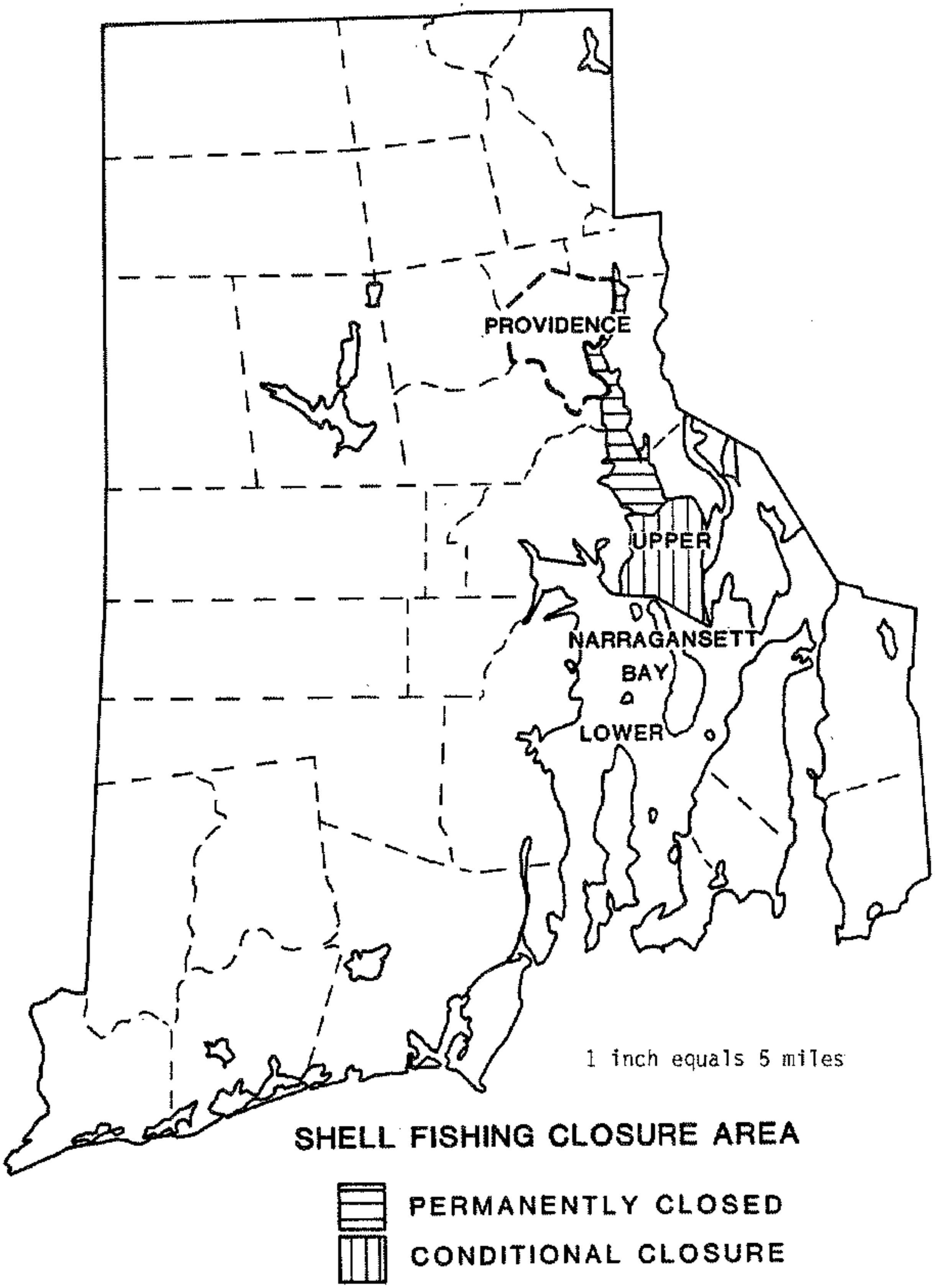
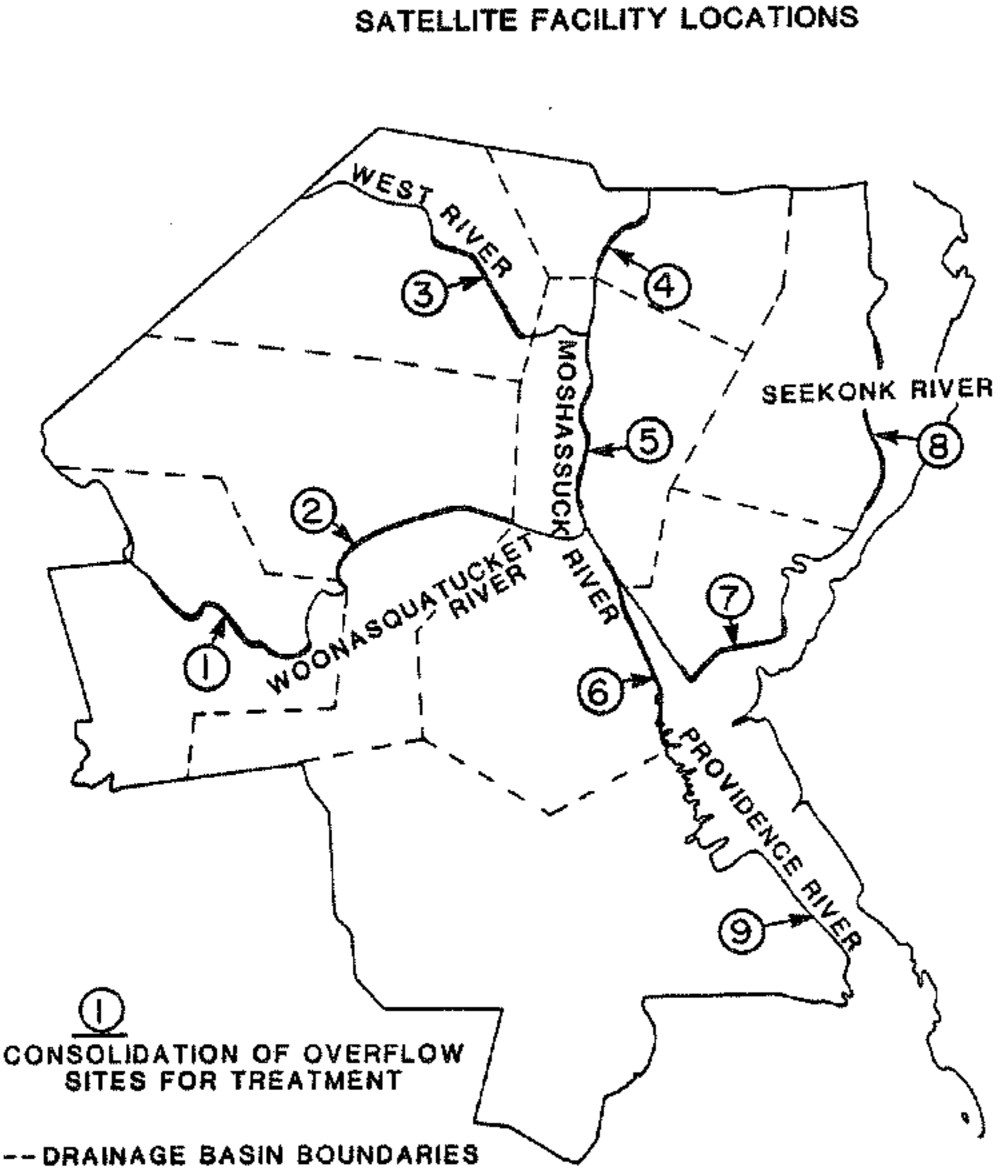


Figure 1. Area of Shell Fishing Closure



1 inch equals 1 mile

Figure 2. Approximate Satellite Facility Drainage Basins

OBJECTIVES

A quasi-continuous simulation framework for evaluation of CSO abatement strategies was recently formulated (Murphy, 1982). This procedure combines the detail of event simulation with long term continuous prediction. This investigation served to modify and verify this procedure with application to the Providence combined sewer system.

The site selected for field investigations was the area originally designated for development of satellite facility 1 (Figure 2). The CSO abatement alternatives investigated were selected to address the NBWQDC's current strategy of regional satellite facilities. The objective of this study addressed the feasibility of reducing the annual pollutant load to the Woonasquatucket River by modifying the flow divider structures, thus increasing the volume of wastewater/stormwater transported by the local interceptors. Treatment of this flow would occur at the regional facility downstream of the study area. The objective should be met with a minumum of structural modifications to the collection system. This strategy would replace the requirement for a satellite facility in drainage area 1.

The specific elements of this study include:

1. Modifications, validation and application of the quasi-continuous framework for development of pollutant load to rainfall response relationships.
2. Ranking of CSO abatement strategies by comparing predicted reductions in the CSO pollutant loading for BOD, COD, and SS.
3. Adaptation calibration and validation of the Environ-

mental Protection Agency (EPA) Stormwater Management Model (SWMM) to the study area.

4. Increase the CSO data base for the Providence area, through field analysis for the determination of hydraulic and pollutant concentrations from overflow events. Analysis of land usage and topographical maps, and cross sectional sewer plates to determine the physical characteristics of the study area.

RELATED RESEARCH

The three basic requirements needed in any CSO modeling effort are a) accurate simulation of CSO water quality and quantity b) evaluation of water resource benefits (pollutant mass loading) resulting from alternative abatement strategies, and c) sufficient model detail to evaluate optimization of the existing collection system. The model which satisfied all three requirements is the EPA Storm Water Management Model (SWMM) Version III.

The original intent of EPA and its contractors was to develop a comprehensive mathematical model capable of representing urban stormwater runoff and CSO phenomena. The original SWMM was published in 1971 (Metcalf and Eddy, 1971 a,b,c,d). Since this effort, SWMM has undergone changes as a result of user input and critical review. In 1975 SWMM Version II was released (Heaney, 1975; Huber, 1975), followed in 1983 by Version III (Huber, 1983).

The SWMM Version III is a relatively sophisticated hydrologic, hydraulic and water quality simulation program. It is a deterministic model which can be utilized in a single event or continuous mode. The model has the capability of simulating varying size multiple catchment drainage areas. The model is divided into "blocks" called Runoff, Transport, Extended Transport (EXTRAN), Storage/Treatment and Receiving. The Runoff block contains the equations for determining the amount of overload flow and surface runoff pollutant loadings, following a storm event. The Transport section of SWMM is used for simulating flow through the collection pipe network. Quality parameters can be included to simulate the concentration of pollutants in the base sewer flow. EXTRAN is a sophisticated hydraulic package which frees the modeler from the constraints of dendritic representation. Drainage system conformations that can be simulated include parallel pipes, looped systems, lateral diversions and partial surcharging conditions. The Storage/Treatment routines are primarily capable of simulating runoff control systems that are based on particle settling theory. The Receiving package, which is for simulation of CSO and/or stormwater receiving water, has not been released for SWMM Version III (Huber, 1983).

The quantity subroutines have been calibrated and verified successfully in many studies (Norman and Estes, 1982; Orlob, 1975). Purenne (1979) developed a method which uses a simplified catchment discretization scheme. Small subcatchments are aggregated into larger units. A weighted average value is used for determining model input parameters. The hydrographs produced by SWMM for a complex and simple discretization pattern were similar. Ahmad (1980) incorporated an equivalent gutter length term into SWMM. This parameter accounted for storage and routing-time that is lost when a simplistic drainage basin discretization scheme is used. Other studies have determined that by manipulating the subcatchment width parameter, a reasonable quantity calibration of SWMM can be achieved (Jewell, 1977).

The water quality subroutines of SWMM have not been successfully calibrated or verified. Colston (1974) used SWMM to predict SS concentrations. In this study, the input parameters for quality prediction were either literature values or model default values. The model predictions did not compare to the observed concentrations. Investigations by Cermola (1979) and Lorant (1980) determined that the accuracy of quality simulation does not approach that of quantity prediction. Alley (1980) suggested that to improve the quality capabilities of SWMM, users should rely on mathematical relationships that define site specific quality observations.

Jewell (1980) conducted a study to develop improved stormwater pollutant prediction techniques. The study reviewed data representing 261 storm events from 26 drainage basins in an effort to develop general pollutant washoff functions. It was concluded that generalized equations could not be developed. The runoff or CSO from drainage basins can only be accurately simulated when site specific data is utilized. Furthermore, when sufficient data is available, quality models should also be developed for the specific investigation.

In the previously mentioned studies, the researchers were attempting to calibrate SWMM in a manner that would predict the instantaneous flux or total load of a pollutant for an individual event. A method of calibrating has been developed that will accurately predict the average annual loading of a pollutant (Jewell, 1978). The objective of this calibrating procedure is to fit the model to average conditions. The approach does not attempt to achieve close agreement between measured and predicted data for individual storm events. The intent is to establish agreement over the entire data set of storm events used for calibration. The criteria for calibration was to reduce the percent error between the predicted and measured total loading (P/M) of a pollutant to less than 1. To achieve a percent error difference of less than 1, the QFACT term, which is the fraction of dust and dirt associated with a particular pollutant, was adjusted. The original QFACT term was divided by the P/M ratio to generate a corrected QFACT value. This process is repeated in subsequent calibration and runs until the desired percent error is achieved. Using multiple storms to calibrate a model for the prediction of annual loadings reduces the bias that occurs when a single event is used for calibration. In the Jewell (1978) study, 5 storms were used to calibrate the model. The P/M ratios for the 5 storms were 1.31, 1.63, 0.75, 2.67 and 0.52. The calibrated model was used to predict annual stormwater pollutant loadings. The annual loadings predicted by the model agreed quite well with the observed measurements. If the model had been calibrated with one storm, the predicted annual pollutant loading would have been 0.52 to 2.67 times the annual loading predicted using the multiple storm calibration technique.

SWMM has been used in CSO management studies as a part of facilities plan development (Ahmad, 1980b; Anderson, 1980; Motta, 1980; Vittands, 1975). For planning studies, continuous simulation is used to generate annual pollutant loadings. Because of the substantial rainfall data requirement, the computer costs of running a continuous model are high. Therefore, the approach to basin discretization, pipe network characterization and number of time steps is simplistic. The lack of detail of a continuous model does not adequately address the dynamics of a CSO event.

Another approach that has been used is the coupling of a detailed event simulator with a design storm to predict annual CSO pollutant loadings. The principle method of developing a design storm is through an intensity - duration - frequency curve (Johansen, 1979). Studies have shown that the rainfall frequency produced by these curves does not correspond to observed runoff. This is because there is no simple linear relationship between the frequency of rainfall events and runoff

(Niemczynowicz, 1983). McPherson as reported by Urbonas (1979) states that the design storms are usually based only on precipitation data with little verification through the investigation of resultant runoff. The use of a design storm is only acceptable when gross comparisons are to be made. Actual historical rainfall information is required for any detailed analysis.

The quasi-continuous simulation framework formulated for the District of Columbia, CSO Abatement Program, by O'Brien and Gere (1983) may be a viable alternative to the design storm simulation and the continuous modeling approaches. The quasi-continuous approach retains the principle advantages of both single event and continuous simulation of sewer systems. In the Washington study, a detailed event model, SWMM, was used to simulate a set of reference storms developed from historical rainfall data. In this study a long-term rainfall data base was dissociated into individual events. The events were characterized by various parameters, including total rainfall, duration, peak intensity and antecedent dry period. The parameters peak hourly intensity and total rainfall were determined to be the most important in the prediction of CSO impact (Murphy, 1982). A frequency distribution curve was developed for peak intensity using a 28 year rainfall record. Five target values were selected that represented the distribution curve. The historical record was searched for actual events that had peak intensities equal to the target values. These reference storms were then used in conjunction with the EXTRAN block of SWMM to predict the quantity of CSO. The hydraulic overflow predictions were combined with pollutant concentration data to determine pollutant loadings for the reference storms. A pollutant load response curve with respect to maximum hourly intensity was developed to project pollutant loading for any given peak hourly storm intensity (O'Brien and Gere, 1983). The quasi-continuous framework maintains the detail necessary for simulation of the dynamic nature of CSO events for evaluation of abatement alternatives and predicts the impact the alternatives will have upon pollutant loadings.

The Providence CSO system has been identified as the primary cause of water quality degradation of the Providence River and its tributaries. Any significant improvement of water quality in the Providence River system above the Fox Point hurricane barrier would require the implementation of a combined sewer management plan (Brueckener, 1979). Three CSO management plans were proposed in 1977 (Anderson - Nichols, 1977). The abatement alternatives considered were a) separation of the collection system, b) construction of storage/ treatment facilities, and c) construction of flow-through satellite treatment facilities. The flow-through option was considered the most cost effective.

The satellite facilities would provide the equivalent of primary treatment and chlorination. The Providence collection system would be divided into nine sub-areas. A satellite facility would be constructed in each sub-area. Two of the sub-basins, 2 and 9, were selected for additional study and development of a facility design. Drainage area 2 has 13 combined sewer outfalls. The monitoring program conducted as part of the design phase indicated that the overflow from this area is not significant when compared to the entire combined sewer system. Therefore, a flow-through facility is not required in this area (C.E. Maguire, 1983). Drainage area 9 has one outfall, however, there are over 20 slot connectors which discharge to the combined sewer. The recommended facility design incorporated an aerated grit chamber and a detention/contact basin (Castellucci, 1982).

Metcalf and Eddy (1983) prepared a water quality benefit analysis for CSO abatement. Control measures would be implemented in areas 9 and 2, and the wet weather capacity of the Fields Point wastewater treatment plant would be increased to 200 million gallons per day (MGD) (Figure 3). The study used a simplified version of SWMM to model the collection system. The pollutant of interest was fecal coliform. The model predicted that the construction of a CSO treatment facility in area 9, slot modifications in area 2, and increasing the primary treatment capacity at Fields Point to 200 MGD would reduce the fecal coliform levels, following a storm event, by 27 to 40 percent. However, no field data or site investigations were conducted to calibrate or verify the models predictions.

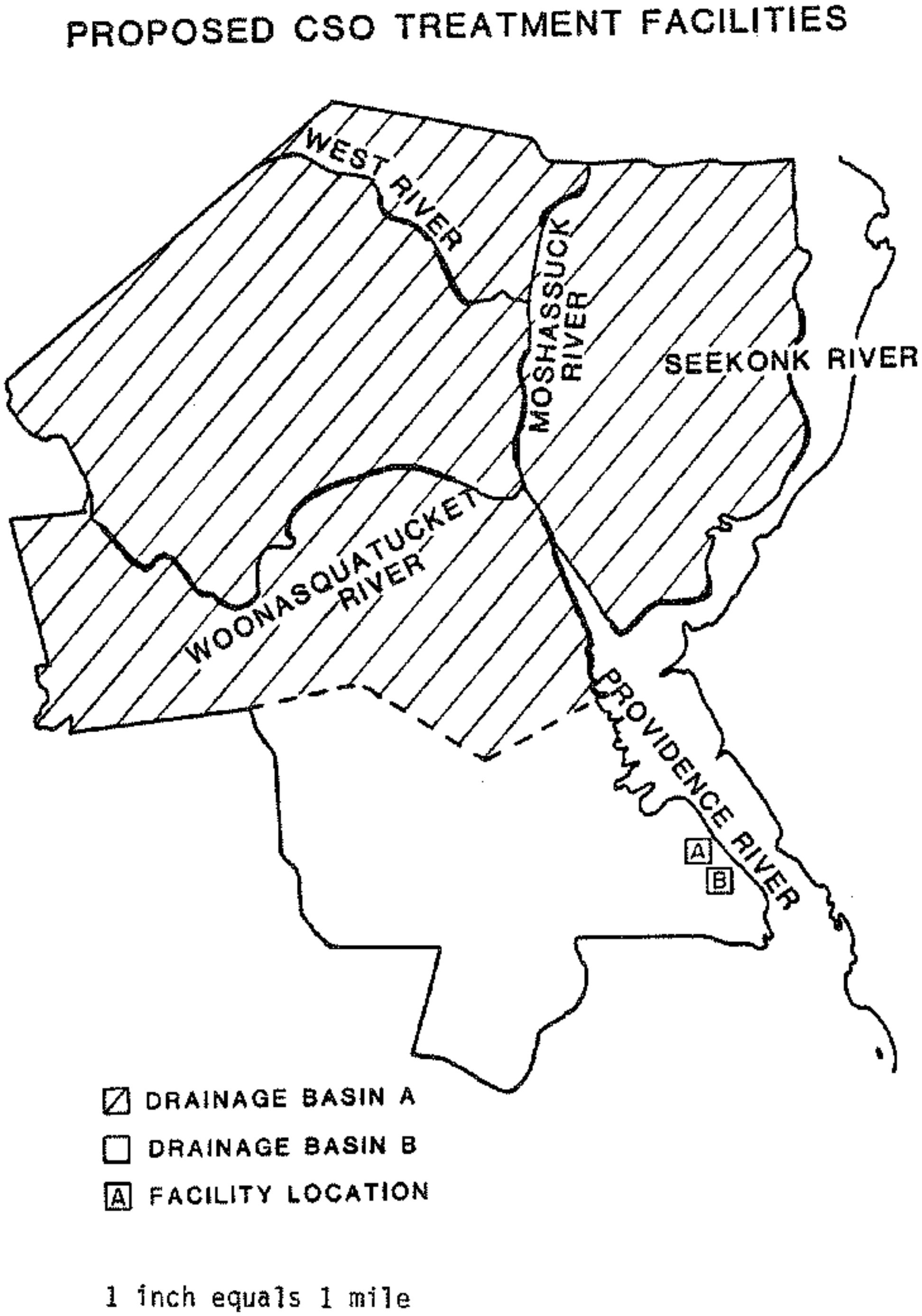


Figure 3. Regional CSO Facilities

METHODS AND PROCEDURES

General

Field investigations were initiated to obtain quantity measurements and flow proportional quality samples. A continuous recording onsite rain gage was operated throughout the study. The data was used to calibrate and verify SWMM Version III.

Continuous simulation of SWMM and the quasi-continuous approach were run on selected rainfall records to determine the validity of the quasi-continuous framework as an alternative for continuous SWMM. Following this procedure selected CSO abatement strategies were evaluated using the quasi-continuous simulation.

Quasi-continuous Framework

From historical precipitation records, individual storms based on a five hour dry interval between events are characterized by peak rainfall intensity and total rainfall. Nominal frequency curves are developed and target frequencies are selected to provide a representative distribution along the curve. The average duration of an event is determined from the record and used in conjunction with peak rainfall intensity and total rainfall to select actual rainfall events from the historical record. These reference storms are the basis for the quasi-continuous procedure.

Abatement strategies and baseline conditions may be simulated with SWMM for each reference storm. Results are used to develop pollutant response curve for each strategy based on peak intensity as well as total rainfall. Either set of curves may then be used for continuous simulation of selected periods of rainfall record. For instance, the loading for each rainfall event in any record can be estimated through the load response curves and the measured peak rainfall intensity. The total load for the rainfall record is determined by summing loadings for each event. Comparisons of abatement scenarios may be made based on pollutant load reduction.

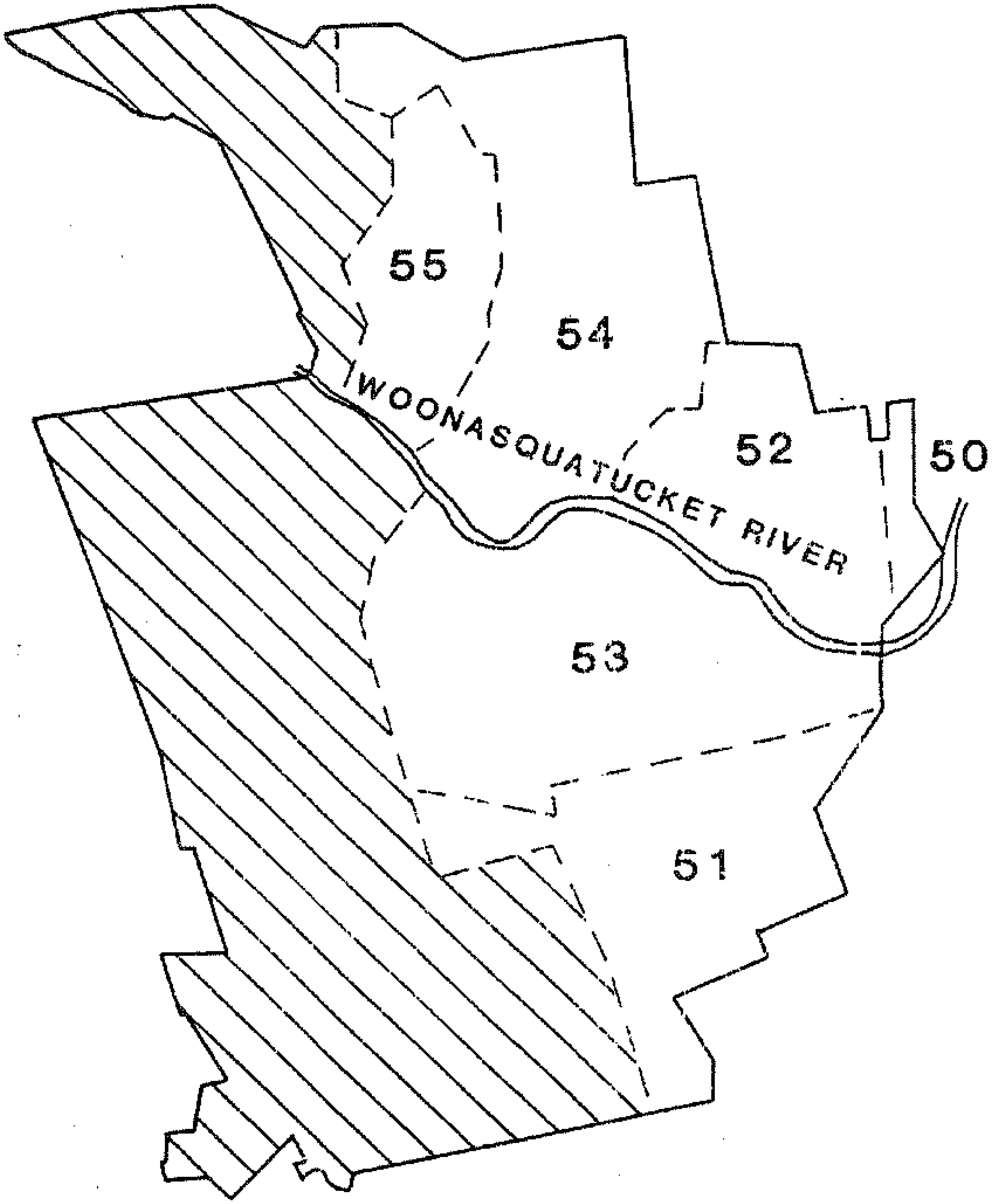
Site Selection

The area contained in the proposed satellite facility 1 has a total drainage area of 502 acres of which 444 acres are mixed residential, 37 acres are commercial and industrial and 21 acres are open space. The area has 13.82 miles of combined sewers which discharge to the Woonasquatucket River at five outfalls, 51 to 55 (Figure 4).

A comparison of drainage areas (Table 1) indicates the 5 basins are similar in composition. Therefore, since sampling equipment was limited to one flow meter (ISCO/1870) and flow proportional sampler (ISCO 2100), one CSO was selected for data collection. CSO 53 was chosen because it encompassed the largest area and the shallow relief line allowed safe entry.

Runoff Block Development

There are eleven input parameters that are required to generate an overland runoff event by the Runoff Block of SWMM. These parameters fall into two categories, those that are developed specifically for the area of concern and those that are based on literature values. Variables in the first category include each subcatchment's area, width, slope and percent impervious. Parameters in the latter category include resistance factors, depression storage and infiltration.



DISTRICT 1 DRAINAGE AREA

55 CSO NUMBER

▨ SEPARATED COLLECTION SYSTEM

☐ COMBINED COLLECTION SYSTEM

1 inch equals 1600 feet

Figure 4. District 1 Drainage Area

Table 1. - CSO Drainage Basin Characteristics

CSO No.	Area (acres)	Average Slope (ft /ft)	Percent Impervious	Land Usage in Percent			
				Multi-Family	Commercial	Single Family	Open Space
51	116.9	0.0210	44.8	71.4	11.2	16.0	1.4
52	42.8	0.0266	44.5	82.7	9.2	5.2	2.9
53	140.0	0.0161	30.0	77.0	8.2	14.8	0.0
54	130.4	0.0272	41.3	58.2	5.2	32.9	3.7
55	72.4	0.0293	32.8	17.5	2.5	61.4	18.6

The site specific information was developed using an overlay technique. Three overlays were developed. The first overlay was a schematic of the collection system within the drainage basin. This was developed using street and sewer maps. The second overlay was the outer limits of the drainage area developed from topographical maps with a scale of 80 feet to the inch and a contour interval of 2 feet. The third overlay represented the pervious, impervious and hydraulically significant impervious areas. The hydraulically significant impervious areas are those that are directly connected to the collection system by streets, driveways, sidewalks and roof leaders. This overlay was developed using land usage maps, aerial photographs and site inspections.

The collection system and the drainage basin boundary overlay were used to determine the discretization scheme. Each area is independent of the other without any interconnections or loops. A further division in one of the areas was made based on land usage. The final discretization used five subcatchments (Figure 5). Three of the subcatchments are mixed residential, the fourth is entirely multifamily, and the fifth is commercial (Figure 6).

The width of each subcatchment is the distance over which overland flow travels to the main drainage channel. This may be a sewer element, a gutter or a natural drainage channel (Jewell, 1977). In this study the central drainage channel is represented by the natural channel of the subcatchment. In an idealized, symmetrical subcatchment the width is equal to twice the length of the main drainage channel (Huber, 1983). Since most subcatchments are not symmetrical, a skewness factor is required. The skewness factor is an area weighted measure of the position of the main drainage channel with respect to the center line of the subcatchment.

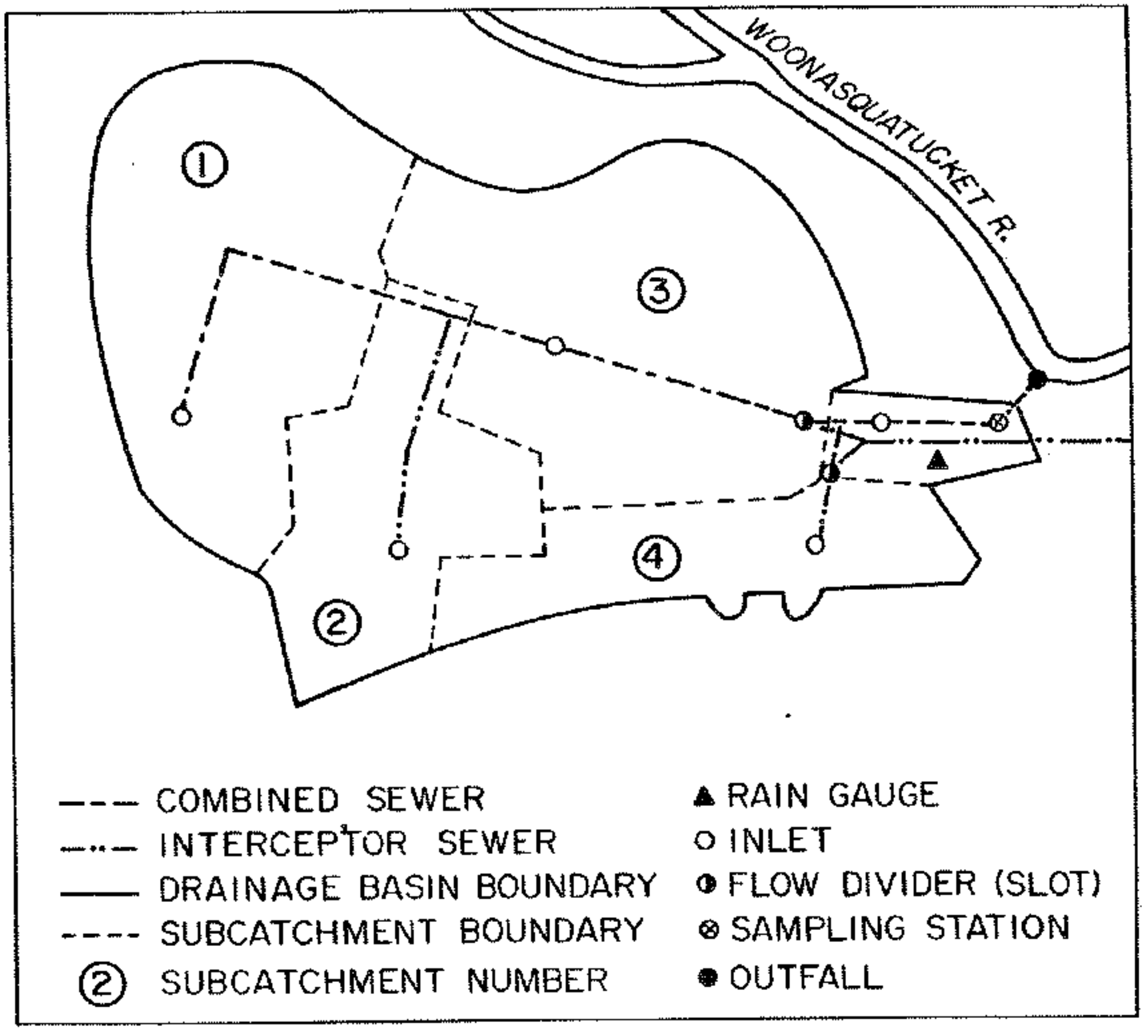


Figure 5. Discretization of CSO 53 Drainage Basin

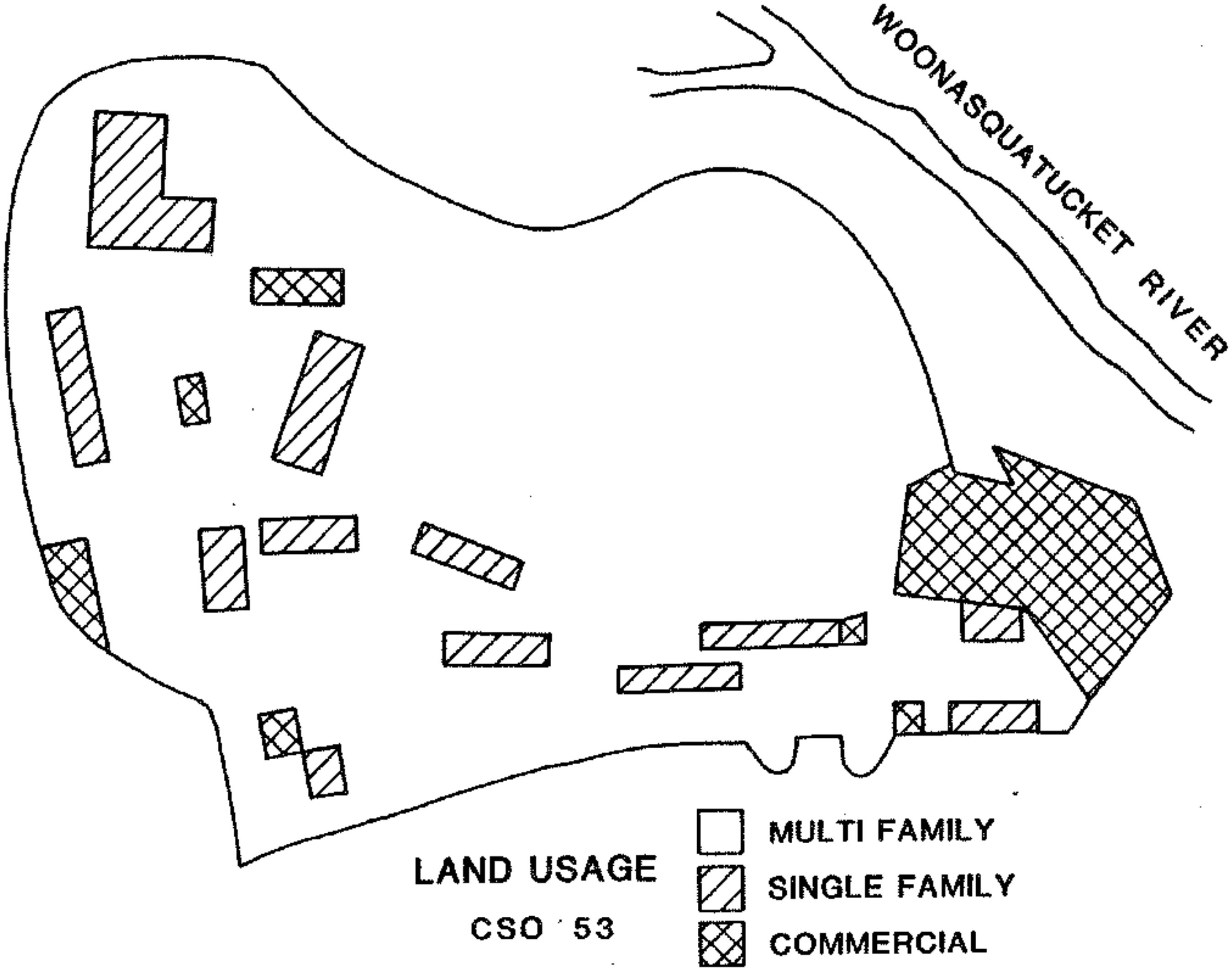


Figure 6. Land Usage in CSO 53 Drainage Basin

The equation for calculating the skewness factor, S is (Jewell, 1977):

$$S = (A-B)/(A+B) \qquad (1)$$

where A and B are the area on either side of the drainage channel. The corrected subcatchment width W is calculated using the following:

$$W = (2-S)L \qquad (2)$$

where L is the length of the main drainage channel.

The percent impervious parameter is the most significant variable for generating total runoff. It is difficult to determine because runoff from an impervious area may flow onto a pervious area and be lost to the system as infiltration. For this study a range of values was determined which had a lower limit set by the hydraulically significant impervious area measured from overlay 3 and an upper limit of all impervious area as measured from the overlays.

The average slope of the subcatchment is determining by calculating the area-weighted average slope (Jewell, 1977). The line of maximum depression for each subcatchment is determined from the topographical maps. This line is divided into equal increments. Perpendicular bisectors are drawn through each increment to the subcatchment boundary. The length of each bisector, x, is measured. The difference in elevation, y, from the two end points is also calculated. The weighted slope is equal to the summation of y divided by the summation of x. For drainage area 53 the slope of the five subcatchments ranged from 0.9 to 3.7 percent (Tabel 2).

Depression storage for impervious areas was developed using an

Table 2. - Coefficients for Quantity Simulation, CSO 53

Subcatchment	Area (acres)	Width (feet)	Percent Impervious Hydraulically Significant	Percent Impervious Total	Slope (ft/ft)	Depression Storage Impervious (inches)
1	44.04	1,940.0	27.0	43.3	0.0094	0.032
2	29.78	2,372.0	30.3	46.9	0.0042	0.043
3	40.50	4,023.0	27.1	39.6	0.0370	0.017
4	21.20	702.0	33.4	51.1	0.0040	0.045
5	7.38	1,295.0	41.3	49.8	0.0310	0.019

empirical relationship developed elsewhere (Kidd, 1978). The relationship estimates the amount of storage as a function of average slope:

$$dp = 0.0303\ G^{-0.49} \tag{3}$$

where dp is the depression storage for the impervious area and G is the average ground slope. The amount of depression storage for the impervious area calculated varied from 0.17 to 0.45 inches. The depression storage for all pervious areas was set at 0.10 inches after Miller (1972) and Viessman (1977).

The Manning's roughness factor used for the impervious area, assuming asphalt and concrete, was 0.14 and for grassed urban areas was 0.20 (Huber, 1983).

Infiltration was determined using the Horton equation (Huber, 1983):

$$fp = f_{\infty} + (fo - f_{\infty})e^{-\alpha t} \tag{4}$$

where fp is the infiltration capacity into the soil in feet per second (ft/sec), f_{∞} is the minimum infiltration rate in ft/sec, fo is the maximum or initial infiltration rate in ft/sec, t is the time from the beginning of the storm in seconds and α is the decay coefficient in sec^{-1}. The minimum infiltration rate f_{∞} is a function of the Hydrologic Soil Group. The predominant soil in the study area is Merrimac Urban (Rector, 1977). The hydrologic group associated with this soil type is group A. Group A soils have an f_{∞} value that range from 0.45 - 0.30 inches per hour. A value of 0.40 was used.

Decay rates reported have ranged from 0.67 to 49.0 hr^{-1}, however, most indicate a tighter range from 3 to 6 hr^{-1}. When there is no field data available, a value of 4.14 hr^{-1} is recommended (Huber, 1983). This implies that under ponded conditions, the infiltration capacity will be two percent of the minimum value after the first hour.

The initial infiltration capacity, fo, is a function of soil type, vegetation cover and the initial moisture condition. An initial infiltration coefficient between 5 and 10 inches per hour is suggested (Huber, 1983). For this study 8 in/hr was used.

Transport Block Development

All flow routing was done using the Transport Block of SWMM. Information requirements for the Transport Block include pipe diameter, shape, slope, length and roughness coefficient. In addition, the capacity of the flow dividers and dry weather flow measurements are needed. The collection system as modeled in CSO 53 is shown in Figure 4. All pipes modeled were circular in shape and of brick construction. A Manning's roughness factor of 0.015 was used for all pipes as suggested by Grant (1981) and Tchobanoglous (1981). The diameter of pipes modeled ranged from 12 to 48 inches with slopes varying from 0.40 to 4.16 percent.

There are two flow dividers in the drainage area located in subcatchments 3 and 4 (Figure 5). The flow dividers are slots which allow dry weather flow to enter the intercepting sewer. The capacity of the slots is limited by the capacity of the connecting pipe. In subcatchment 3 and 4 the capacity of the slots is 1.63 cubic feet per second (cfs) and 6.32 cfs, respectively.

The average dry weather flow for CSO 53 was determined during the infiltration and inflow study for the City of Providence (Anderson - Nichols, 1975). Average dry weather flow was determined to be 0.52 cfs.

Sensitivity Analysis

A sensitivity analysis was done to evaluate the impact of each individual runoff input parameter on model predictions. The analysis included reducing each coefficient by a factor of 0.5 and increasing each coefficient by a factor of 2, while holding all other parameters constant. The model was most sensitive to changes in the percent impervious and subcatchment width (Table 3). Similar results have been reported by others (Huber, 1983; Jewell, 1977; Jewell, 1978). The analysis also showed that the non-site specific parameters have little effect on the overflow hydrograph.

Quantity Calibration

Calibration of the quantity section of the model was done with on-site rainfall data. Rainfall intensities were measured using a tipping bucket rain gage calibrated to 0.01 inches and a continuous recorder. Flow measurements in the overflow line were taken using a bubble flow meter.

The conventional method of calibration is to match the predicted and measured total volume by arbitrarily adjusting the percent impervious coefficient. The subcatchment width parameter is then adjusted to align the predicted and measured peak overflow (Huber, 1983; Zaghloul, 1981). These two parameters are used to calibrate the model for several reasons: (1) subcatchment width and percent impervious have the greatest effect on the shape of the overflow hydrograph; (2) developing the percent impervious term requires considerable effort; (3) adjusting the subcatchment width allows the use of a course discretization scheme which greatly reduces the amount of time required to set up the model and the amount of

Table 3. - Results of Sensitivity Analysis

Parameter	Difference in Percent			
	Total Volume		Peak Overflow	
	Parameter Increase of 100 Percent	Parameter Decrease of 50 Percent	Parameter Increase of 100 Percent	Parameter Decrease of 50 Percent
Subcatchment Width (ft)	+ 8.9	- 7.7	+ 70.7	- 18.9
Percent Impervious	+ 193.2	- 68.9	+ 97.3	- 58.3
Slope (ft/ft)	+ 4.5	- 3.8	+ 9.5	- 9.3
Impervious Resistance Factor	- 7.7	+ 10.2	- 18.9	+ 19.8
Pervious Resistance Factor	0.0	0.0	0.0	0.0
Impervious Depression Storage (in)	0.0	0.0	- 2.5	+ 0.3
Pervious Depression Storage (in)	0.0	0.0	0.0	0.0

Table 3. - Results of Sensitivity Analysis (CONT.)

Parameter	Difference in Percent			
	Total Volume		Peak Overflow	
	Parameter Increase of 100 Percent	Parameter Decrease of 50 Percent	Parameter Increase of 100 Percent	Parameter Decrease of 50 Percent
Maximum Infiltration Rate (in/hr)	0.0	0.0	0.0	0.0
Minimum Infiltration Rate (in/hr)	0.0	0.0	0.0	0.0
Infiltration Decay Rate (1/sec)	0.0	0.0	0.0	0.0

computer time necessary to run to model (Ahmed, 1980; Huber, 1983; Jewell, 1977; Zaghloul, 1981).

Quality Simulation

Three pollutants were modeled during the quality study. The pollutants simulated were suspended solids (SS), five-day biochemical oxygen demand (BOD) and chemical oxygen demand (COD). Data used for calibration were derived from two sources. As with quantity date acquisition, CSO 53 was used for quality data collection. Flow proportional overflow samples were taken using a discrete sampler in conjunction with the bubble flow meter. In addition, quality data accumulation during the CSMR for the City of Providence for CSO 53 was used (Anderson - Nichols, 1977).

In SWMM all parameters that determine the water quality of overload runoff are included in the Runoff Block. The principal mechanisms for determining pollutant loading are pollutant buildup and washoff.

There are four options in SWMM to simulate the pollutant buildup phenomena. These options include linear, power, exponential and Michaelis-Menton equations. The linear buildup functions was used in this study.

Each pollutant was assumed to be a fraction of the dust and dirt on the subcatchment surface. The dust and dirt accumulation variable is based on a study conducted by the American Public Works Association (APWA, 1969) (Table 4). Using the technique developed by Jewell (1978), an area weighted dust and dirt build-up rate was developed for each subcatchment land use (Table 5).

Table 4. - Dust and Dirt (DD) Accumulation Rates (APWA, 1969)

Land Use	Pounds DD/dry day/100 ft curb
Single Family	0.7
Multi Family	2.3
Commercial	3.3
Industrial	4.6
Undeveloped	1.5

Table 5. - CSO 53 Dust and Dirt (DD) Accumulation Rates

Land Use	Pounds DD/dry day/100 ft curb
Mixed Residential	1.9
Multi Family	2.3
Commercial	3.3

The APWA study also determined the fraction of a pollutant associated with the dust and dirt for each land use (Table 6). As with the dust and dirt, an area weighted pollutant coefficient was developed for each subcatchment land use (Table 7).

The washoff phenomena in SWMM is an exponential relationship based on work by others. The form of the general washoff equation is (Huber, 1983):

$$\text{POFF}\ (t) = \text{PSHED}\ (1-e^{Kt}) \tag{5}$$

where POFF is the cumulative amount of washoff at time, t, PSHED is the initial pollutant loading on the surface at t = 0, and K is a coefficient defined as:

$$K = \text{RCOEFF} \cdot r \tag{6}$$

where RCOEFF is equal to the washoff coefficient in in^{-1}, and r is the runoff rate over the subcatchment in in/hr. In the original SWMM development it was assumed that one-half inch of total runoff would washoff 90 percent of the initial pollutant load, resulting in an RCOEFF of 4.6 in^{-1}. Sensitivity analysis has shown that for a wide range of RCOEFF values (0.1 to 20 in^{-1}) there is a little variance in predicted loadings (Jewell, 1978).

Quality Transport Parameters

The only water quality coefficient input from the transport block was the pollutant concentration of the raw sewage. Average concentrations for the City of Providence collection system have been determined to be

Table 6. - Milligrams of Pollutant Per Gram of Dust and Dirt (APWA, 1969)

	Land Use			
Pollutant	Single Family	Multi-Family	Commercial	Industrial
BOD5	5.0	3.6	7.7	3.0
SS	1000	1000	1000	1000
COD	40	40	39	40

Table 7. - Milligrams of Pollutant Per Gram of Dust and Dirt, CSO 53

	Land Use		
Pollutant	Mixed Residential	Multi-Family	Commercial
BOD	4.1	3.6	7.7
SS	1000	1000	1000
COD	40	40	39

170, 290 and 500 mg/l for BOD, suspended solids and COD, respectively (Anderson - Nichols, 1977).

RESULTS AND DISCUSSION

Quantity Calibration

The two parameters that have the most significant impact on quantity hydrographs are the percent land area that is impervious and the width of the subcatchments. The percent impervious factor is the principle parameter in determining the volume of runoff that can occur. The subcatchment width term controls the routing-time which determines the shape of the hydrograph. When calibrating SWMM, the usual procedure is to adjust the percent impervious variable until there is agreement between the predicted and measured volume of overflow. The width of the subcatchment is adjusted to align the position of the measured and predicted overflow peaks.

In this study arbitrary adjustment of the percent impervious variable was not done. The measurement of total volume of runoff would have required placing the additional sampling equipment in the lines above the slots. Since there was only one set of sampling equipment available, this was not possible. Instead, a percent hydraulically significant impervious factor was developed from the overlays. Calibration was accomplished by adjustment of the subcatchment width. The storm of November 28, 1983 was used as input for calibration. The duration of the storm was 3.5 hours and the peak rainfall intensity was 0.6 inches per hour. A 90 percent reduction of the subcatchment width calibrated the model. A difference of 2.5 percent in total volume and a 5.2 percent difference in peak flow was observed (Figure 7).

The model was validated using three independent and dissimilar storms. The results of the verification runs are present in Figures 8,

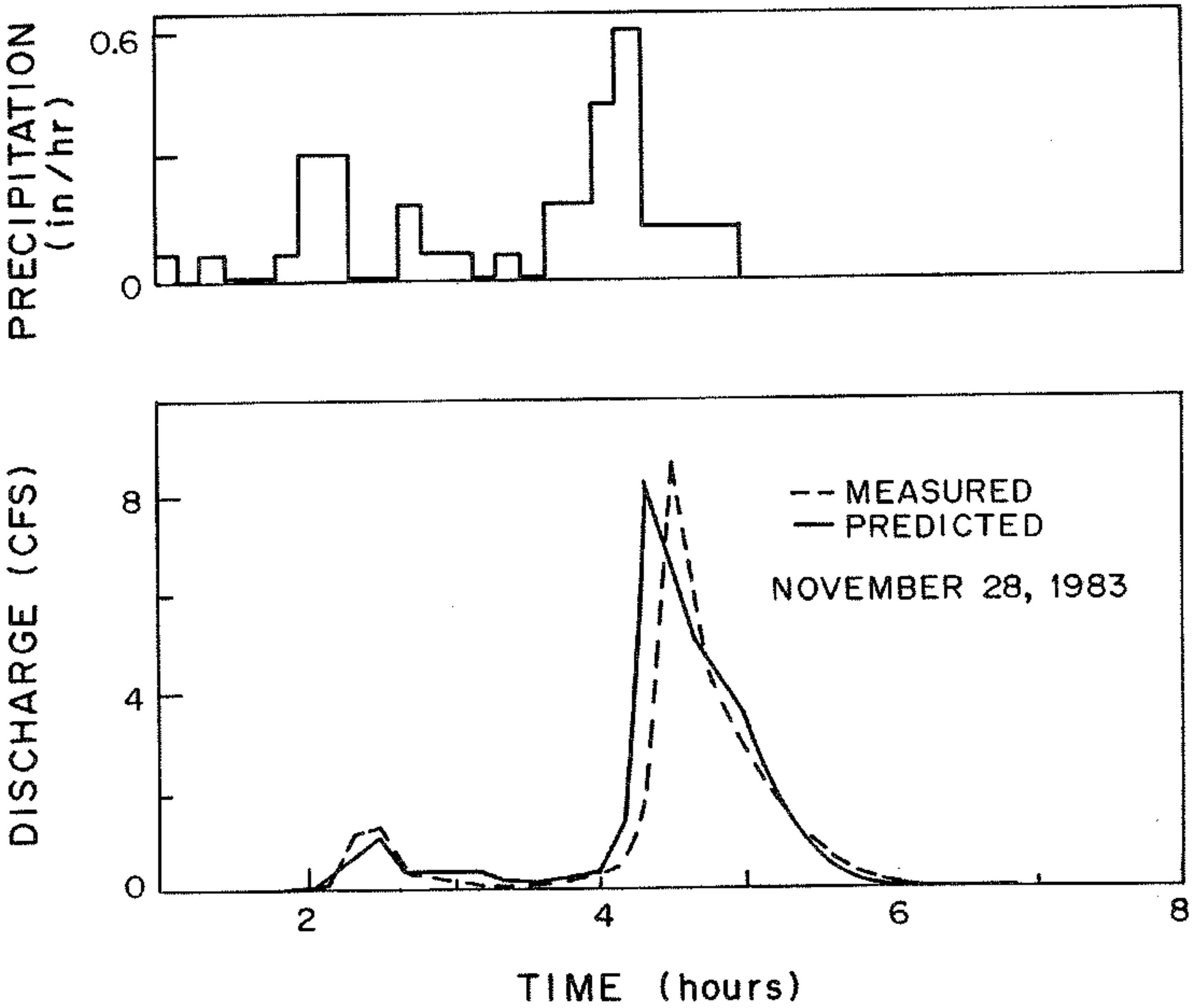


Figure 7. Predicted and Measured Hydrographs for the Storm of November 28, 1983

9 and 10. Review of the hydrographs confirm that the outcome of overflow events were simulated successfully for varied rainfall conditions. The absolute difference of measured and predicted volumes and peak overflows are presented in Table 8.

The technique used to develop model coefficients for CSO drainage basin 53 were employed to determine coefficients for CSOs 51, 52, 54 and 55. The same method of calibration used in CSO 53 was also used in the other CSOs.

Quality Calibration

The three water quality parameters simulated in this study were BOD, COD and SS. SWMM was calibrated to predict BOD and COD average annual loadings using the methodology developed by Jewell, (1978). The BOD calibration data set was made up of 3 storm events. The QFACT parameter for BOD was adjusted using an iteration procedure. The uncalibrated QFACT term was divided by a correction factor. The correction factor was developed by dividing the summation of the three predicted event loadings by the summation of the three measured event loadings. This process was repeated in subsequent calibration runs until the predicted to measured ratio (P/M) for the summation of the three storm events approached unity (Table 9).

The multiple storm calibration technique for the prediction of average annual loading buffers the inherent variability of CSO quality data. This results in a more realistic prediction of annual loadings. If one of the three storms had been used to calibrate SWMM, the BOD annual loading rate would have varied between 0.40 and 1.58 times the

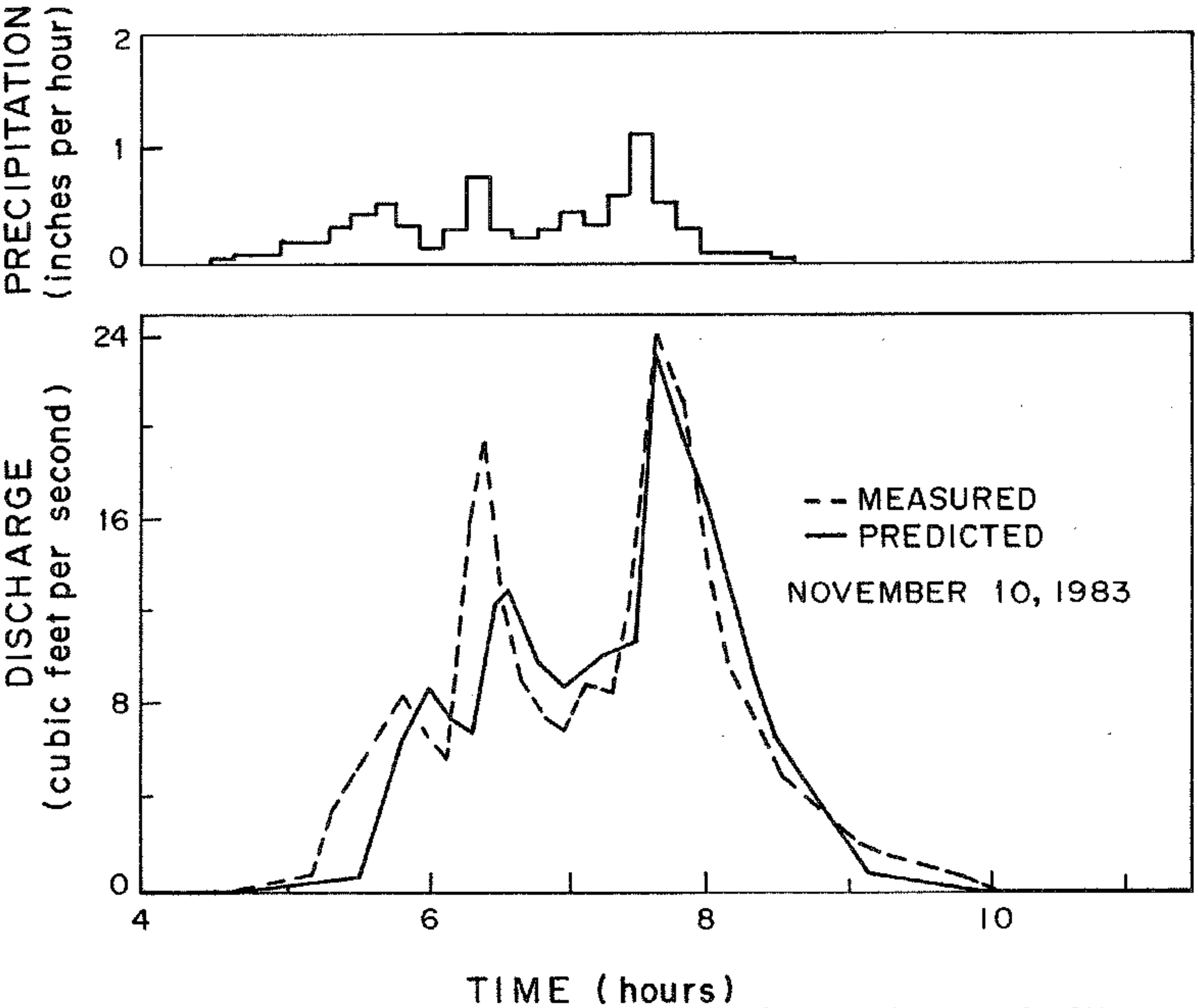


Figure 8. Predicted and Measured Hydrographs for the Storm of November 10, 1983

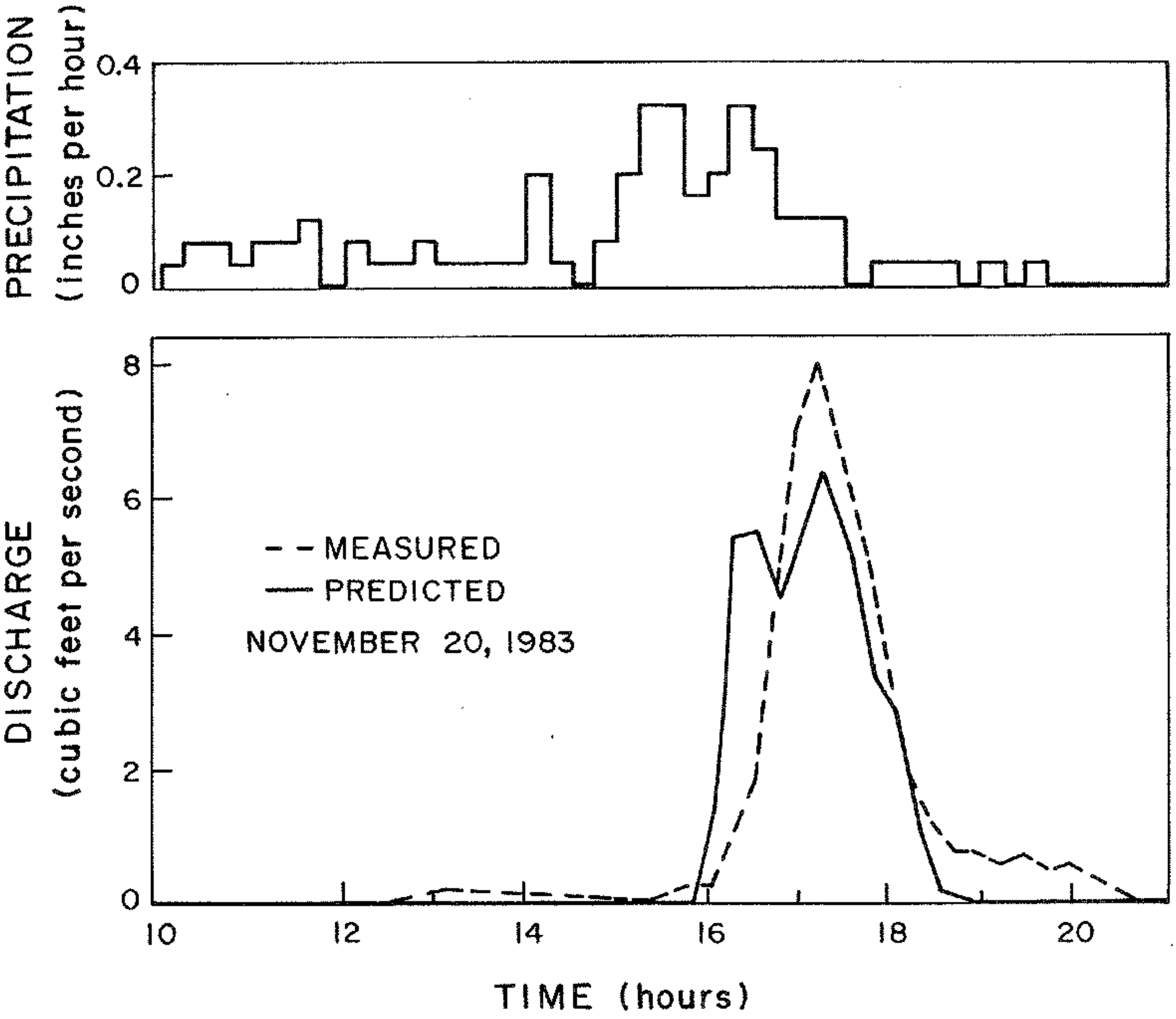


Figure 9. Predicted and Measured Hydrographs for the Storm of November 20, 1983

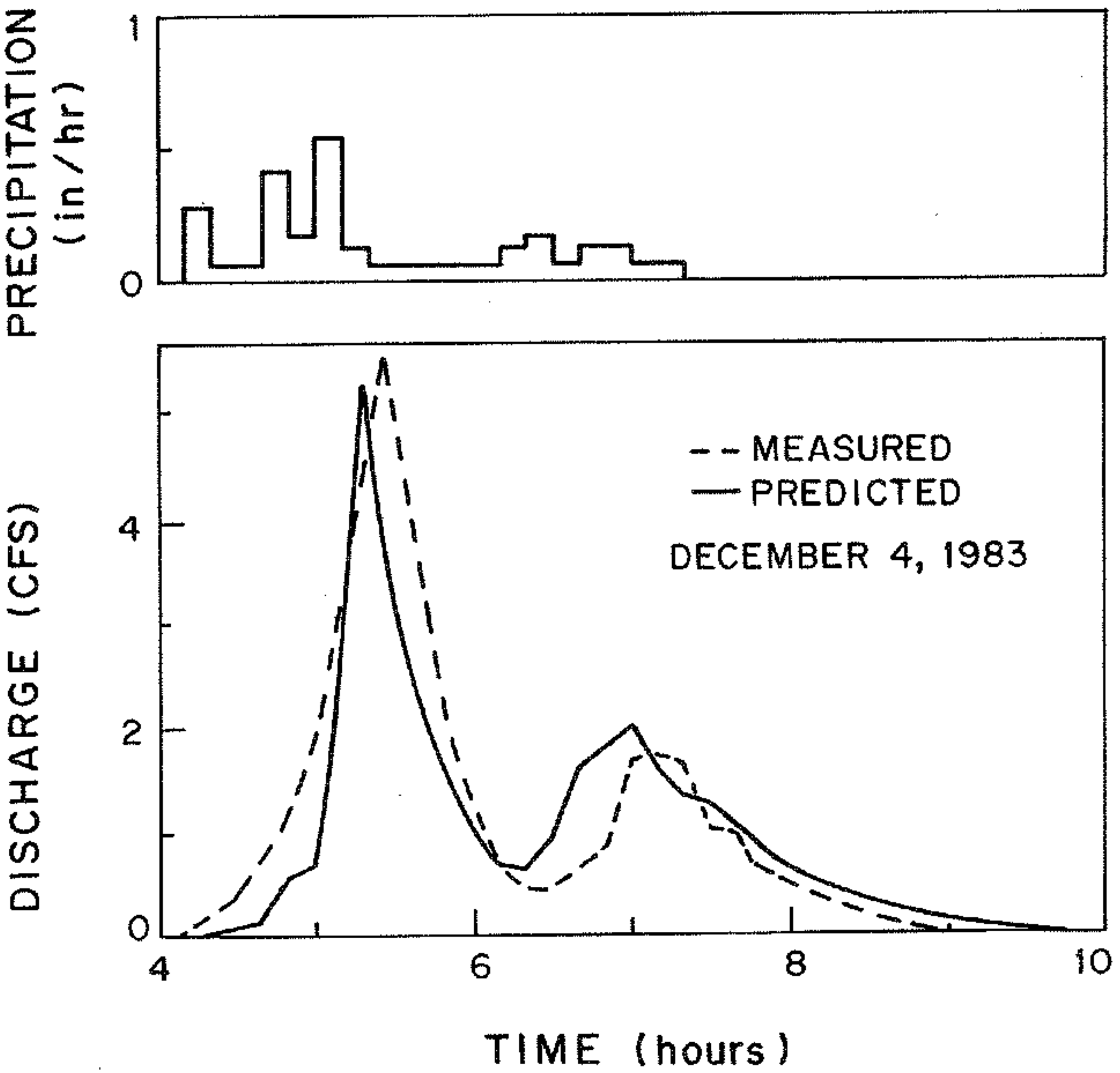


Figure 10. Predicted and Measured Hydrographs for the Storm of December 4, 1983

Table 8. - Comparison of Predicted and Measured Overflow

Storm	Date	Predicted Volume (cf)	Measured Volume (cf)	Percent Difference	Predicted Peak (cfs)	Measured Peak (cfs)	Percent Difference
1	11/28/83	20,649	21,005	2.5	8.34	8.80	5.2
2	11/10/83	123,520	130,780	5.6	23.24	24.00	3.2
3	11/20/83	36,601	42,750	14.4	6.40	7.80	18.3
4	12/04/83	20,262	18,540	8.5	5.23	5.50	5.1

Table 9. - Predicted to Measure (P/M) Quality Comparison

Pollutant	Summation P/M	Individual P/M		
	(all Storms)	Storm 1	Storm 2	Storm 3
BOD	0.996	1.58	1.01	0.40
COD	0.995	0.90	1.09	-

loading predicted using multiple storms calibration (Table 9). The data set for COD calibration contained two storm events. As with BOD, SWMM was calibrated for COD using the multiple storm technique. The calibration process was terminated when a P/M value of 0.995 was achieved. The P/M ratios for the individual storms were 0.90 and 1.09. The COD data was not as variable as the BOD data. This may be attributed to the effect toxic materials have on BOD measurements (Colston, 1974). However, a larger data base is required to conclusively established whether toxins in runoff from CSO 53 are altering BOD measurements.

SWMM was not calibrated for SS. Failure of the sequential sampler and/or the flow meter prohibited the acquisition of sufficient data to develop pollutographs for determining SS event loadings. To obtain a reasonable prediction of SS, the concentration of SS was compared at peak flows for measured and predicted events. The QFACT parameter for SS was adjusted until the measured and predicted concentration during peak overflows were the same order of magnitude.

As with quantity simulation, the techniques used to develop quantity coefficients for CSO 53 were employed in the other drainage areas.

Reference Storm Selection

Reference storm selection was based on peak rainfall intensity, total rainfall, and effective rainfall duration. Nominal frequency curves were generated for both peak rainfall intensity and total rainfall. Five frequencies were selected to cover the range of values. The historical record was searched for individual events meeting these criteria and an effective rainfall duration similar to the average calculated for the historical record of 10.4 hours. A summary of the reference storms is provided in Table 10.

The selection process of reference storms in this study differed from the approach used by others (Murphy, 1982). In previous applications, the selection of reference storms was based entirely on peak intensity. The arbitrary selection of reference storms may result in the development of an erratic intensity-loading relationship. In an effort to develop a methodology that would eliminate the randomness of reference storm selection and produce a smooth intensity-loading curve, the author incorporated into the selection process an effective average rainfall duration term. The inclusion of the rainfall duration term standardizes the selection of reference storms and reduces any bias that an investigator may introduce in reference storm selection.

Quasi-continuous Framework Validation

To determine if quasi-continuous simulation is a valid means of predicting annual loading, a direct comparison of predicted loading for conventional continuous and quasi-continuous simulation was performed. Continuous simulation is the method most often used for determining annual loading, however, there are several disadvantages: (1) the analysis of years of rainfall record, which is necessary to develop an average annual loading, requires considerable computer time; (2) because of the amount of computer time required, a simple discretization, usually one catchment, is used; (3) continuous simulation is not designed for use

Table 10. - Selected Reference Storms

Date of Storm[1]	Peak Intensity (in./hr.)	Total Rainfall (in.)	Effective Rainfall Duration (hrs.)	Nominal Frequency
1-11-74	0.19	0.66	10	22/yr.
1-3-53	0.29	1.09	9	12/yr.
1-1-61	0.49	1.87	10	4/yr.
11-29-63	0.70	2.87	10	2/yr.
7-29-76	1.70	4.81	10	1/10 yr.

---

[1] National Weather Service Rainfall Record, Providence, Rhode Island

with the transport block of SWMM. In studies when there are no flow regulating devices this last consideration is not a concern, however, when CSOs are modeled one must simulate the flow dividers.

The comparison of quasi-continuous to conventional continuous simulation was done for average and extreme rainfall conditions. The average rainfall was determined from a 28 year record for the Providence, Rhode Island area. In addition to average rainfall, the average antecedent dry period and the number of events with a rainfall intensity greater than 0.15 inches per hour were determined (Table 11). The antecedent dry period is an important parameter because pollutant buildup was modeled as a function of the number of dry days. The number of storms with an intensity greater than 0.15 inches per hour represents the events that produce appreciable overflow in the study area. The year 1951 was selected as the year that best represented the average rainfall condition. In 1951 there was a total rainfall of 45.6 inches, and 38 events had a rainfall intensity greater than 0.15 in/hr.

The years selected for extreme hydrologic periods representing dry and wet conditions, were 1970 and 1972, respectively. Descriptions of each year are presented in Table 11.

The calibrated SWMM was run in the continuous mode for each of the three years. In the quasi-continuous simulation, the reference storms and appropriate antecedent dry period were used to develop load response curves for both peak rainfall intensity and total rainfall. A flow chart of the entire quasi-continuous framework is found in Figure 11.

The comparison of predicted loadings for both techniques was made at the subcatchment inlets to the transport system. The comparison at this location is reasonable since the transport block of SWMM models quality

Table 11. - Characteristics of Dry, Average and Wet Years

Year[1]	Annual Rainfall (in.)	No. of Storms	No. of Storms Intensity ≥ 0.15	Average Antecedent Dry Period (days)
All Years (1949-1976)	43.8	112	38	11.3
Dry Year (1970)	37.6	83	27	13.1
Average Year (1951)	45.6	105	38	11.3
Wet Year (1972)	64.2	114	45	7.7

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[1] National Weather Service Rainfall Record, Providence, Rhode Island

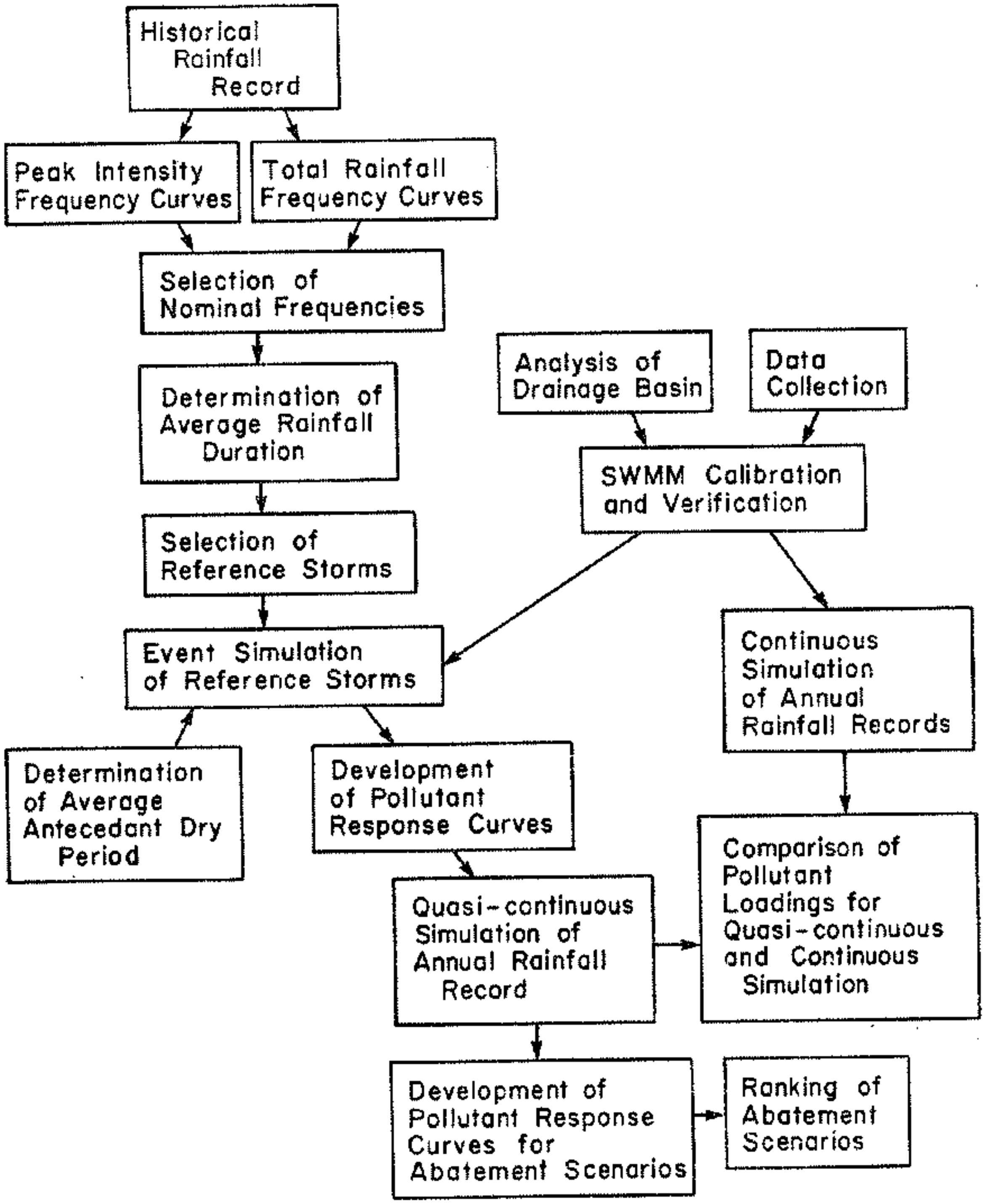

Figure 11. Quasi-Continuous Flow Chart

constituents as a completely mixed phenomena (Huber, 1983). The difference in pollutant loading above and below the flow dividers is a function of the slots ability to intercept the combined flow.

The results are summarized for both hydrologic parameters, peak rainfall intensity and total rainfall in Tables 12 and 13, respectively. The peak rainfall intensity load response curves predict more closely the results of continuous SWMM. For the average rainfall year, the loadings predicted by peak intensity differed by less than 3.5 percent for all three water quality parameters. There were greater differences for the extreme hydrologic conditions, however, differences did not exceed 12.2 percent. Quasi-continuous appears to be a valid alternative to continuous SWMM.

Evaluation of System Optimization

Upstream reaches of receiving waters generally have a lower waste assimilative capacity due to lower dilution than downstream reaches. Therefore, if wastewater can be collected and treated at a regional facility located in the downstream reaches, discharges to the more sensitive areas of the river can be avoided. The concept of regional treatment at two or three satellite facilities addresses this and is a more cost effective approach to reduce water quality problems than the original recommendation of nine flow through facilities. The goal is to optimize the current system with a minimum of structural modification and at the same time provide maximum wastewater transportation from the drainage basin to a proposed facility located downstream. Of primary concern, are the local interceptor capacities within the drainage area of

Table 12. - Percent Loading Difference Between Quasi-continuous and Continuous Simulation for Peak Intensity

Year	Pollutant		
	BOD	COD	SS
Dry (1970)	- 4.40	- 6.75	+ 4.99
Average (1951)	+ 3.25	+ 2.30	+ 1.85
Wet (1972)	- 6.60	- 12.16	- 11.67

Table 13. - Percent Loading Difference Between Quasi-continuous and Continuous Simulation for Total Rainfall

Year	Pollutant		
	BOD	COD	SS
Dry (1970)	- 10.7	- 12.4	- 11.0
Average (1951)	- 16.4	- 16.2	- 16.3
Wet (1972)	- 15.8	- 14.6	- 14.1

CSO 51 through 55 and the main downstream interceptors.

Since this study area is the upstream boundary of the Providence system with respect to the Woonasquatucket River basin, the capacities of the two local interceptors are available for transport of runoff and sewerage from the study area with one exception. The interceptor receiving CSO 52, 54, and 55 has a capacity of 41.0 cfs but receives a dry weather wastewater flow of 15.9 cfs from an upstream area. The available interceptor capacity is reduced accordingly to 25.1 cfs. CSOs 51 and 53 are connected to a separate interceptor with a capacity of 19.7 cfs.

The four abatement options considered include: (1) System as it presently exists; (2) Relocation of slots, thus, optimizing current slot capacities; (3) Increased slot capacity to approximately 80 percent of available local interceptor capacity; (4) Increased slot capacity to 100 percent of available local interceptor capacity. Options 2, 3 and 4 require structural changes to relocate and modify the current slot arrangement (Table 14). In keeping with the objective of minimum structural modification, no alterations of the interceptors are proposed.

Each option was simulated with the calibrated SWMM program using quasi-continuous framework for the average rainfall conditions of 1951. Pollutant load response curves to peak rainfall intensity were generated for each parameter (Figures 12, 13, 14). The quasi-continuous simulation using the selected reference storms provided an estimate of the volume of each overflow and the quantity of pollutants discharged to the Woonasquatucket River. The predicted impact of each option is indicated by the reduction of pollutant loads based on comparison of options 2, 3 and 4 to the existing conditions. The results of the simulations may

Table 14. - Relocation and Modification of Slot Capacities

CSO	Slot Capacities (cfs) Option 1	Option 2	Option 3	Option 4
051	5.60	5.60	8.90	8.90
052	6.96	3.56	3.56	3.56
053	8.95	8.95	8.95	10.75
054	3.56	6.96	11.76	16.86
055	0.93	0.93	4.68	4.68

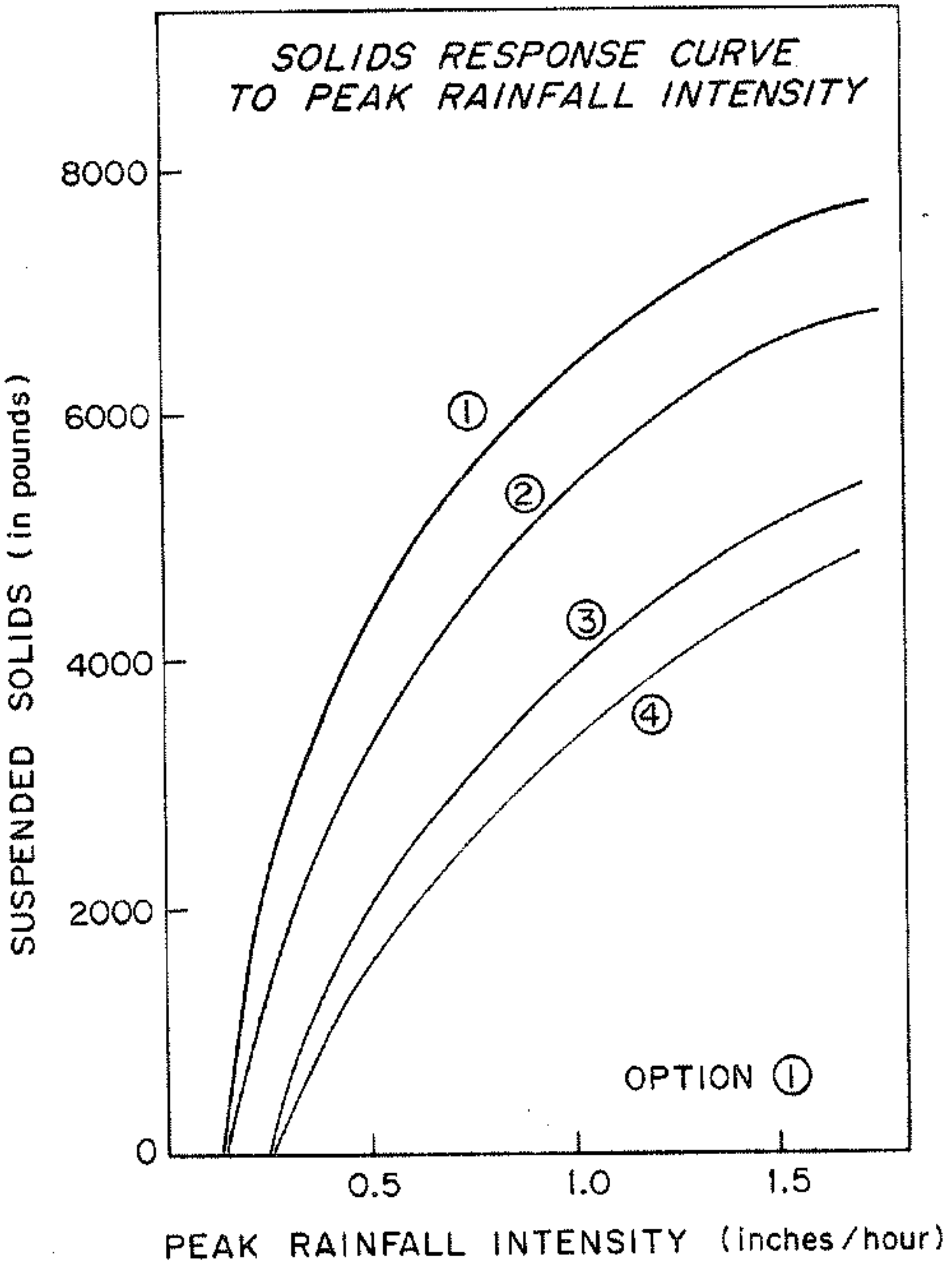

Figure 12. SS Loading Response to Peak Rainfall Intensity for Abatement Options

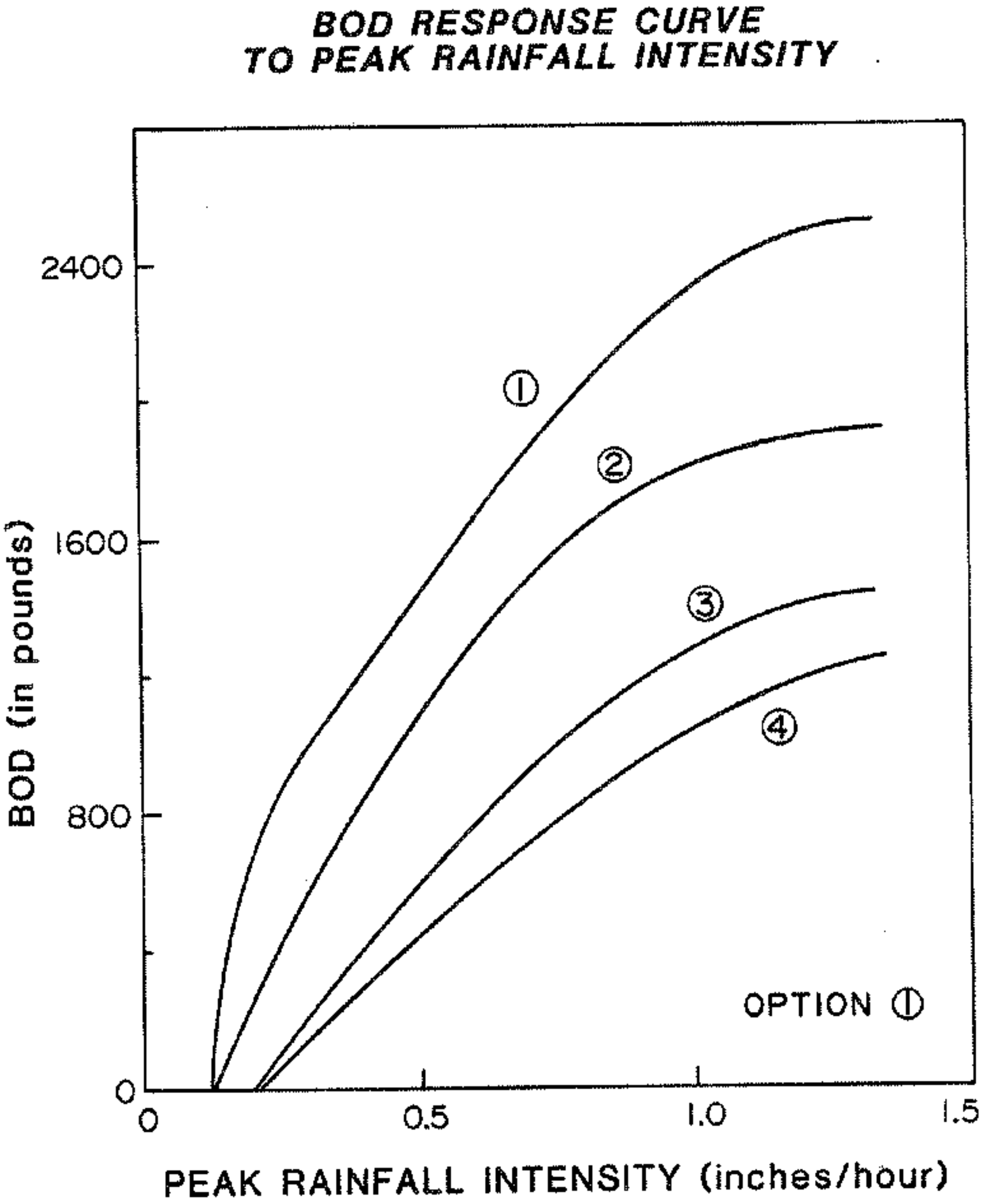

Figure 13. BOD Loading Response to Peak Rainfall Intensity for Abatement Options

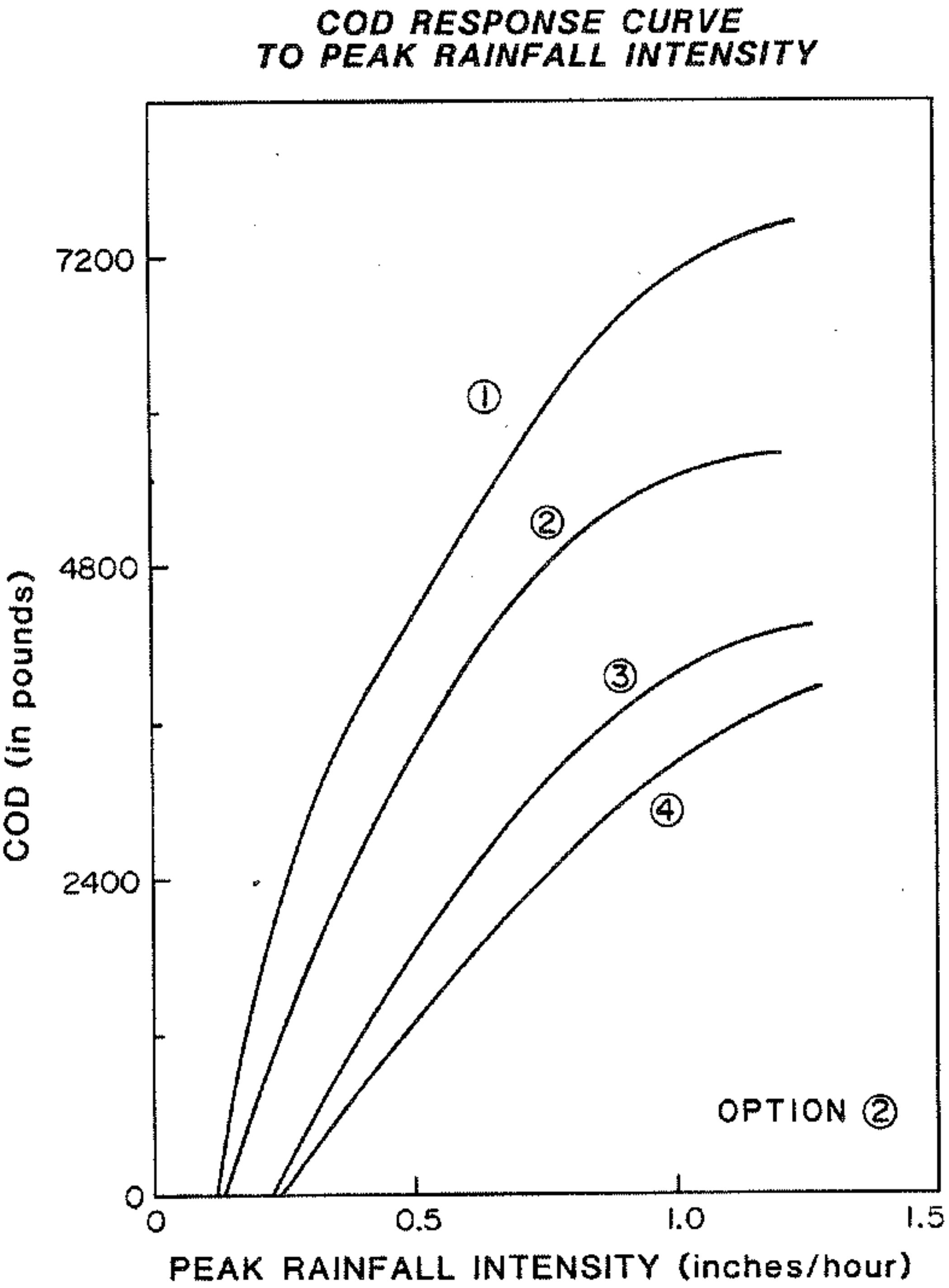

Figure 14. COD Loading Response to Peak Rainfall Intensity for Abatement Options

may be compared to typical suspended solids and BOD reductions by primary and secondary conventional treatment of 35-50 percent and 80-90 percent, respectively.

The proposed satellite facility was to have the equivalent of primary treatment. Both options 3 and 4 exceed primary treatment, with option 4 approaching the equivalent of secondary treatment (Table 15).

The amount of interceptor capacity required by each option is summarized in Table 16. The main interceptor below the study system was not modeled. The minimum capacity of this interceptor, based on an observed pipe slope (0.005), diameter (56 inches) and Manning's roughness (0.015), is used for this comparison. A complete analysis of the entire collection system is essential prior to implementation of any of the abatement options.

Table 15. - Reduction of Pollutant Loading

Option	Suspended Solids Percent Reduction	BOD Percent Reduction	COD Percent Reduction
1	---	---	---
2	31	38	35
3	67	74	75
4	77	82	82

Table 16. - Optimization of System Capacity

Option	Local Interceptor Capacity Used (Percent)	Main Interceptor Capacity Used (Percent)	Reduction in Main Interceptor Capacity (Percent)
1	58.1	19.5	---
2	58.1	19.5	0
3	84.7	28.5	9.0
4	100.0	33.6	14.1

CONCLUSIONS

The following conclusions are based on the results derived from the application of SWMM to a selection of the Providence CSO system and the validation and utilization of the quasi-continuous simulation framework.

1. Quantity simulation using SWMM for CSO District 1 was successfully calibrated and verified. The average percent error between observed and predicted values of the 4 storms used for calibration and verification was 7.9 for peak overflow and 7.1 for total overflow volume.
2. Quality calibration using SWMM for CSO District 1 was successfully calibrated for the prediction of annual loadings. There was insufficient data to verify the quality predictions.
3. The inclusion of a rainfall duration parameter in the determination of reference storms standardized the selection process. Storm events selected in this manner producted a smooth peak intensity or total rainfall loading curves.
4. The modified quasi-continuous simulation, which combines event simulation with historical rainfall records, is a viable alternative to conventional continuous simulation.
5. Peak rainfall intensity provides a more accurate verification of quasi-continuous than total rainfall,

and as a result it should be used when developing load response curves.

6. Optimization of the collection system through the modification and relocation of slot structures provides local annual pollutant reductions to the Woonasquatucket River that approach secondary treatment levels.

RECOMMENDATIONS

The quasi-continuous technique should be used for the determination of annual pollutant loadings from CSOs. It is also recommended that during future evaluation of the regional facility, the entire drainage area be considered together to determine the hydraulic limitations of the main interceptors and the optimum placement of regional facilities.

A receiving water quality model should be incorporated into any future CSO investigation to determine the environmental benefit of specific abatement alteration.

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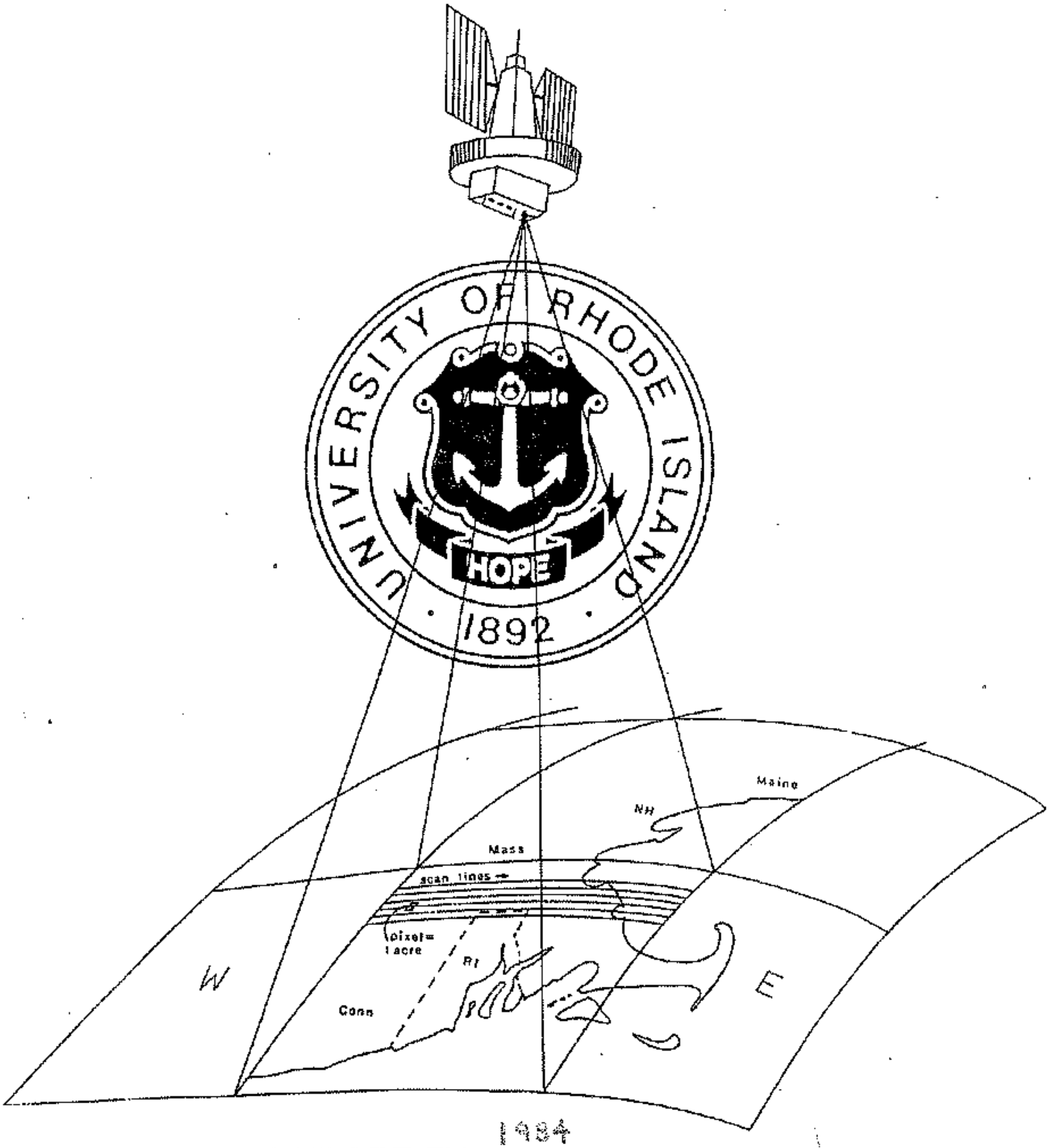

1984

REPORT FY-1985 PROGRAM

GEOPHYSICAL AND REMOTE SENSING STUDIES OF BEDROCK AQUIFERS IN FRACTURE ZONES

by

R.K. Frohlich & John J. Fisher

COMPLETION REPORT

PROJECT TITLE: Geophysical and Remote Sensing Studies of Bedrock Aquifers in Fracture Zones

PRINCIPAL INVESTIGATORS:
R.K. Frohlich and John J. Fisher
Department of Geology
University of Rhode Island
Kingston, RI 02881

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GEOPHYSICAL AND REMOTE SENSING STUDIES OF BEDROCK AQUIFERS IN FRACTURE ZONES

1. INTRODUCTION

Fractures are one of the oldest known features common in rocks. In igneous-metamorphic rocks fracture systems offer the only means of groundwater storage and migration. Since intensely fractured rocks are easily erodable, the most extensive fracture systems are often at the bottom of valleys that are usually filled with younger deposits. In spite of our knowledge of fractures, mostly from outcrop studies, we may not fully realize their order of magnitude, since larger fracture zones may be expected at the bottom of valleys. In New England these valleys are often filled with glacial deposits of large size, in which major groundwater resources are found.

Crystalline bedrock is presently being investigated as a potential site of a high level radioactive waste repository. Most crystalline rocks, in particular granites, are considered as suitable for the isolation of nuclear waste from the biosphere because of their high strength, low thermal conductivity and low porosity and permeability--but only if the rock is not fractured. Therefore one of the most important investigations necessary for the location of a suitable burial site for nuclear waste is the hydrological characterization of the crystalline rock body.

Zones with sufficiently dense fractures form bedrock aquifers that are relatively free from surface pollution. Finally the characteristics of surface water resources, including the location of swamps and lakes, and the course of streams is probably controlled in a large part by bedrock fractures or the glacial deposits filling these fracture valleys. The location of fracture systems may therefore have some significance for wetland and water resources management. Because of the lack of outcrop exposures of major fracture zones in glaciated regions, for reasons mentioned above, locating them, mapping their fracture density and pattern and determining their hydrologic characteristics will predominantly depend on remote sensing and geophysical methods. Such methods are based on any technique that is applied above the ground surface while the observation results are related to the subsurface conditions.

In this study several methods were applied to characterize the hydrogeological behavior of fracture zones in selected parts of Rhode Island. Remote sensing methodology in this study was based on state-wide lineament mapping utilizing Landsat satellite multi-spectral imagery. Remote sensing mapped lineaments have ben shown to be related to regional bedrock fracture zones, specifically faults and joint systems. Preliminary Rhode Island lineament mapping (Fisher and Boyle, 1982) have indicated a complex pattern of such bedrock lineament zones. Geophysical methods in this study were based on gravity and magnetic studies conducted for the Seismotectonic Group of New England (Frohlich, 1982 and 1983). The interpretation of many anomalies was related to various effects caused by fracture zones.

Finally, the geoelectrical resistivity method was used, to a lesser extent. Bedrock effects were observed earlier during resistivity studies of glacial deposits in glacial stream channels in Rhode Island (Frohlich and Kelly, 1985).

Educational, state and community awareness of this research as objectives were also realized during the period of this study. Graduate student H. Hurd received his M.S. degree with partial support of his research from this grant (R. Frohlich). Two graduate students (D. Owen and J. Savarese) were also employed in part by this grant (R. Frohlich, J. Fisher). Presentation of the ground-water aspects of this research were presented at a Cranston citizens town meeting (J. Fisher). Discussion of this research was presented to the Rhode Island Dept. of Environmental Management, Ground Water Division together with the R.I. Audobon Society Directors (Frohlich and Fisher). Surface and subsurface water resources aspects of this research was published in an article in the June, 1985 Rhode Island Audubon Society Report (Fisher, 1985).

2. REMOTE SENSING (John J. Fisher)

2.1 EVIDENCE OF FRACTURE HYDROGEOLOGY FROM REMOTE SENSING

Remote sensing techniques utilizing Landsat satellite imagery has strongly influenced the application of scientific research to numerous fields during the last decade. There have been numerous applications in the fields of economic geology exploration and environmental geology planning and monitoring (Fisher, 1977). While satellite imagery of various types (Apollo, Skylab and Landsat) have been used in numerous applied geologic studies in both the petroleum and mineral exploration fields (Halbouty, 1980), it is only in a lesser amount that satellite imagery has been used for hydrological studies. Application of remote sensing for surface water flood hazard mapping were among the earliest applications (Rango and Anderson, 1974) as was its use in planning water resources development (Rango, Foster and Salomonson, 1975).

Use of remote sensing for subsurface water studies relates to the mapping of lineaments as related to bedrock fractures. Lineaments are linear or curvilinear features that are usually detectable only on regional aerial photographic mosaics or more recently on different types of remote sensing satellite imagery. Early Landsat-1 imagery was used to map lineaments in Pennsylvania and related to basement tectonics (Kowalik and Gold, 1974). The relationship between fracture traces (lineaments) and ground water in carbonate rock in humid areas was determined much earlier (Lattman and Parizek, 1964). Linear features related to ground water distribution in the Ogallala Formation of Texas in an arid region was also established (Finch and Wright, 1970). More recently a direct relationship was shown between lineaments and ground water for the Susquehanna River Basin in central Pennsylvania using Skylab satellite imagery (Parizek, 1976).

2.11 Lineaments, definition and features

Interestingly enough, the initial studies of lineaments using the newly produced topographic maps were conducted in near-by Connecticut (Hobbs, 1904). Linear features as mapped initially by Hobbs as lineament units included: a. ridge crests b. drainage segments c. shorelines, and d. boundaries of geologic formations, rock types or outcrop patterns. Later (Hobbs, 1912) added valley segments and fracture or fault breccia zones. The most common definition of lineament is that of O'Leary et al. (1976) which is: a lineament is a mappable linear feature (simple or composite) whose segments are aligned in a rectilinear or slightly curvilinear relationship, which differs from the patterns of adjacent geologic features and is often considered to reflect subsurface control. Lineaments are also a common feature on gravity and magnetic maps as anomalously aligned trends. Often there is found to be a relationship between the trends of these geophysical lineaments and those mapped from satellite imagery. These combined studies have been presented recently as a series of international conferences devoted to the "New Basement Tectonics" (1974, 1st Conference; 1976, 2nd Conference, etc.). The general tectonic theory is that basement regional structure trend expressed in geophysical mapping are transmitted through overlying rocks and are expressed as linear geologic geomorphologic terrain features, the "lineaments". Lineaments as indicators of folds, faults and joints can thus be related to past tectonic stress fields (Saunders and Hicks, 1976). Major continental lineament tectonic patterns are thought to have developed during the initial development of the crust during PreCambrian (Pilger, 1974). The more regional lineament patterns however are probably related to later plate tectonic movements but this has yet to be established.

2.12 Lineaments, New England Studies

Lineament satellite studies in southern New England whether of a geological or hydrological have not been common. Barosh (1974) showed that in general various regional geophysical studies over the past few years by the U.S. Geological Survey studies (gravity, aeromagnetic and aeroradioactivity) indicated patterns that complemented satellite imagery. Only a few very large-scale lineaments based on Landsat satellite imagery in southern New England were mapped. More recently the present author conducted a study of the general Rhode Island lineament pattern relative to that of southeastern New England (Fisher and Boyle, 1982). Indications were that the Rhode Island pattern did not coincide with the rest of the region, and thus there was a possibility, that it was a sub-plate, the Avalon plate, that welded on to the larger New England plate during a plate collision as has been predicted from other geologic studies.

2.2 LANDSAT REMOTE SENSING - FEATURES

Because Landsat satellite mapping applications differs markedly from the usual standard field mapping or surveying techniques it is useful to point out certain features of the Landsat satellite imagery system, especially those aspects that apply to the present study. Landsat imagery differs markedly from aerial photography which it at times appears to resemble. First, the satellite is in a near-polar, near-circular sun-synchronous orbit at an altitude of 565 miles and passes over the same area every 18 days and images at about 9:00 AM local time (Fig. 2-1).

There were two sensor systems on the first three Landsat satellites, a Return-Beam Vidicon (RBV) which is basically a television camera system, and a multi-spectral scanner (MSS) which electronically sweeps or scans ("scanner") an east-west swath on the earth's surface and measures the differences in sun reflectance at different spectral frequencies ("multi-spectral"). The RBV system (Bands 1, 2, and 3) have been little used in the past, in comparison to the MSS system (Bands 4, 5, 6 and 7). These band signals are converted to digital form and electronically transmitted back to earth where it is transcribed for storage on computer-compatible tapes (CCT). This digital tape data can be used in that format on a main-frame computer system or converted into photographic-like images.

In general there is only one Landsat satellite system in operation for any particular length of time since the electronic systems do fail from repeated usage after a period of two to three years. While a particular Landsat satellite is in orbit, another one, therefore, needs to be in the construction stage, while still a third has to be in the planning stage to allow lead time, so as to provide uninterrupted continuous coverage.

2.21 Landsat multi-spectral system

The most commonly used sensor package, and as used in this mapping, is the Multispectral Scanner System (MSS). It consists of four optical scanners, individually filtered to record portions of both the visible and nonvisible electromagnetic spectrum reflected from the scene. The Landsat multispectral system consists of the following spectral wavelengths or bands (Landsat Data Users Handbook, 1979):

Band 4: 500-600 nanometers (0.5-0.6 micrometers or 5,000-6,000 Angstroms), Blue-green Light.

Band 5: 600-700 nanometers (0.6-0.7 micrometers or 6,000-7,000 Angstroms), Red Light.

Band 6: 700-800 nanometers (0.7-0.8 micrometers or 7,000-8,000 Angstroms), near Infra-Red.

Band 7: 800-1100 nanometers (0.8-1.1 micrometers or 8,000-11,000 Angstroms), near Infra-Red.

It should be emphasized that the "near Infra-Red" in bands 6 and 7 refer to infra-red radiation emitted by the sun and reflected by the object. It is not the same as "far infra-red" radiation which is thermal radiation ("heat") as emitted by an object. A different type system is needed to record this radiation. Variation in the intensity of the reflected sunlight is telemetered to earth as four separate signals (bands 4, 5, 6 and 7) which can each be processed into a black and white image and utilized individually or combined in various ways using color-enhancement techniques. These different bands alone or in combination provide different spectral reflectance information about the terrain (geomorphology), vegetation, man-made cultural features, hydrology and geologic features.

2.22 Landsat field resolution

A common misconception concerning Landsat satellite imagery is that of its "resolution", i.e., its ability to discern objects. It is often thought that this particular imagery also possesses the high resolution of the military surveillance remote sensing systems. The satellite scan system produces an image of a ground area that is 185 km (115 mi.) on each side. The state of Rhode Island, at 35 by 45 miles occupies about 15 percent of such an image. Individual radiation measurements on this image are made from a ground area 79 m square which are reformatted to an area of 56 m by 79 m so that geometric distortions are removed. This 56 m (180 ft.) by 79 m (260 ft.) area is called a Landsat picture element or "pixel". Thus the pixel area approximates the area covered by an acre or a football field. The actual resolution is usually even less than this value.

Computer remote sensing analysis of the original computer-compatible tapes (CCT) is usually more complicated and expensive than direct visual analysis of the photographic-like produced images. However, it has been suggested (Nat'l. Conf. of State Legislatures, Remote Sensing

Project, 1979) that while the computer can identify objects as small as 1 acre (one pixel), the visual analysis techniques are limited to objects of 10 acres or larger. Since lineament analysis extend over numerous pixels rather than one pixel, it appears that the limit of resolution when mapping lineament features is also in the one pixel (1 acre) range.

2.23 Lineaments, geology and hydrogeology

The ability for Landsat satellite imagery in mapping lineaments is the large scale view of regional scope rather than that of detailed field or aerial photographic as well as the uniform and even illumination of the Landsat image. In addition, the unique synoptic aspect of this imagery further yields information not readily identified or not perceived at all by conventional methods (Fischer and Latham, 1973). Quite often, wide ranging regional or state-wide features such as faults or lineaments on the earth's surface are visible on Landsat imagery but are undetected on aerial photographs because of the lack of the broad view of a single frame (Nat'l. Conference of State Legislatures, Remote Sensing Project, 1979).

Regional geological studies in other areas (The Alps, Balkans, etc.) utilising Landsat imagery have indicated the following relationship of geological structures to lineaments based on the mappable parameters of length and shape (Foose and Brigham, 1976):

A. Prominent joint sets and normal faults produce lineament lengths of less than 12 km (7.5 mi.).

B. Strike-slip, thrust and low-angle reverse faults exhibited lineament lengths of greater than 12 km (7.5 mi.).

C. Most straight lineaments the result of joint sets, normal faults or strike-slip faults.

D. Wavy or irregular lineaments were produced by thrust faults (including gravitational gliding).

Statistical structural geology analysis of the lineaments of the morphotectonic Tyrrhenian Basin indicate short lineaments are more common than long, and straight lineaments more common than irregular lineaments. This suggests that normal faults dominate formed under a regional tensional stress conditions (Foose, 1977).

Recent recommended techniques for monitoring and sampling ground water for pollution protection as proposed by the National Water Well Association (Short Course Outline, Orlando, Florida and Houston, Texas, October 1985) include the following for selecting locations for installed monitoring devices:

A. Existing site geology/hydrology information.

B. Subsurface contaminant behavior.

C. Surface geophysical methods.

D. Fracture trace analysis and other remote sensing methods.

The first suggested technique as well as the last two techniques have been investigated at both the regional and local level in this present state-wide study of bedrock fractures as related to water resources.

2.3 RHODE ISLAND LANDSAT LINEAMENTS

2.31 Research Objectives of Lineament Mapping

Relationship of remotely sensed lineaments to bedrock fractures has been established using Landsat satellite imagery over the past ten or so years. The purpose of the remote sensing portion of this bedrock hydrogeology fracture study was to:

A. Identify Rhode Island lineaments by applying remote sensing techniques to Landsat multi-spectral satellite imagery.

B. Prepare a state-wide map showing the location trend and pattern of these lineaments.

C. Prepare a state-wide map showing the density of these lineaments across the state.

D. Analyze the pattern and density of these lineament maps in terms of bedrock geology and hydrogeology.

The significance of using Landsat imagery for this phase of the bedrock fracture study is that prior to this approach, lineaments had to be mapped indirectly from linear geologic or geomorphologic trends, but satellite imagery in addition to confirming these trends, can locate additional trends as well as adding a great amount of secondary fracture lineament data (Saunders and Thomas, 1973).

2.32 Rhode Island Lineament Mapping, Methodology

Landsat imagery in the form of photographic images was used to map the Rhode Island lineaments. Various types of multispectral imagery were utilized which had been computer enhanced to improve imagery. Earlier Landsat imagery was not computer enhanced and scan lines could often be seen on earlier imagery (compare below, 1972 non-computer enhanced imagery with later 1976 enhanced imagery). The primary imagery was in the form of positive film transparencies at the scale of approximately 1:1,000,000 giving 9 inch by 9 inch transparencies. Our earlier studies (Fisher, 1977) indicated that transparencies produced better resolution than the usual, less expensive paper prints. It has been estimated that use of film rather than paper improves resolution for lineament mapping by a factor of 5 to 10 times. In addition, consistent and better tonal range and contrast is observed when mapping transparencies by transmitted light. Also, reflected lighting on a photographic print often produces glare which often can distort some of the lineament features.

The following imagery was used in the Rhode Island lineament mapping:

A. Landsat-1, Band 4, May 5, 1976, positive film.
B. Landsat-1, Band 5, May 5, 1976, positive film.
C. Landsat-1, Band 6, May 5, 1976, positive film.
D. Landsat-1, Band 7, May 5, 1976, positive film.
E. Landsat-1, Color composite, May 5, 1976, positive film.
F. Landsat-1, Color composite, Oct. 8, 1972, positive, paper.

In general, Band 4, in the blue-green part of the electromagnetic spectrum shows best atmospheric features (clouds, haze, etc.), turbid sediment laden water and moisture in general. Band 5, in the red band, indicates boundaries between vegetative cover (dark) and cleared land (white) while water bodies are shades of gray. Bands 6 and 7, in the reflective infrared band show the terrain and vegetation in tones of gray, man-made features appear white to light gray and water is totally black. It should be pointed out that the original multi-spectral bands are all originally recorded on the satellite in various tones of black through gray to white indicating the different levels of terrain reflectivity. A composite color image consisting usually of bands 4, 5 and 7 has been produced by NASA and with its distinctive red tones for vegetation, it resembles the image produced by color infrared film. The best bands for mapping the lineaments were the bands 5 and 7 as well as the color composite imagery.

Linear features (lineaments) from 0.5 km and longer, were mapped from each of the above bands onto dimensionally stable mylar film using a Bausch and Lomb Zoom Transfer Scope. The Bausch and Lomb Zoom Transfer Scope is an optical anomorphic correcting, copy (transfer) system that allows ratio comparison of 1:14, which enables direct optical overlays of larger scale satellite imagery onto smaller scale maps. The base map used for this study was A. Quinn's U.S. Geologic Survey map of Rhode Island (Quinn, 1971) at a scale of 1:125,000. This enabled determining lineaments that related to faults and geologic contacts. At this point, by reference to topographic maps and recent aerial mosaics and aerial photographs, all lineaments that were related to man-made linear features such as highways, railroads, agricultural and vegetational boundaries were elminated. Final mapping of the lineaments was facilitated by the production by the author of a 1:125,000 color composite print of Rhode Island, at the same scale as the A. Quinn state geologic map. This image was photographed from the original color composite positive film transparency using special flat-field lenses in a bellows copy system. In contrast, the largest scale satellite imagery available from NASA is only 1:250,000.

2.33 Previous Rhode Island Studies

For the New England region in general, it has been pointed out (Barosh, 1979) that geologic mapping utilizing remotely sensed lineament and geophysical data could provide information on "brittle tectonics" as well as fault density. Good correlation has been demonstrated in southern New England between geologically known faults and both remote-sensing and geophysical data and therefore demonstrates the feasibility of using such data to extend known faults and interpret new ones (Barosh, 1976; Isachasen et.al., 1974). Since many lineaments in New England are found to lie along dislocations in the basic geologic and geophysical data and apparently represent hidden faults, remote sensing lineament analysis will provide an efficient method to obtain structural geology data (Barosh, 1979). The only published Landsat lineament maps of southern New England (Barosh, 1976) indicate only a few major first order lineaments (e.g., Connecticut Valley boundary fault), none of which were mapped in Rhode Island (note that lineament overlay was reversed in relation to

Landsat photo when published; P. Barosch, personal communication).

The only Landsat lineaments mapped in Rhode Island were included as part of the Preliminary Safety Analysis Report (Fig. 2-2) for the proposed New England Power Company's Nuclear Power Plants in Charlestown, Rhode Island (NEPCO, 1977). For the study of regional tectonics in addition to faults, Landsat features were also studied (referred to in original report as "ERTS Features", p. 2.5-16, early on the satellites were referred to as Earth Resources Technology Satellites or ERTS). Using a "composite photograph" (not indicated as whether color or black and white image in original report) of Rhode Island, eastern Connecticut and southeastern Massachusetts, forty "linears" (NEPCO term) greater than 10 miles in length were recognized and mapped in an area extending approximately 100 miles to the east and west and to the north. Linears were determined both by "tone" and "topographically". Three categories of linears were identified: 1) those coinciding with mapped faults, 2) those coinciding with mapped geologic contacts, and 3) those coinciding with neither mapped faults nor mapped geologic contacts.

For Rhode Island proper only 5 linears were mapped and they all fell in the third category (neither mapped faults or contacts) however, in adjacent eastern Connecticut, 4 mapped linears fell into the first category of coinciding with known faults (Fig. 3-2). Of the Rhode Island linears they were related to primarily topographic features as follows: end moraine (A), "topographic highs" (B), "topographic relief" (C south), stream valleys, including lakes and topographic lows (C north, D, E). The northern third of the state had no "linears" mapped from this study. Although this earlier study used the same satellite for imagery (Landsat 1 or "ERTS-1") there may be several reasons for the paucity of "linears" in contrast to the present study with over 150 mapped lineaments. First, the earlier NEPCO study used prints rather than transparencies as recommended in the present study. Secondly, the present study used all four multi-spectral bands rather than only a composite print. Third, the color composite used in the present study was computer enhanced. Fourth, in addition to the NASA 1:1,000,000 scale imagery studied on a zoom transfer scope, the present study also produced a 1:125,000 enlargement. All of the above earlier study limitations, probably limited it to linears with a lower limit of 10 miles, while the present study was able to map lineaments at a lower limit of 0.5 km (0.3 miles).

Of the earlier mapped linears, the end moraine linear (A) was not included in the present study because it is probably not related to bedrock fractures and is not in any case a regular trend. Two of the other linears, B (topographic high) and E (valleys), were mapped as lineaments in the present study. Two other linears (C and D) could not be validated in the present detailed study, although linear C (valleys) does terminate to the north in the most concentrated lineament area of Rhode Island as mapped in the present study.

2.34 Rhode Island Lineament Map

Over 150 lineaments of 0.5 km (0.3 mi.) length were mapped for Rhode Island and its adjacent borders (Fig. 2-3). Distribution of the lineaments is neither irregular or random in its pattern but has several regular trends. In general the area surrounding Narragansett Bay has the least lineaments with over 80 percent of the mapped lineaments in the western half of the state (Boyle, 1980). The southwest margin of the state in the Hope Valley town area has the greatest number of lineaments per unit area (A, Fig. 2-3). A second concentration of lineaments is in the north central area of the state around the town of Greenville (B, Fig. 2-3) with a lesser concentration to the southwest in the Scituate Reservoir area (C, Fig. 2-3). In fact, these three concentrations together form another major concentrated fracture zone transversing the state from the southwest corner, north of the town of Westerly, to the northeast corner near the town of Cumberland.

The concentration around the town of Hope Valley (A of Fig. 2-3) is at the northern extension of one of the few "linears" mapped in the earlier nuclear power plant study (NEPCO, 1977, see "C", Fig. 2-2 this report). In addition, recent studies (Gromet and O'Hara, 1985) have indicated the existence of a "major but previously unrecognized shear zone in southwestern Rhode Island and eastern Connecticut now called the 'Hope Valley shear zone'". This zone located and identified by field study as well as petrographic and geochronological techniques indicates highly strained, dutiley deformed gneisses. Structural geology studies suggests they formed "within a major right-leteral shear zone". This zone separates two groups of late Precambrian rocks Avalon zone basement rocks (Hermes, Gromet and Zartman, 1981). This shear zone "extends from south-central Rhode Island northward along the Rhode Island-Connecticut border into adjacent Massachusetts". Its southern terminus is also indicated on the lineament map by the concentration of lineaments in Hope Valley (A of Fig. 2-3). The extensive north-south lineament in eastern Connecticut (D of Fig. 2-3) is also probably a feature of this shear zone. This relationship of lineament trend and lineament concentration to recently mapped basement rock shear zones shows that this lineament mapping does indicate zones of fractured bedrock.

A prominent northeast trending linear feature in southwestern Rhode Island appears on the May 5, 1976 satellite imagery but did not appear on the October 8, 1972 imagery. It starts at Stonington, Connecticut and trends about 24 miles to the western West Greenwich area. Although prominent, when investigated in the field, no ground geomorphologic or geologic feature could be found to correspond to it. Investigation of band 4 imagery shows a linear cloud (a "contrail"), condensed exhaust vapor from a high flying airplane. The shadow cast by this contrail and observed on band 6 and 7 imagery is responsible for this "pseudo-lineament".

The previously mentioned northeast-southwest zone of concentrated lineaments that extend from Hope Valley to the northeast is itself part of two other northern prominent lineaments. These two lineaments, also trend in a northeast pattern and are lying in an en echelon or overlapping, steplike pattern. This is a common pattern in both fault and joint fracture pattern. The first lineament (1-1' of Fig. 2-3), begins near the town of Hopkins Hollow in west Coventry and extends for 21 miles to Lincoln Woods Park. Along its trend it passes through the east, dam, end of the Scituate Reservoir (E) and the Central Landfill Site (F) in Johnston, also the concentrated zone "B". This is the longest lineament lying wholly in Rhode Island and was also one of the lineaments identified in the Nuclear Power Plant safety study (NEPCO, 1977; see "E" Fig. 2-2 this report). This lineament was also previously identified as a magnetic lineament from both ground and aeromagnetic geophysical survey (Schwab and Frohlich, 1976). The magnetic lineament extended from Lincoln Woods some 7 miles southeast to the first concentrated satellite lineament area (B, Fig. 2-3), just reaching the Johnston Central Landfill site (F, Fig. 2-3). Truncation of northwest trending magnetic highs of almost 1000 gammas was interpreted as a right lateral strike-slip fault. Two other paralleling short magnetic lineaments were found 5 miles to the northwest and 4 miles to the southeast. Parallelism of lineaments is often considered indication of a structural relationship. In addition the trend and right lateral movement is the same as major fault zones in eastern Massachusetts to the north. In the present study, R. Frohlich has also identified this lineament as a gravity high lineament of the gravity map of Rhode Island (2B of Fig. 3-1 this report) and continuing into Massachusetts (3F of Fig. 3-1).

The northernmost major satellite lineament in Rhode Island (2-2', Fig. 2-3) extends for 24 miles, almost the same length as lineament 1-1'. It extends from the town of Rockland at the western head of the Scituate Reservoir, trending northeast to the Rhode Island border, east of Woonsocket, at Cumberland Hill and Diamond Hill but then continues in Massachusetts across Route 495 at least to Wrentham, Massachusetts. It has also been identified as a gravity lineament in this present study by R. Frohlich (1, Fig. 3-1). The gravity lineament begins in the lower third of lineament 2-2' and then parallels it, but continues beyond it some 8 miles to the Connecticut border.

The next major grouping of satellite lineaments are found in the southern half of the state. They are a series of again northeast trending lineaments which extend from Westerly northeast through Kingston to Narragansett Bay. The westernmost lineament (3-3', Fig. 2-3) starts in Connecticut, just north of Watch Hill and extends some 6 miles to east of Westerly, Rhode Island. Along this trend it parallels within a half a mile the trend of the Watch Hill fault (Quinn, 1971). The only major known mainland fault in southern Rhode Island. Where this fault abruptly begins to trend north towards Burdicksville, is exactly where the satellite lineament ends. Swampy lowland terrain at present prevents mapping this Watch Hill satellite lineament further but ground magnetic surveys by R. Frohlich in this present study show an extension of this lineament into the Bradford area (Fig. 3-5, this report).

While the Watch Hill satellite lineament terminates west of the town of Bradford, along the same trend on the west side of Narragansett Bay is an extensive set of parallel northeast trending satellite lineaments. The longest of these (4-4') extends from south of Usquepaug some 9 miles to Wickford harbor. This lineament was also mapped as the only satellite "linear" in this area in the earlier Nuclear Power Plant Safety analysis (NEPCO, 1977). Identification of a gravity lineament (4 of Fig. 3-1, this report) following the trend of the above South County lineaments (3-3', 4-4', Fig. 2-3) has been identified by co-author R. Frohlich in this report. Immediately south of this lineament is a parallel trending set of 4 satellite lineaments which extend from the shore of The Great Swamp east to Narrow River. Along Narrow River is a north-south trending lineament which extends north beyond the river valley and which also parallels several other north-south trending lineament to the west in South County. Across Narragansett Bay in the Portsmouth and Tiverton area on an extension of the South County lineament is another prominent satellite lineation trending northeast (5-5', Fig. 2-3). This lineament may be an extension of the Watch Hill and Kingston lineaments (3-3' and 4-4', Fig. 2-3). It follows both the trend of the Taunton River and the southern margin of the Narragansett Basin.

In summary, the satellite lineament pattern as mapped in this study also bears a valid relationship supporting the general plate tectonics structural geology proposed for southern New England (Fig. 2-4). First, the Avalonian microcontinent of north-eastern North America, including Rhode Island, during the early and mid Paleozoic time welded itself to the main North American continent. The motion of these two plates produced a compressional zone of strike-slip, northeast-trend faults with dextral (right-hand) movement (Barosh, 1976). This pattern established for eastern Massachusetts (Barosh, 1979) can now be seen in the major satellite lineament pattern of Rhode Island mapped from the present study (Fig. 2-4A). In Carboniferous time, a "pull-apart" basin developed between two sets of these en echelon strike-slip faults (Fig. 2-4B), one to the north and another to the south (McMaster, de Boer and Collins, 1980). A basin of sedimentation then developed in this pull-apart structure which later developed into the well-known Narragansett Basin. While, McMaster, et. al. 1980 have found evidence below Narragansett Bay for this development and subsequent basin tectonics, the present satellite lineament study presents evidence by which to identify this fault pattern in the crystalline bedrock of mainland Rhode Island. Satellite lineament 2-2' (Fig. 2-3) indicates the trend of the northern basement strike-slip fault for the northern boundary of the Narragansett Basin's Norfolk Basin (Fig. 2-4C). Satellite lineaments 3-3', 4-4' and its extension 5-5' across Narragansett Bay indicates the trend of the strike-slip fault trend that formed the southern boundary of the Narragansett Basin in adjacent southern Massachusetts (Fig. 2-4C). Extension of the Watch Hill gravity lineament as mapped in this study (Fig. 3-1) is also indicated as trending into this southern boundary of the Narragansett Basin (R. Frohlich, personal communication). The previously mentioned lack of major satellite lineaments across the Narragansett Bay area of this Narragansett Basin is because most of the geologic structures developed during post-Carboniferous times (McMaster et. al 1980) and thus the earlier basement crystalline rock strike-slip faults do not show through the sedimentary rocks in the basin (Fig. 2-4D). Outside the Avalon Zone in adjacent Connecticut and Massachusetts (preliminary studies, Fisher and Boyle, 1982), there appears to be a general N-S major regional lineament trend. For Rhode Island, within the Avalon Zone, the major satellite lineament trend is now mapped as NE-SW. These trend differences further reflects the relict pre-plate collision lineament trend for the Rhode Island region.

2.4 Hydrogeology of Rhode Island Lineaments

Analysis of the relationship of the mapped satellite lineaments to the hydrogeology of Rhode Island is based on the following three aspects:

A. Individual lineaments as related to hydrogeologic features both surface and subsurface

B. Patterns of lineaments trends as related to hydrologic features, primarily subsurface bedrock

C. Density of lineaments as related to hydrogeologic aspects, primarily bedrock features

Linear geologic features such as non-resistant rock zones surrounding faults and fracture zones are etched out by erosion of the bedrock (Roseboom et. al, 1985). In humid regions these erosion zones will become part of the surface drainage systems. All or parts of a drainage basin pattern will be controlled by these fracture systems. Many of the Rhode Island lineaments were initially related to bedrock fracture zones, such as faults or joints. Later, normal fluvial erosion will cause these fracture zones to develop into valleys. Sometimes it will be the main major trunk stream or river valley which will develop along the lineament zone. Other times it may be the tributary valleys of the smaller first and second order streams. Later damming by man may produce reservoirs along the lineament. Natural dams by glacial deposits may produce lakes, ponds, swamps or wetlands along these same lineaments as has been found here in Rhode Island.

Hence, it is not surprising that there develops a direct relationship between hydrogeology patterns and satellite lineament patterns. Since bedrock in the northeast, and Rhode Island is covered by glacial deposits and with limited bedrock outcrops, initial satellite lineament hydrogeologic analysis followed by various geophysical field studies can assist in locating these fractured bedrock zones. While satellite remote sensing is useful in providing a regional synoptic view with the ability to observe qualitatively and measure quantitatively it has limits in its resolving abilities, especially the multi-spectral system (see discussion elsewhere, section 2.22 on resolution). The discussion of the hydrogeology that follows is restricted in part therefore to the major lineaments that have been mapped (see Fig. 2-3). Detailed site specific studies will often require the use of more detailed remote sensing imagery such as: A. Thematic Mapper (used on Landsat 4 and 5) with at least twice the resolution of the Multi-Spectral System, B. Airborne systems such as High Altitude Photography ("HAP") with still greater resolution, and C. Side-looking Airborne Radar ("SLAR"), with less resolution but greater drainage and fracture pattern information (Pohn, et. al, 1984). In some cases, even conventional aerial photography will be necessary for first and second order tributary drainage systems.

2.41 Hydrogeology of Specific R.I. Lineaments

First of all, certain individual major lineaments are related to certain prominent hydrologic features. Perhaps the most dramatic relationship is that of the major lineament in northern Rhode Island (1-1', Fig. 2-3) which crosses the mouth of the Scituate Reservoir (E, Fig. 2-3). The southwest limb of the reservoir east of Tunk Hill follows a valley that developed by erosion along this lineament's fracture zone by normal fluvial erosion. Later the dam was built and filled with water, drowning this valley. The fracture trace probably continues a half mile to the west of the dam at the bottom of the reservoir. Continuing to the northeast the lineament probably forms the combined hydrologic features of Kent Brook, Betty Pond and an unnamed swamp wetland on the northern side of Scituate Reservoir. The geohydrogeologic relationships at the mouth of the Scituate Reservoir are more obvious because of the size of the reservoir. It therefore appears that numerous other surface hydrological features other than streams are related to the satellite lineaments. Further north, this same lineament, passes near the Central Landfill Site in Johnston (F, 1-1', Fig. 2-3), where Almy Reservoir lies directly on the trend of this lineament.

Evidence that these satellite lineaments may also indicate concentrations of bedrock fracturing has appeared in the case of hydrocarbon pollution at two bedrock sites. At Tiverton, Rhode Island, fuel oil has polluted several bedrock wells for the past two years, 1984-85. Within one mile of this site, a major lineament trends northwest through eastern Rhode Island (G, 6-6', Fig. 2-3). Field examination has indicated highly fractured Bulgarmarsh Granite, a few miles to the north directly along this lineament. Along the western side of the bay, automotive gasoline pollution, again of bedrock wells at the intersection of Routes 1 and 138, has occurred within the last two years. Again this site lies within one-half mile of a major mapped satellite lineament (H, Fig. 2-3). Thus the ability of these lineaments to indicate potential bedrock fracture hydrological zones is apparent.

on bedrock hill,

2.42 Hydrogeology of Rhode Island Lineament Patterns

The overall pattern of the satellite mapped Rhode Island lineaments appear to exhibit relationships to both the surface and subsurface hydrogeology of several areas of the state. Many major subsurface aquifers appear to be at an angle to the general northeastern trends of the lineaments. For example, the Watch Hill-South County lineament (3-3', 4-4', Fig. 2-3) crosses all the major subsurface aquifers in southern Rhode Island (I, J, K, Fig. 2-3). These aquifers (Fig. 2-4) as mapped by the federal government consists of stratified drift fills in preglacial stream channels in the bedrock (Johnston, 1985). Sediments are 75 to 100 feet thick near the axes of these buried relict stream channels and in some places over 300 feet thick. Where this stratified drift is permeable, it forms major ground-water reservoirs "that have the potential for providing large quantities of water for public supply and industrial use", (Lang, 1961). If these satellite mapped lineaments are shown to be faults, as has the Watch Hill fault in the southwestern corner of the State (Quinn, 1971) or other major fracture systems it will have an impact on the future development of these regional water systems. In addition, it has recently been suggested (Fisher, 1985) that perhaps even the trend or axes of these major pre-glacial relict buried stream channel systems may themselves have been localized by earlier similar bedrock fracture or fault systems (Fig. 2-4). All these above-mentioned aspects of the aquifer systems and lineament patterns will require detailed subsurface analysis of these major aquifers, possibly by geophysical techniques.

2.43 Hydrogeology of Rhode Island Lineament Density

Reference to the satellite lineament map (Fig. 2-3) shows that the lineament distribution is not regular nor is the lineament pattern random. Previous discussions (sections 2.41, 2.42) pointed out some of the geologic and hydrogeologic relationships for this distribution and pattern. However for the purposes of future water resources land use planning a different type of lineament map was produced. A unique isodensity lineament map has been produced detailing the density distribution of the satellite mapped lineaments (Fig. 2-5). The data base of this contoured map was produced by determining the total length of lineaments, one kilometer or longer, within a 10 kilometer diameter circular area. These circular areas were distributed in a regular north-south, east-west grid pattern consisting of 38 circular cells. The total length of lineaments within each of these cells were then measured. Then the centroid of each cell value was contoured at a 2 km interval for the entire state. The resulting map (Fig. 2-5) is unique in that it diagrams the distribution of total satellite length for a given area throughout the state.

Distribution patterns of satellite lineament density for Rhode Island (Fig. 2-5) can be shown to relate closely to the bedrock geology or the structural geology in many cases. First of all, the lowest density, values of 10 or less, surround Narragansett Bay and the outcrop area of primarily Pennsylvanian sedimentary rocks (sandstone, shale, conglomerate) of the Narragansett Basin (Quinn, 1971). Along the west side of the Bay, the 10 value contour interval is near the edge of this basin (A, Fig. 2-5) while along the east Bay this contour passes through the crystalline rocks of the Bristol dome (B, Fig. 2-5). The highest values (40-48) as found in the north-central portion of the state (C, Fig. 2-5) center on the metamorphic rocks of the Plainfield formation of the Blackstone Series which consists primarily of a medium-grained gneiss (Quinn, 1971). A similar major value site (40-48) occurs in the southwestern area of the state (D, Fig. 2-5). It occurs within the igneous rocks of the Hope Valley medium-grained alaskite gneiss (Quinn, 1971). The occurrence of this area as a high lineament density region is supported by the recent discovery of the Hope Valley shear zone in this same area (Gromet and O'Hare, 1985).

Only a small region of above average satellite lineament density occurs on the east side of Narragansett Bay (E, Fig. 2-5). It is in the Tiverton area of the Bulgarmarsh coarse-grained granite which extends into adjacent Massachusetts (Quinn, 1971). Recently in this area (1984-85), fuel oil pollution of bedrock wells suggested highly fractured bedrock which allows the migration of the fuel oil together with ground water in the bedrock. This illustrates the use of the lineament density map in predicting potential bedrock fracture hazard sites.

This contoured distribution plotting is also useful for land planners, for the siting of landfill or hazardous waste, as well as engineering and zoning planning. For example, the best sites of potentially less fractured bedrock would be indicated by the areas of low density lineament contouring. In a similar manner, areas of above average concentration of lineaments or areas of intersecting lineaments can indicate bedrock areas potentially unsuitable for hazardous waste disposal, especially either high or low level nuclear waste. The bedrock fracturing will have increased permeability and impact on the subsurface water resources is probable. Regional and local land use planning should consider carefully such placement in these areas without additional ground studies. Environmental engineering firms have even used such maps in the past to determine potentially hazardous seismic areas for nuclear power plant siting (Dames and Moore, Inc., 1974). Areas that had above average satellite lineament density were not even considered as possible candidate sites for nuclear power plants.

The use of remote sensing has been suggested as a tool in the exploration of crystalline rocks for nuclear waste repositories (Roseboom et. al, 1985). Pointing out "that remote sensing technology provides a quick and convenient means of initial analysis". Satellite imagery in the mid-west, (MSS) were used to examine structural (lineaments) and geomorphic features for regional screening studies of bedded salts on potential high level waste storage sites (Earth Technology Corp., 1985). Meanwhile, in New England, the state of Maine is presently conducting a "photo-geologic" analysis of fractures and lineaments to determine the possible effect of bedrock fractures on radionuclide migration in ground water (Maine Geological Survey, 1985).

Quantitative analysis of satellite lineament density can be conducted utilizing the state-wide lineament intensity map (Fig. 2-6). First, the contoured minimum to maximum value range must be established. Values range from 0-5 around Narragansett Bay to maximum values of 40-48 in western and north-central Rhode Island. These values are not simply anomalous point values but in both cases cover a wide area. Thus the average value of satellite lineament density for the state therefore is about 20 units. Areas with values above this amount should be considered least for potentially hazardous waste or even low level nuclear waste sites. Lineament density areas above the average have been indicated by shading on Figure 2-6. Note that this above average area covers most of the southwestern corner of the state, from western West Greenwich 10-15 miles, east to middle Exeter and then down 10-12 miles south to Usquepaug and then southeast to Narragansett Pier.

The other major area with satellite lineament density above the state average is in the north central part of the state (Fig. 2-6). This area runs from the towns of Harrisville-Pascoag, southeast through Greenville and through Johnston. It covers a zone some 10 miles wide through this region for a distance of about 22 miles. A minor area of above average satellite lineament concentration on the east side of Narragansett Bay is an area of less than 5 miles centered on the town of Tiverton (E, Fig. 2-6). Since this is a small part of a more extensive granite mass in Massachusetts, Bulgarmarsh granite, it is expected that satellite mapping in adjacent Massachusetts would show a wide area of above average satellite lineament densities.

Comparison of the Rhode Island satellite lineament density map to the potential map for radioactive waste disposal in southeastern New England (Fig. 2-7) reveals several interesting relationships. The U.S. Department of Energy has mapped nationwide, areas suitable for disposal of high level nuclear waste. Primarily, it is based on the suitable bedrock type being available. In the south and mid-west, salt bearing sedimentary rocks are being considered while in the east "crystalline rocks" are being considered. A total of 17 states have been identified which have crystalline rocks suitable for a repository (Frohlich and Vild, 1986). The U.S. Department of Energy map indicates almost the entire western half of the State, west of the Narragansett Basin boundary as having suitable crystalline rocks (A, Fig. 2-7). The far eastern side of the state together with most of adjacent southeastern Massachusetts is also mapped as suitable (B, Fig. 2-7). However satellite lineament density analysis indicates at least three of these areas probably have above average bedrock fracturing for even the crystalline rocks. If the non-crystalline rocks are excluded,the lineament density ranges from 10-40 plus, with an average density value of 25 for the crystalline rocks alone. This still leaves unchanged the three areas mapped for the state with above average lineament density (C, D, E, Fig. 2-6, and C, D, E, Fig. 2-7). Thus these areas probably would not be considered as potentially suitable nuclear waste disposal sites because of potential bedrock fractures. Extensive ground surveys both geological and geophysical should be necessary to even consider these sites. Interestingly enough the area of crystalline rocks in Rhode Island that might be suitable, with below average lineament density, (between C and D on Fig. 2-6, or Fig. 2-7) would be discounted on a hydrological basis in any case. This is the location of the Scituate Reservoir and the future Big Wood River Reservoir and their associated watersheds.

FIGURE CAPTIONS - Remote Sensing

Fig. 2-1 Parameters of the Landsat Satellite System as it relates to Rhode Island imagery used in the study. Multi-spectral imagery in 4 bands (Blue, Red and near Infrared), resolution to 1 pixel, approximately one acre. Total Landsat image is 115 miles by 115 miles and State of RI occupies 15-20 percent of total image.

Fig. 2-2 Previous Rhode Island Landsat satellite "linears" (lineaments) as mapped for seismic safety analysis for proposed Charlestown Nuclear Power Plants. Lack of mapped lineaments in this study probably due to level of experience (?), use of paper prints and non multi-spectral imagery.

Fig. 2-3 Landsat Satellite Lineaments of Rhode Island. Lineaments as mapped 0.5 km or longer from color composite and bands 4, 5, 6 and 7 black and white positive film transparency. Significant northeast trending lineaments (1-1', 2-2', 3-3', 4-4', 5-5'), high intersection concentrations (A, B, C), Scituate Reservoir (E), Central Landfill (F), and Bedrock oil pollution (G, H).

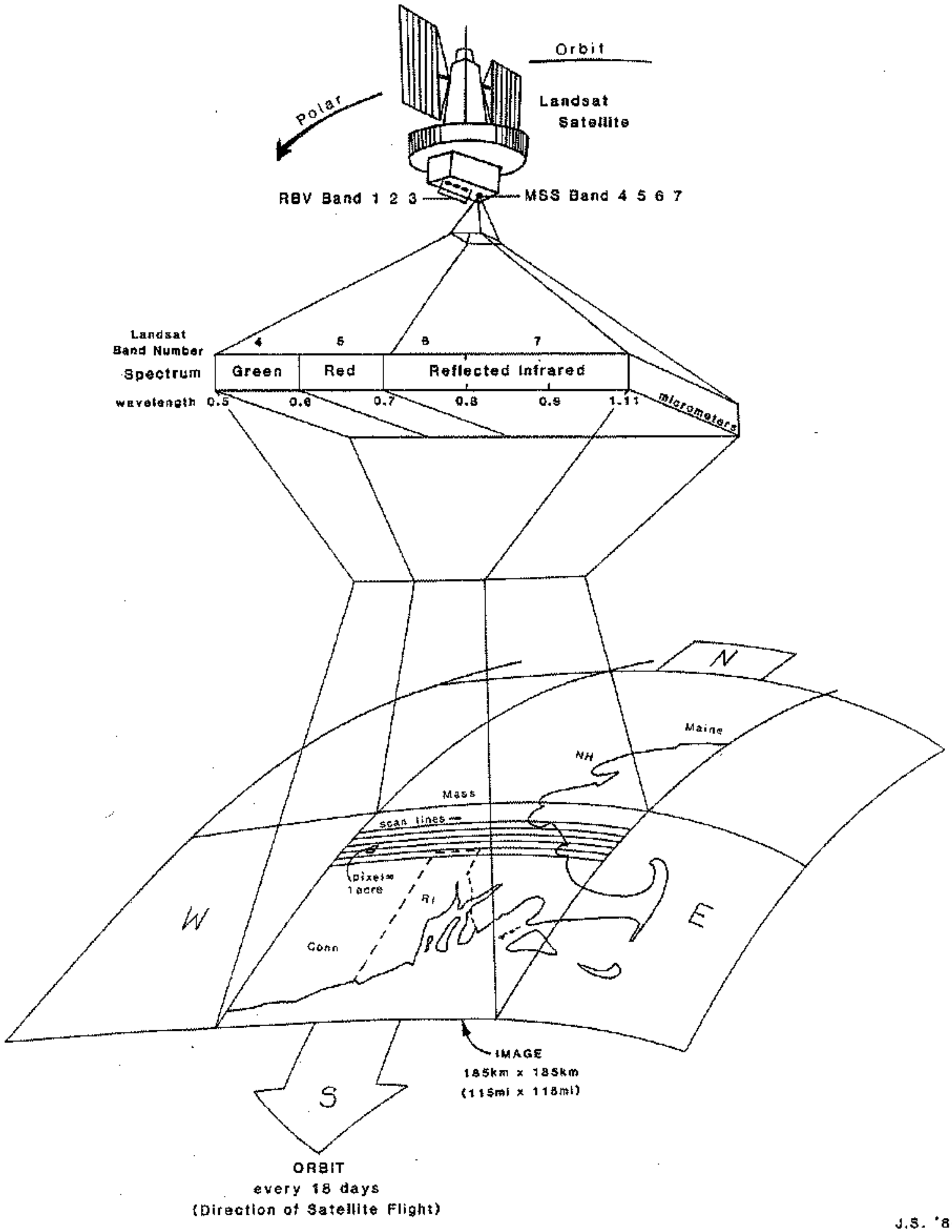
Fig. 2-4 Development of Northeast trending major satellite lineaments proposed as developing from Avalonian plate collision. Later east-west extension along these lineaments caused rifting and formed Narragansett Basin (C and D after McMaster et. al., 1980).

Fig. 2-5 Example of major glacial outwash aquifer in pre-glacial bedrock valleys in Rhode Island to depths of 200 feet. Possible bedrock fracture zones in buried relict valleys localizing these valleys (after Fisher, 1985).

Fig. 2-6 Landsat lineament intensity map of Rhode Island indicating density of lineaments. Contoured on basis of total length of lineaments in kilometers per 80 km square unit area. Margin of Narragansett Basin (A-A) adjacent to sedimentary rocks with lowest contour interval. Concentration of contours over Bristol granite (B). Maximum concentration over crystalline rocks (C, D, E). Shaded area is above average lineament density.

Fig. 2-7 Crystalline rocks of southeastern New England considered as potential suitable sites for disposal of radioactive waste (source U.S. Dept. Energy). Rhode Island areas considered suitable (A, B) also have highest and above average satellite lineament density (C, D, E) and thus unsuitable fractured bedrock.

LANDSAT CHARACTERISTICS
FOR RHODE ISLAND AREA



J.S. '86

Fig. 2-1

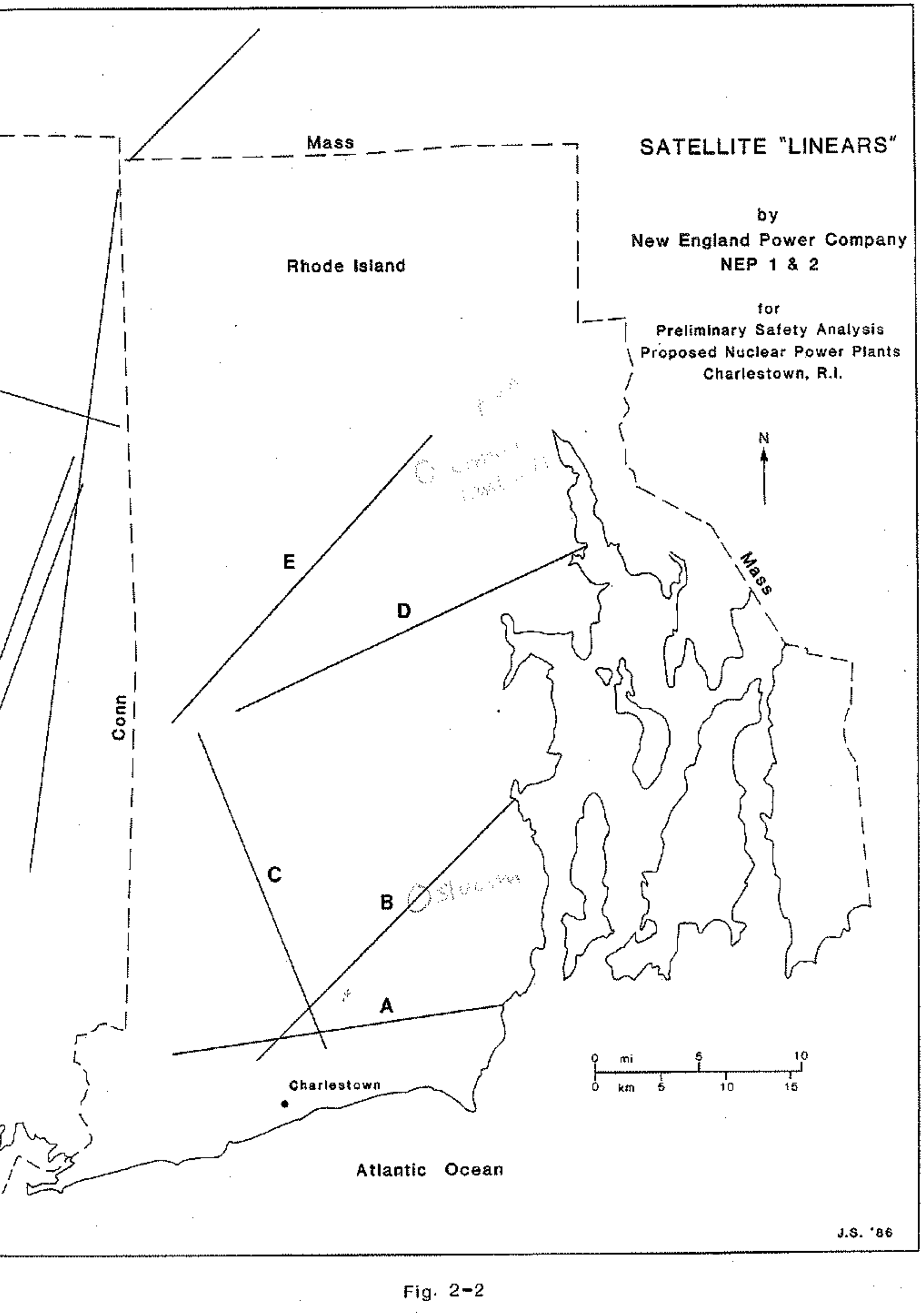

SATELLITE "LINEARS"
by
New England Power Company
NEP 1 & 2
for
Preliminary Safety Analysis
Proposed Nuclear Power Plants
Charlestown, R.I.
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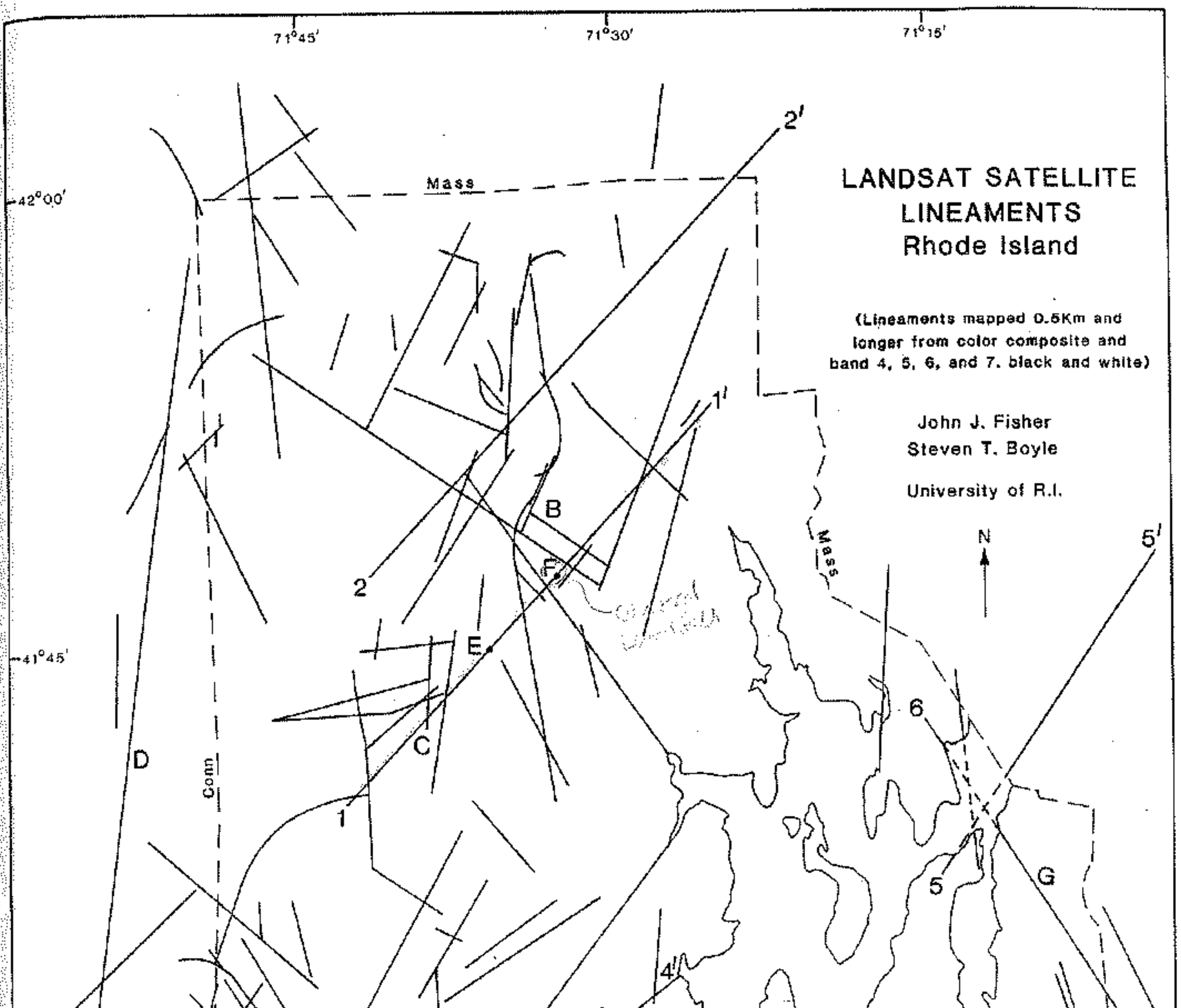
Fig. 2-2


71°45'
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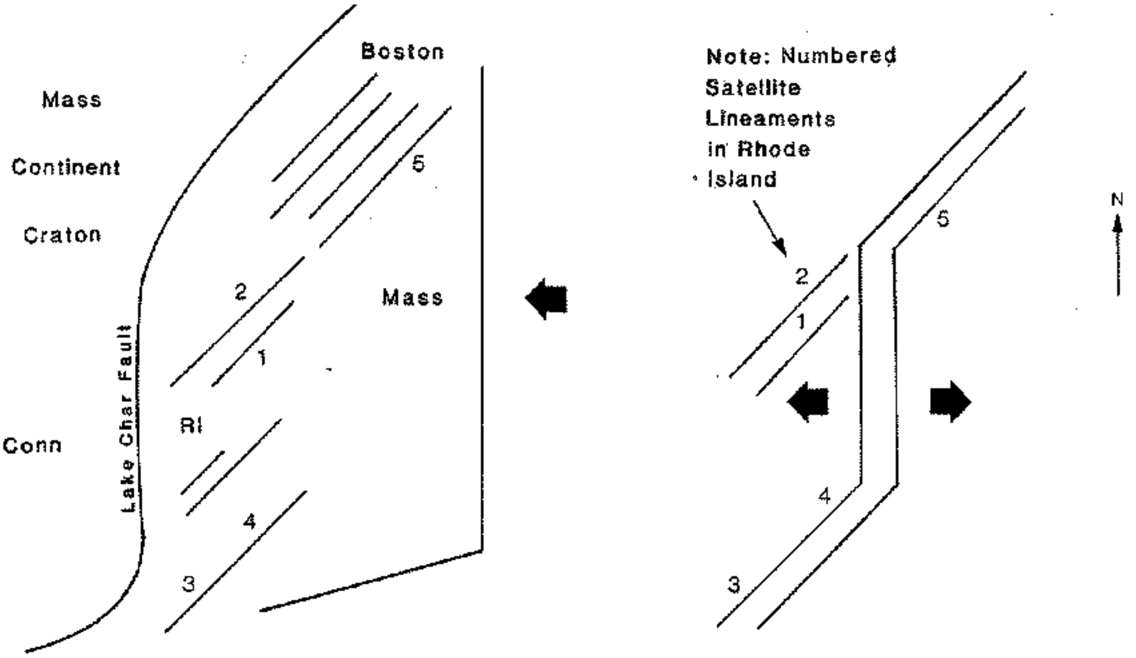
LANDSAT SATELLITE
LINEAMENTS
Rhode Island
(Lineaments mapped 0.5Km and
longer from color composite and
band 4, 5, 6, and 7. black and white)
John J. Fisher
Steven T. Boyle
University of R.I.
N
Mass
Conn
1
1'
2
2'
3
3'
4
4'
5
5'
6
6'
A
B
C
D
E
F
G
H
I
J
K
0 mi 5 10
0 km 5 10 15
J.S. '85

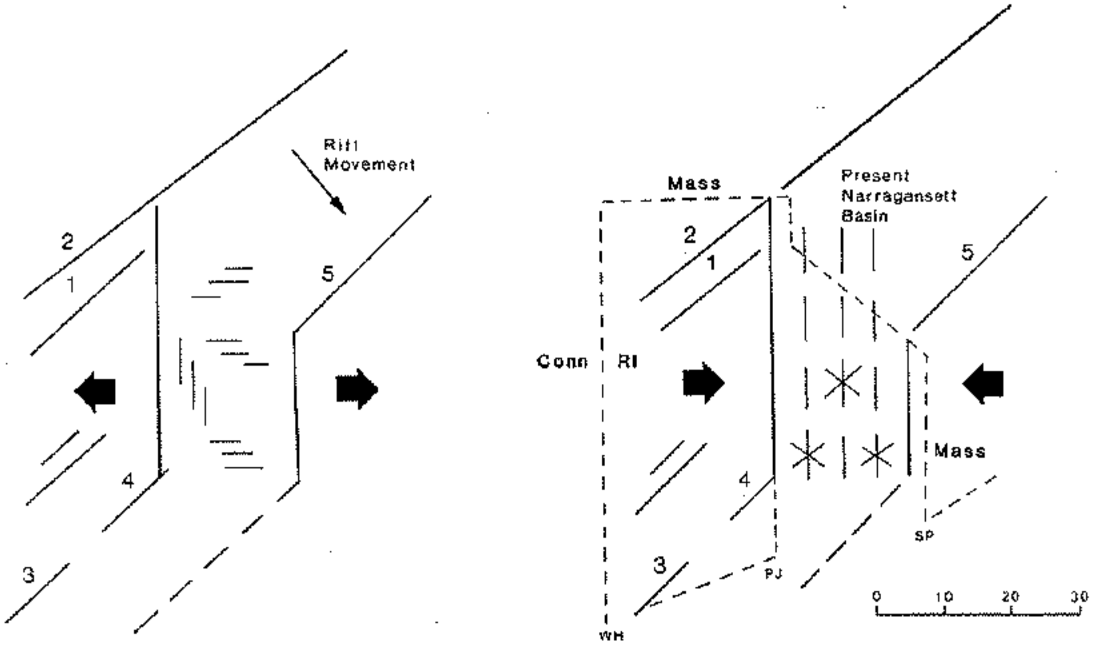
Fig. 2-3

RHODE ISLAND SATELLITE LINEAMENTS
(DEVELOPING BY WELDING OF AVALON PLATE)
(LATER RIFTING OF NARRAGANSETT BASIN)
(ALONG THESE NORTHEAST FAULTS)



A. Avalonian Plate Welding
RI Satellite Lineaments (this study)
Mass Strike-slip Faults (Barosh, 1976)

B. East-West Extension
early Carboniferous



(after McMaster et. al., 1980: for Narragansett Basin)

C. Rifting, Carboniferous

D. Compression-Fracturing & Folding
post-Carboniferous

.S. '86

Fig. 2-4

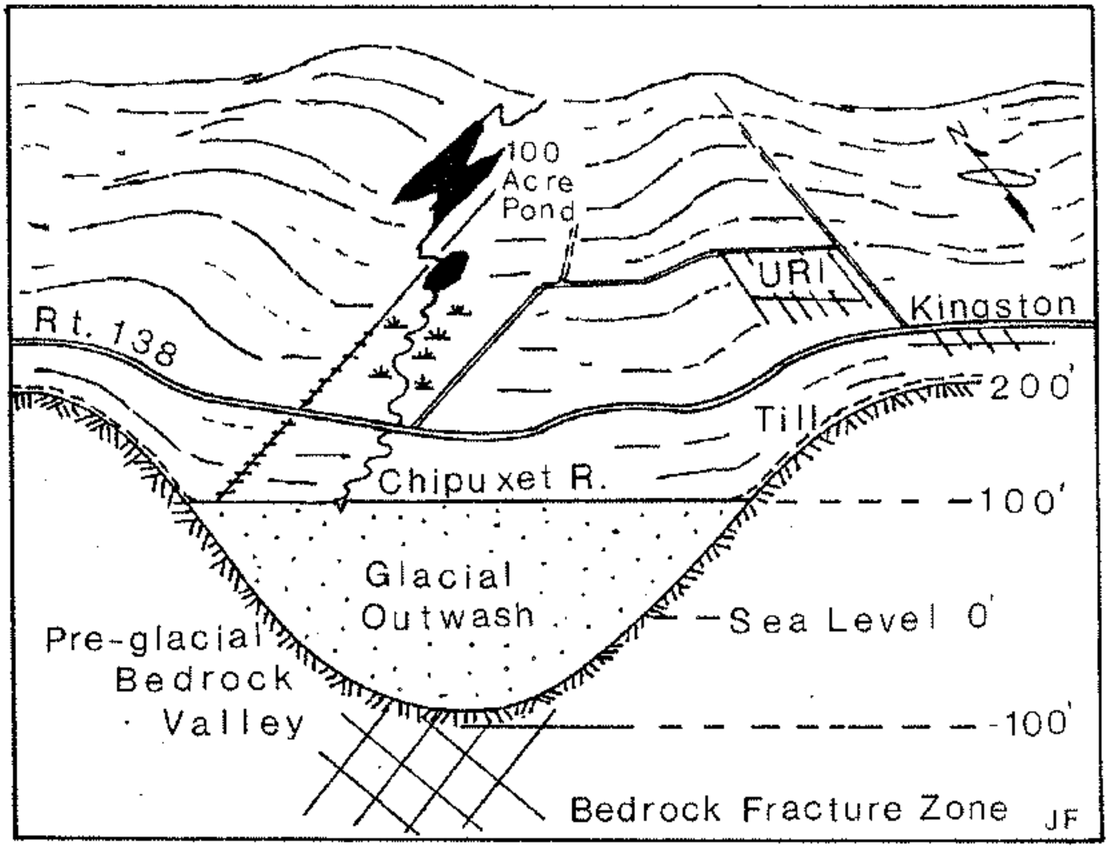

100 Acre Pond
N
URI
Kingston
Rt. 138
200'
Till
Chipuxet R.
100'
Glacial Outwash
Sea Level 0'
Pre-glacial Bedrock Valley
-100'
Bedrock Fracture Zone
JF

Fig. 2-5

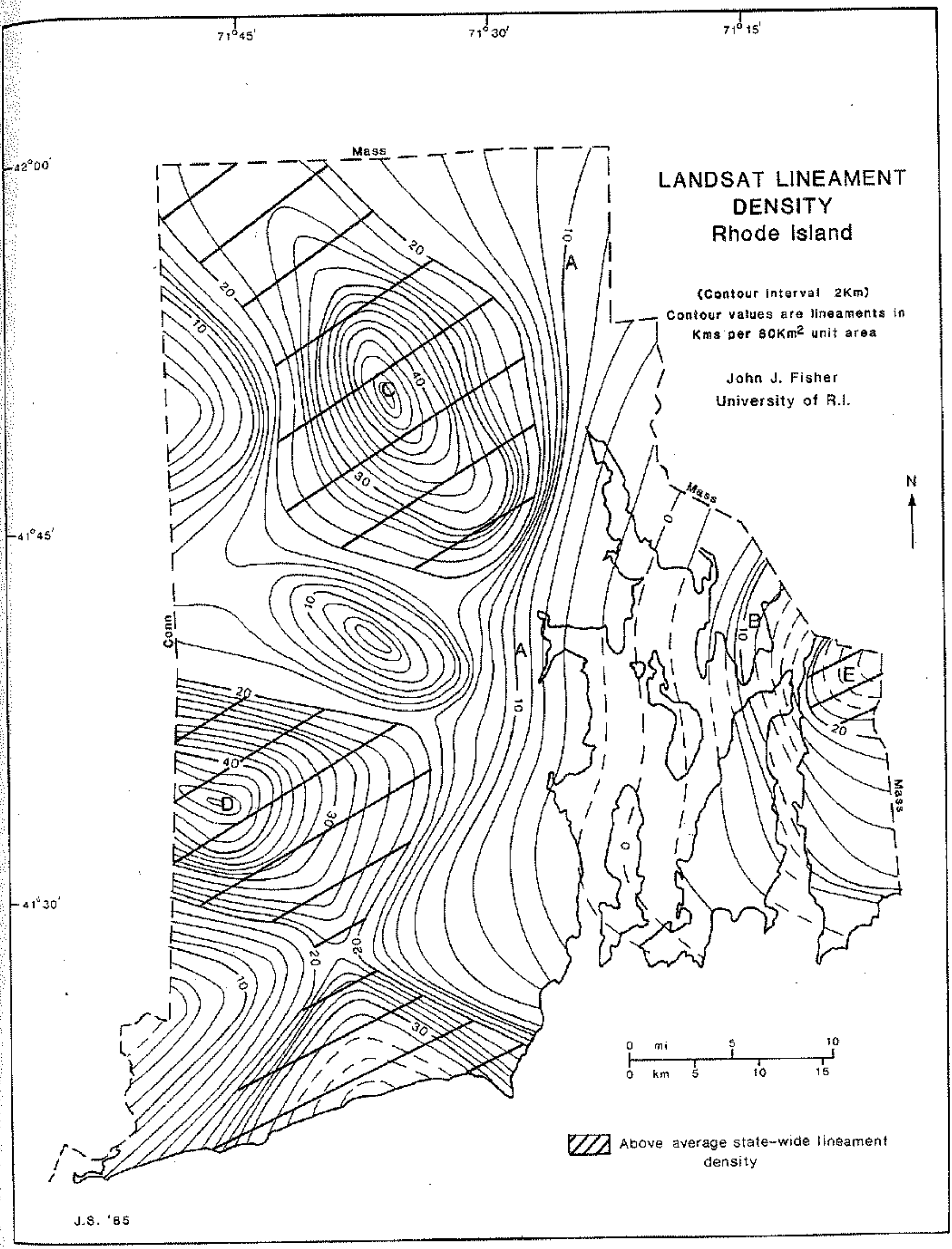

LANDSAT LINEAMENT DENSITY
Rhode Island
(Contour interval 2Km)
Contour values are lineaments in Kms per $80Km^2$ unit area
John J. Fisher
University of R.I.
71°45'
71°30'
71°15'
42°00'
41°45'
41°30'
Mass
Conn
N
A
B
C
D
E
0
10
20
30
40
0 mi 5 10
0 km 5 10 15
Above average state-wide lineament density
J.S. '85

Fig. 2-6

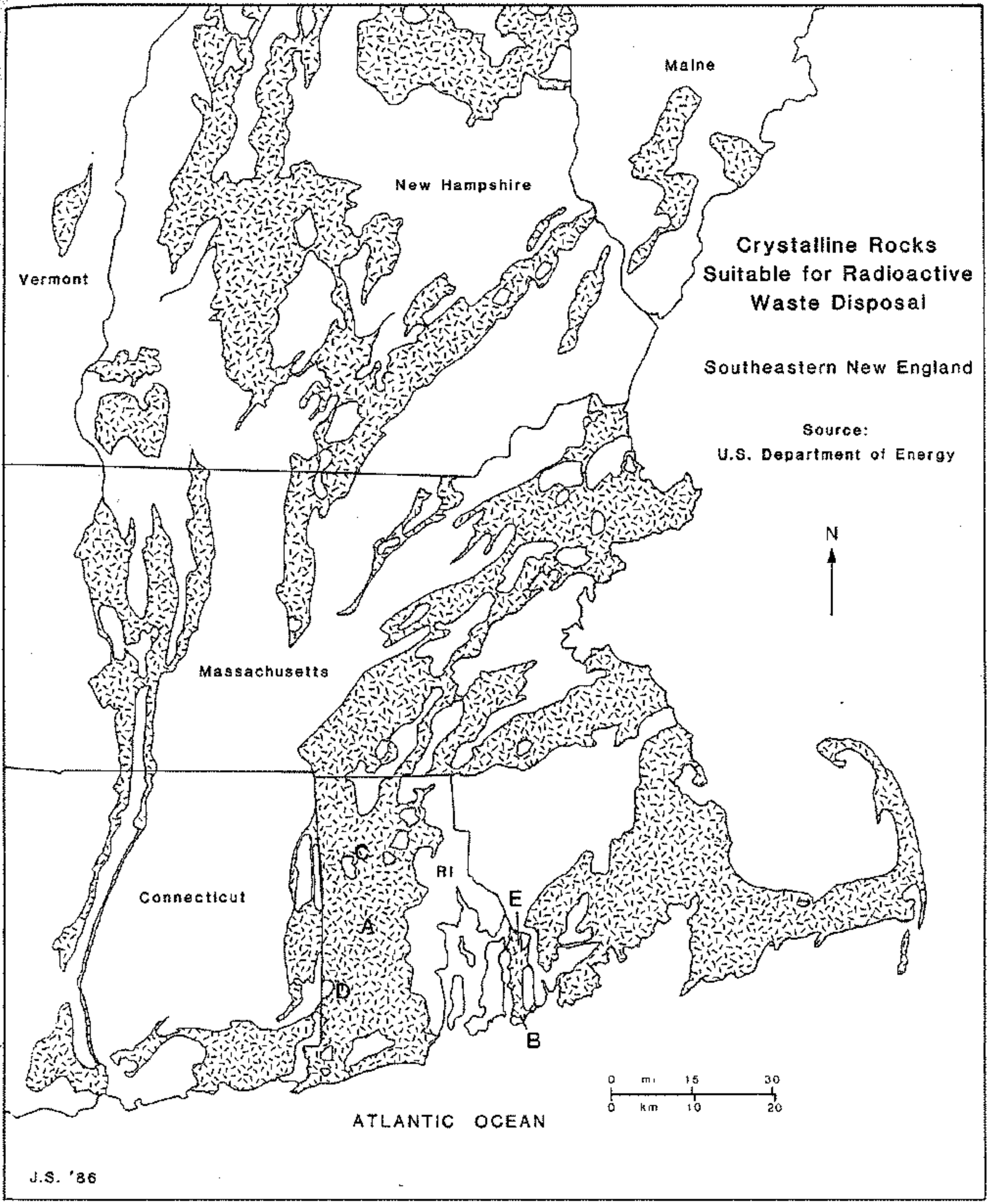

Crystalline Rocks
Suitable for Radioactive
Waste Disposal
Southeastern New England
Source:
U.S. Department of Energy
Maine
New Hampshire
Vermont
Massachusetts
Connecticut
RI
A
B
C
D
E
N
0 mi 15 30
0 km 10 20
ATLANTIC OCEAN
J.S. '86

Fig. 2-7

3. GEOPHYSICS (Reinhard K. Frohlich)

3.1 EVIDENCE OF FRACTURES FROM GRAVITY ANOMALIES

Detailed gravity surveys were conducted over known fracture zones and areas where they were suspected. The gravity map of the State of Rhode Island is shown in Fig. 3-1. Geological field checks and a comparison with the State Geological Map suggest that many anomaly trends are related to faults and in some cases to fracture systems in the bedrock. Small elongate NNW-striking gravity lows (Nos. 5 to 8) are located over glacial stream channels which reach thicknesses of 300 feet. It is impossible to account for the gravity lows with the density contrast between unconsolidated sediments and the granitic bedrock only, unless the glacial stream channels are unreasonably deep. Part of the gravity low is caused by the density contrast between fractured and massive bedrock.

The notion of fracture porosity as a cause of gravity lows is further supported by gravity lows Nos. 6, 8 and 9. They increase in size at the intersection with the NE-striking Watch Hill Lineament, shown as lineament No. 4 in Fig. 3-1. This bulge of the gravity lows of NNW-striking anomalies at the intersection with the NE-striking lineament suggests an increase of the fracture density at the intersection of two fracture trends.

The Watch Hill Lineament does not show an elongate gravity low, as expected, since it strikes parallel to the gravity contours of a strong regional field, which decreases from SE to NW across the entire western part of the State. A detailed gravity map (s. Fig. 3-2) shows anomaly trends 11 and 12 over the quadrangles Wickford, Narragansett, Kingston, and Slocum. Both anomalies are superposed over a strong regional gravity trend which decreases from SE to NW. This regional gradient in the order of 1-2 mgal/km reflects the change of a crustal gravity effect from the dense metamorphic sediments of the Narragansett Basin to the lighter crystalline rocks of granitic composition which increase in thickness towards the northwestern part of the State. Both anomalies coincide with topographic depressions which are the Narrow River (11) and Point Judith Pond (12). Profile lines A-A' and B-B' across anomaly 11 are shown in Fig. 3-3. The dashed line is a continuation of the regional gravity field which facilitates the separation of the local gravity field as shown in Fig. 3-3. Though there is some uncertainty in estimating a smoothed regional field, errors are usually relatively small.

3.11 Model estimates for the local anomaly.

An estimate of the density contrast between overburden and granitic bedrock is based on the width of the valley as seen on the topographic map and on fathometer depth transects (J.J. Fisher, Narrow River Study. 7/14/74). The maximum width of the overburden in the valley is 500 m. Across sections of the transects channel depths as deep as 20 m were observed over maximum widths of 150 m. This volume is summarized in a rectangular square section of 500 m by 10 m (s. Fig. 3-4) with a density of 1.15 gr/cc. This value is only slightly higher than that of water, since at least half of this volume consists of unconsolidated sediments. An additional rectangle 500 m by 20 m (depth) with a density of 1.95 gr/cc shall account for glacial deposits underneath the river. For the ambient granite a density of 2.60 gr/cc was assumed based on numerous density measurements of R.I. granites. The resulting density differences that cause the gravity low are shown in the gravity model of Fig. 3-4. Approximately 60% of the observed gravity minimum in Fig. 3-4 can be attributed to the water and unconsolidated sediments. This is probably an overestimate of the influence of the valley deposits which leads to the conclusion that at least 40% of the anomaly must originate from another low density source. There are no other means of explaining the unaccounted 40% than to assume an extensive fracture system underneath the Narrow River. Several simple rectangular gravity models and their calculated gravity effects are shown in Fig. 3-4. The dashed curve represents the effect of the overburden material; the drawn curves show the combined effect of overburden and fracture zone. Different models are shown for the density contrast and depth of the fracture zone which is also 500 m wide.

3.12 Estimate of the Fracture porosity

Several models can account for the fracture zone ranging in depth between 1 and 4 km and in density contrast between 0.035 and 0.06 gr/cc. Any decrease in the density contrast would require width and/or depth to be increased and vice versa to account for the 40% of the anomaly. Without further detail on the overburden depth it is difficult to make a distinction between the suggested fracture models, except that depths of the fracture zone which are smaller than 1 km cannot reproduce the width of the observed gravity anomaly. The density contrast $\Delta\sigma$ can be converted into normative fracture porosity n, if σ is the density of the compact unfractured bedrock:

$$\Delta \sigma = \sigma - (1 - n) \cdot \sigma - n \qquad (1)$$

In this case the fractures are filled with water of density 1 gr/cc. The normative porosity is a function of σ and $\Delta\sigma$:

$$n = \frac{\Delta \sigma}{\sigma - 1} \qquad (2)$$

For σ =2.60 gr/cc (granite) the density contrasts of the fracture zone, $\Delta\sigma$, corresponds with the percentage of fracture porosities N as follows:

Depth (km)	:	4.5	2.0	1.0
(gr/cc)	:	0.03	0.04	0.06
N %	:	2.0	2.5	3.7

Table 3-1: Models for the fracture zone derived from gravity anomalies.

3.13 Sensitivity analysis.

The models in Fig. 3-4 are simple and do not explain details, such as the asymmetry of the anomalies and the relation with the dip of the fracture zones. While the suggested models show ballpark figures for the average fracture porosity and depth, the true fracture porosity is probably higher at shallow depths and smaller at greater depths than the average porosity used in the model. In spite of the uncertainty with respect to the depth of the fracture zone, it is certainly in the order of 1 km and possibly larger. Further refinements of the models are possible if there is more certainty on information such as:

- separation of the local from the regional field
- density measurements of the unconsolidated sediments
- depth-to-bedrock data from borings or other geophysical methods, such as seismic refraction or geoelectrics.
- application of the topographic reduction
- elevation-controlled short-spaced gravity profiles

3.2 EVIDENCE OF FRACTURES FROM MAGNETIC ANOMALIES

3.21 The southwestern part of the Watch Hill Lineament

This lineament (gravity trend No. 4 in Fig. 3-1) is characterized over a distance of 12 km by a series of magnetic lows. They extend over the quadrangles Watch Hill, Ashaway, and Carolina in the southwestern part of the state, as shown in Fig. 3-5. A major portion of this lineament appears as a prominent satellite lineament on the Landsat Lineament Map. The southwestern part has been mapped as a fault on the State Geological Bedrock Map (Quinn, 1972). Most of the magnetic lows are not associated with a high, which is not characteristic for magnetic anomalies in the northern hemisphere. It is difficult to reproduce isolated magnetic lows with a magnetic model that represents a buried geological body with a given rock magnetization. One possibility of obtaining a magnetic low is an elongate body of reverse remnant magnetization as it is found in basalts and gabbros. Such rocks, however, are an unlikely source for the magnetic lows associated with the Watch Hill Lineament. Neither is there any outcrop evidence for such rocks nor is there a gravity high that is usually associated with mafic rocks, even if they do not appear at the surface.

A possible case is suggested that explains the low as an edge effect between two separate layers that are magnetized by induced magnetization. Both layers are separated by a non-magnetic gap as shown in Fig. 3-6. The series of models A, B, and C show calculated anomalies over a gap that increases in width from 40, over 80 to 100 m. Both magnetized horizontal layers are 50 m thick. The non-magnetic section represents a fracture zone along which circulating erosional water or hydrothermal water oxidized the magnetite. The magnetization of outcropping rocks was measured with a handheld susceptibility meter (Scintrex M5). A value of 1.0* 10 -3 emu (electromagnetic units) was used with a declination and inclination of the ambient magnetic field of -14° and 72° respectively. The strike of the fracture zone is N 45° E. The dip angle was varied from 20° SE (model series A) to 20° NW (model series C). The magnetic anomalies across the Watch Hill Lineament (s. bottom of Fig. 3-6) are comparable with the modeled anomalies of series A.

It must be emphasized that, in contrast to gravity models, the same geological models will produce different magnetic anomalies depending on the strike direction of the gap, and the size and orientation of the ambient magnetic field, which is different in other regions.

Important is that no unreasonable assumptions about the body and magnetization are necessary to reproduce the observed magnetic anomalies.

3.22 The "Almy Reservoir" magnetic anomaly

The notion that fractures in granitic rocks produce magnetic lows due to a loss of magnetization was tested near the Almy Reservoir Site. A large NNW-striking aeromagnetic anomaly crosses the intersection of Highway 295 with 195 West (s. Fig. 3-7). The site offers ample outcrop evidence of granites with several fracture and shear zones. The major part of the aeromagnetic anomaly can be reproduced as a 1 km thick magnetized granite which is in contact with a different type of granite. Both granites belong to the Scituate Granite Gneiss Complex. A detailed groundmagnetic anomaly-profile was measured along the median strip of Highway 295 across the aeromagnetic anomaly (profile 1, s. Fig. 3-7). At an approximate distance of 20 feet, three readings at slightly changed locations were averaged to present one magnetic observation on this profile. The result is the heavy curve in Fig. 3-8 of the magnetic field.

Along four faces of the two-lane highway magnetic susceptibility was measured on outcrops to provide rock magnetization values for the magnetic model. Each of the plotted values in Fig. 3-8 for the magnetic susceptibility represents the average of more than 5 independent readings. Susceptibilities were compared with structural observations of fracture and shear zones.

3.221 Model Discussion

The magnetic model at the bottom of Fig. 3-8 was constrained by: 1) The measured groundmagnetic profile, which has to be matched,

2) The magnetic susceptibility measurements, and 3) The location of shear and fracture zones observed along the outcrops. One can correlate at least three fracture zones with magnetic lows that can be modeled with nonmagnetic gaps. The downwards pointing arrows indicate locations where the magnetic susceptibility is consistently negligibly small. The adopted magnetization of the granite at $1.2*10^{-3}$ emu to the SW and $1.9*10^{-3}$ emu to the NE was also confirmed with susceptibility measurements. It provides an almost perfect match with the observed anomaly. Shear zones at the northeastern part of the anomaly were found to be strongly magnetized. The rock within the shear zones is considerably altered to a mylonite by ductile/brittle shear deformation. They showed the highest susceptibility values, which is common for some mylonites.

A parallel magnetic profile was measured across the anomaly approximately 1.2 km to the northwest of the "Median Strip" anomaly (profile 2, s. Fig. 3-8). The profile runs north of the Almy reservoir and is shown in Fig. 3-9 as the "Almy Reservoir" profile. The similarities between both anomalies even in small details suggests that short-spaced changes along the profiles of the magnetic anomalies are most likely related to continuous extensions of fracture zones. This will be confirmed by additional magnetic profiles in the second year of this study.

3.23 The Turf Farm Anomalies

The magnetic lows of the Watch Hill Lineament seem to fade out to the northeast as shown in Fig. 3-5. Either the lineament terminates or the magnetization of the unfractured bedrock decreases. SLAR imagery and the gravity trend in Fig. 3-1, however, suggest a continuation of the lineament. It is therefore more likely that the magnetic anomalies become weaker because of a decrease in rock magnetization. A short-spaced magnetic survey was conducted near the turf farm southeast of the Hundred Acre Pond on the Kingston Quadrangle. A total of 470 field points were occupied, where each point represents the average of 3 adjacent measurements. An additional observation, while the sensor head was elevated, helped to identify nearby noise from buried pipes, etc. The distance of the field points was 100 feet and in some cases reduced to 50 feet. The resulting magnetic anomaly map in Fig. 3-10 shows two NE-striking elongate magnetic lows that are paralleled by two smaller lows to the southeast. Here the contour interval is 20 gammas in comparison to an interval of 100 gammas in the southwestern part of the lineament (s. Fig. 3-5)

Even with resolution of the magnetic survey of only 1 nT (gamma) short-spaced magnetic surveys produce reliable results for locating buried fracture zones and for determining their strike, length, and width. Detailed magnetic modeling is suggested for the next phase of this study to determine the dip and depth extension of the fracture zones. For further efforts to locate fractures in crystalline bedrock it is recommended to conduct groundmagnetic surveys with an instrumental resolution of 0.1 nT (gamma). Such instruments are available at reasonable cost (Geometrics, Model G856A) and can produce useful results at very small levels of bedrock magnetization.

3.3 GEOELECTRICAL DEPTH SOUNDINGS OVER FRACTURES

Several geoelectrical depth soundings after Schlumberger were conducted over a fracture zone near the Turf Farm. The center of the depth sounding was over the northeastern magnetic low as identified in Fig. 3-10. If the fracture zone is filled with water, the electrical resistivity of the bedrock is expected to be low.

The principle of the geoelectrical depth sounding method is shown in Fig. 3-11 (top). The current electrodes at a distance L/2 from the center of the array are successively expanded to force the current into greater depths. For the Schlumberger configuration the potential electrodes are kept stationary and close to the center of the array. The electrical resistivity is obtained by passing a direct electrical current through the electrodes into the ground. The measurement is repeated by reversing the current. Fig. 3-11 (bottom) shows the time function of a current flow and its reversal (I). The voltage response is observed between the potential electrodes and is usually proportional to the current sequence due to Ohm's Law (curve C in Fig. 3-11). Occasionally the voltage response is distorted and shows either an overvoltage as in curve a or an exponential build up, as in curve b of Fig. 3-11. This symmetric impulse deformation of the voltage response is known as induced polarization and occurs over certain ore deposits and clay depositions.

The geoelectrical depth sounding near the Turf Farm showed a symmetrical voltage response for electrode separations between

5 and 130 feet (L/2). For larger separations the resistivity changed when the current was reversed. At L/2 values beyond 200 feet the measured voltage was opposed to the electrical current as shown in Fig. 3-12, i.e. in spite of a current reversal the voltage remains of the same polarity. The voltage between potential electrodes was amplified and monitored with a strip chart recorder. The geoelectrical depth soundings are shown in Fig. 3-13. The apparent resistivity is plotted on the ordinate versus the half-electrode separation L/2 on the abscissa. Both axes are on a logarithmic scale. Beyond L/2 = 130 feet the resistivity curve is divided due to the change in apparent resistivity when the current is reversed. Within 14 days four points of the curve were repeated. The same "current reversal" effect was observed but with different values. A depth sounding over the same location in Nov. of 1985 shows a decrease of the abnormal effect.

The objective of the next phase (2nd year) is to investigate this abnormal nonlinear effect systematically by changing current, orientation and electrode array relative to the magnetically determined fracture zone. The goal of this second phase is to arrive at a model that can explain the abnormal resistivity effects and show their relation to the hydraulic characteristics of fracture zones.

FIGURE CAPTIONS - Geophysics

Fig. 3-1: Gravity map of Rhode Island with major fracture and fault zones, (R.K. Frohlich, unpublished NRC report).

Fig. 3-2: Detailed gravity map of the Kingston, Slocum, Wickford, and Narragansett Quadrangles. Profiles A - A' and B - B' extend across the Narrow River gravity low, which is caused in part by fractures.

Fig. 3-3: Gravity profiles across the Narrow River, RI showing a strong regional field with a superposed local gravity low.

Fig. 3-4: Separated local gravity low from profile B - B' of Fig. 3-3. Model anomaly shows contribution from overburden deposits, such as water, sediments, and glacial deposits alone (dashed curve). Model curves 1, 2, and 3 represent the combined gravity effect of overburden and fractured bedrock due to the respective models. n is the fracture porosity.

Fig. 3-5: Groundmagnetic map of southwestern Rhode Island covering parts of the Watch Hill, Quonochontaug, Carolina, and Ashaway Quadrangles. The Watch Hill Lineament shows a series of negative magnetic anomalies (Frohlich, 1982). The magnetic lows are separated by mapped N-S trending fractures (a to q), (Smith and Barosh, 1980).

Fig. 3-6: Models of a magnetized horizontal layer separated by a nonmagnetic fracture zone with the calculated model anomalies. Series A, B, and C show a change in dip of the fracture zone; the width increases from top to bottom. Field anomalies D - D', E - E', F - F' from groundmagnetic profiles of the map (s. Fig. 3-5) show best similarity with series A models.

Fig. 3-7: Aeromagnetic map section with a NW-striking magnetic high near the Almy Reservoir. 1 and 2 are groundmagnetic profiles.

Fig. 3-8: Groundmagnetic anomaly of profile 1 along the median strip of Highway 295 (drawn curve). Model anomaly (dashed curve) due to magnetic susceptibilities observed and shown in the model at the bottom. Magnetic susceptibilities measured on outcrops are shown at the top.

Fig. 3-9: Comparison of magnetic profiles along the Median Strip (profile 1) and the Almy Reservoir (profile 2). Location see Fig. 3-7.

Fig. 3-10: Magnetic anomaly map over the URI Turf Farm. Elongate NE-striking magnetic lows indicate buried fracture zones. Observation interval: 100 ft; contour intervals: 20 nT gamma); VES: Vertical electrical sounding.

Fig. 3-11: Principle of the geoelectrical depth sounding method (top). Possible voltage responses U to a direct current and its reversal (I). Curve a: negative induced polarization; curve b: positive induced polarization; curve c: voltage response due to Ohm's law.

Fig. 3-12: Abnormal, nonlinear voltage response due to a reversed current (s. Fig. 3-11) for electrode separations between L/2 = 200 and 500 ft. Current reversal does not cause a reversal of the voltage for L/2 = 250 to 500 ft. The center of the depth sounding is located over the fracture (VES of Fig. 3-10).

Fig. 3-13: Geoelectrical depth soundings over the fracture zone (VES of Fig. 3-10) of March 30, April 11 and Nov. 1, 1985. For large electrode separations two resistivities are obtained, one for each current polarity.

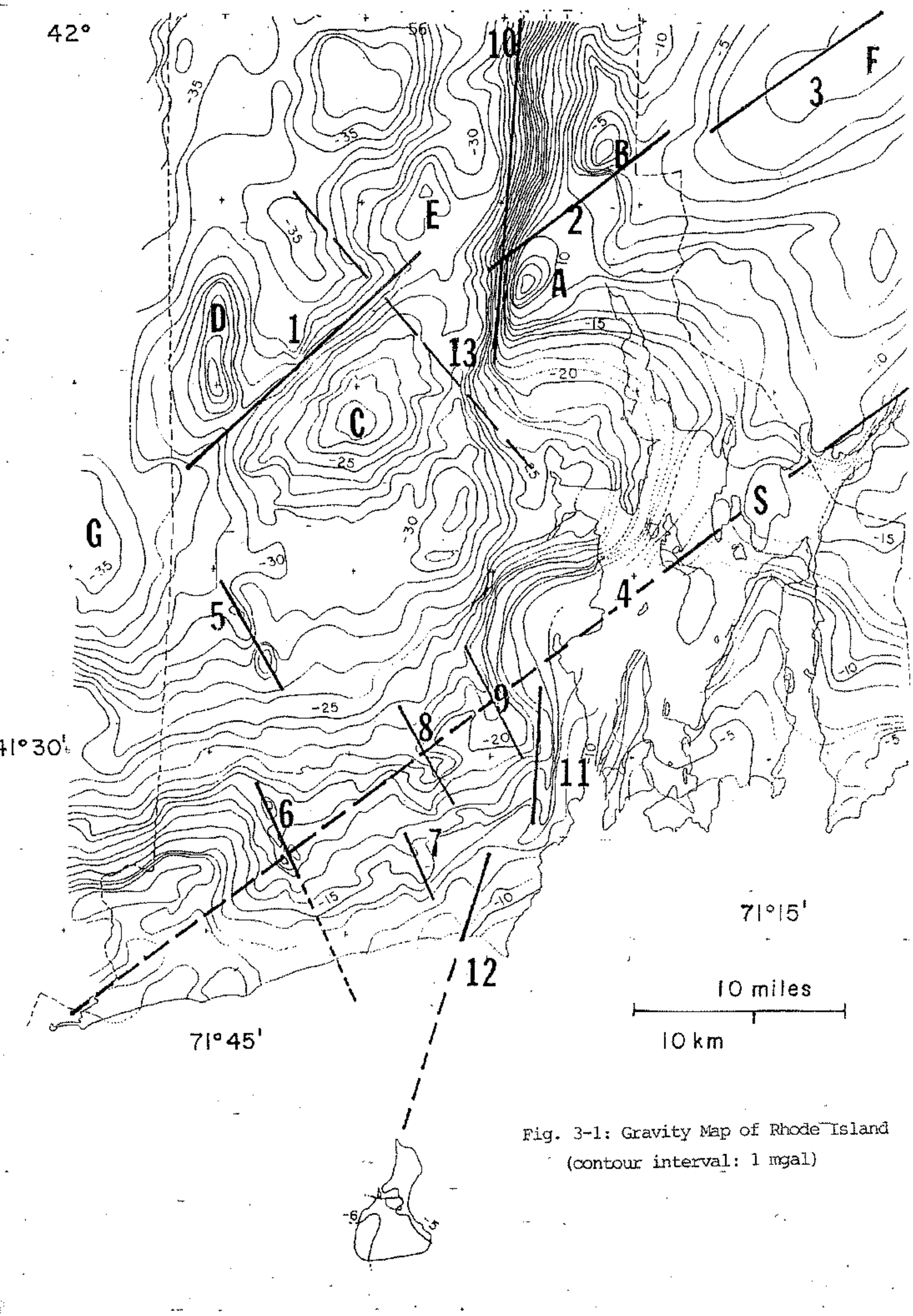


Fig. 3-1: Gravity Map of Rhode Island
(contour interval: 1 mgal)

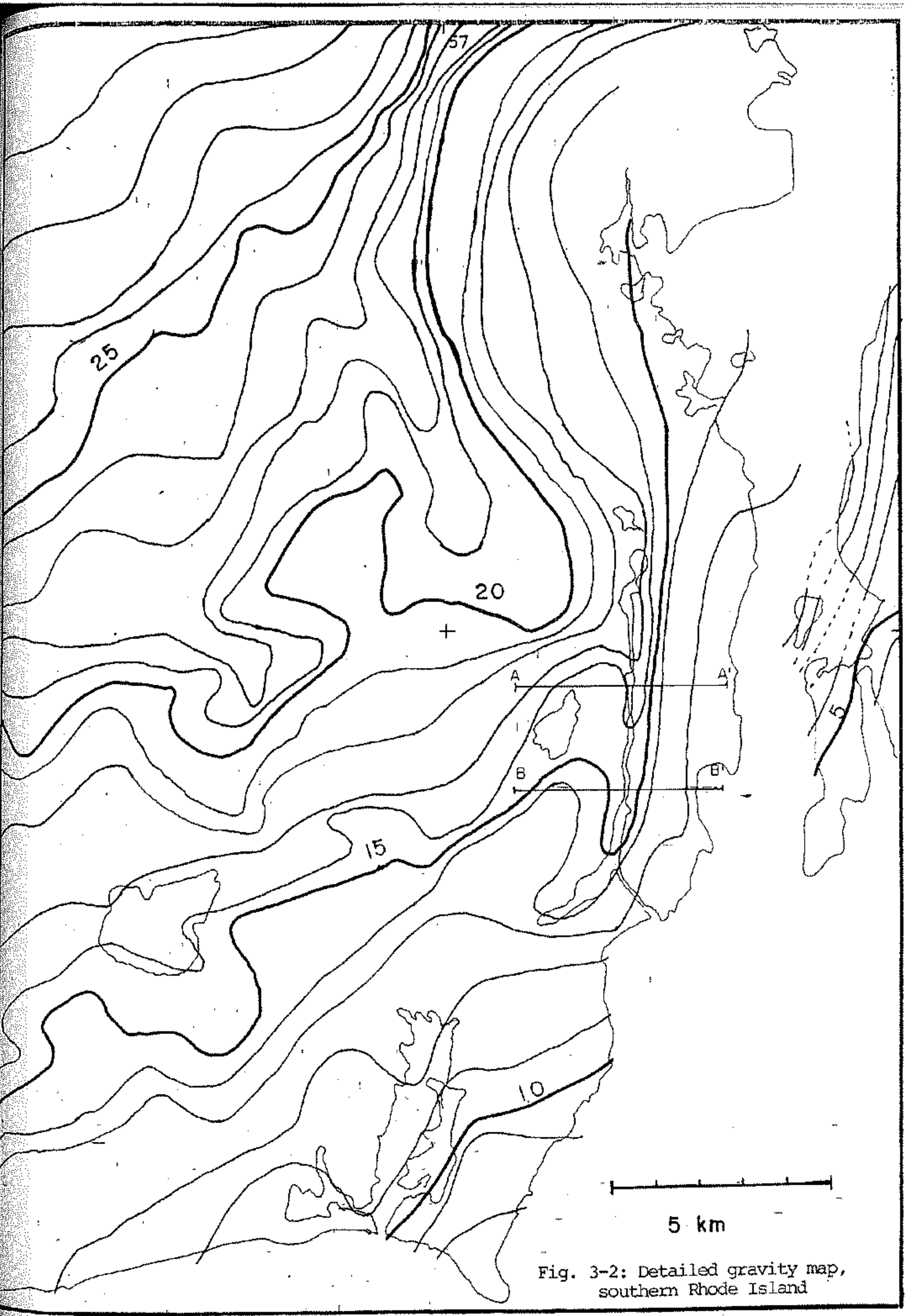


Fig. 3-2: Detailed gravity map, southern Rhode Island

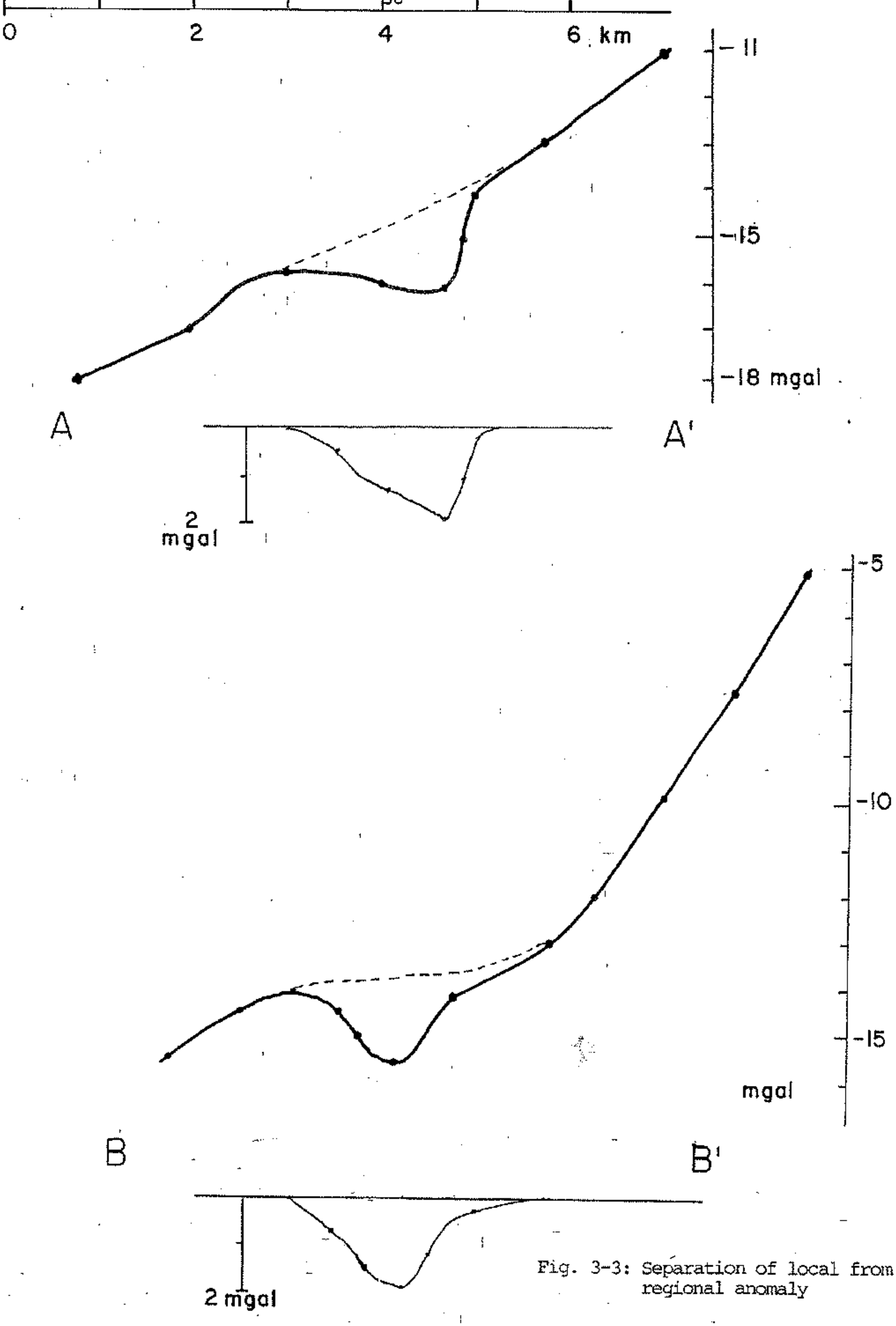


Fig. 3-3: Separation of local from regional anomaly

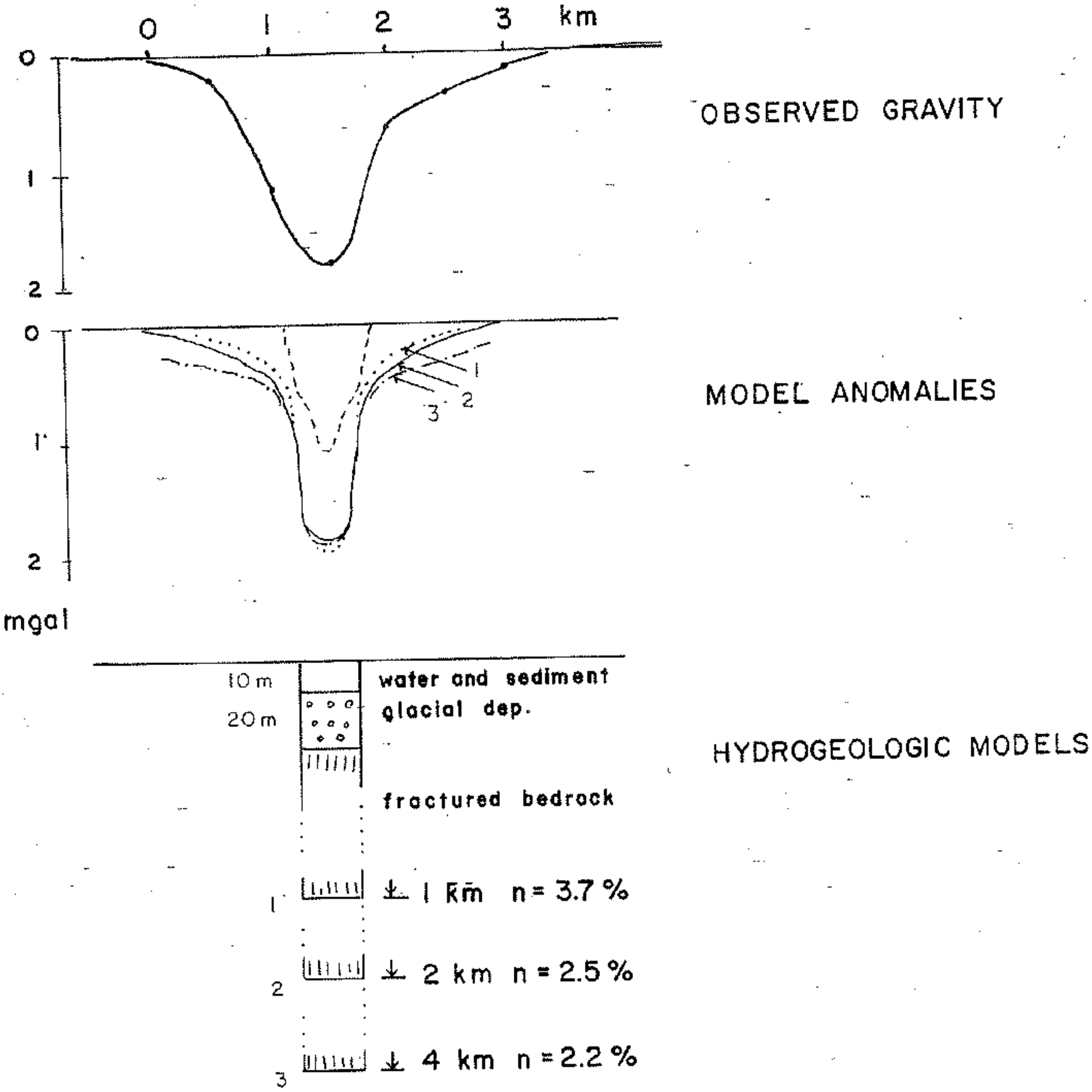


Fig. 3-4 : Gravity models

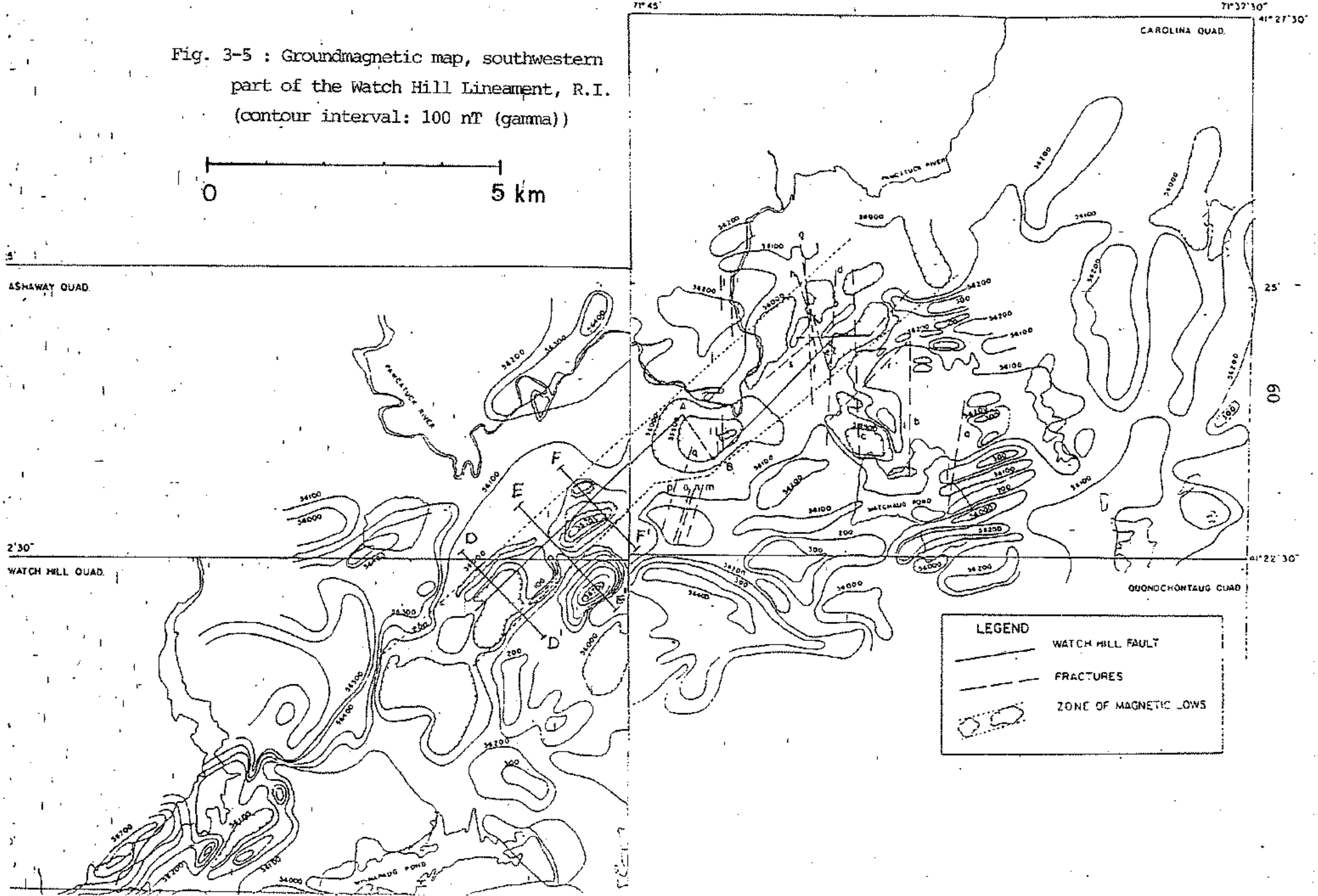
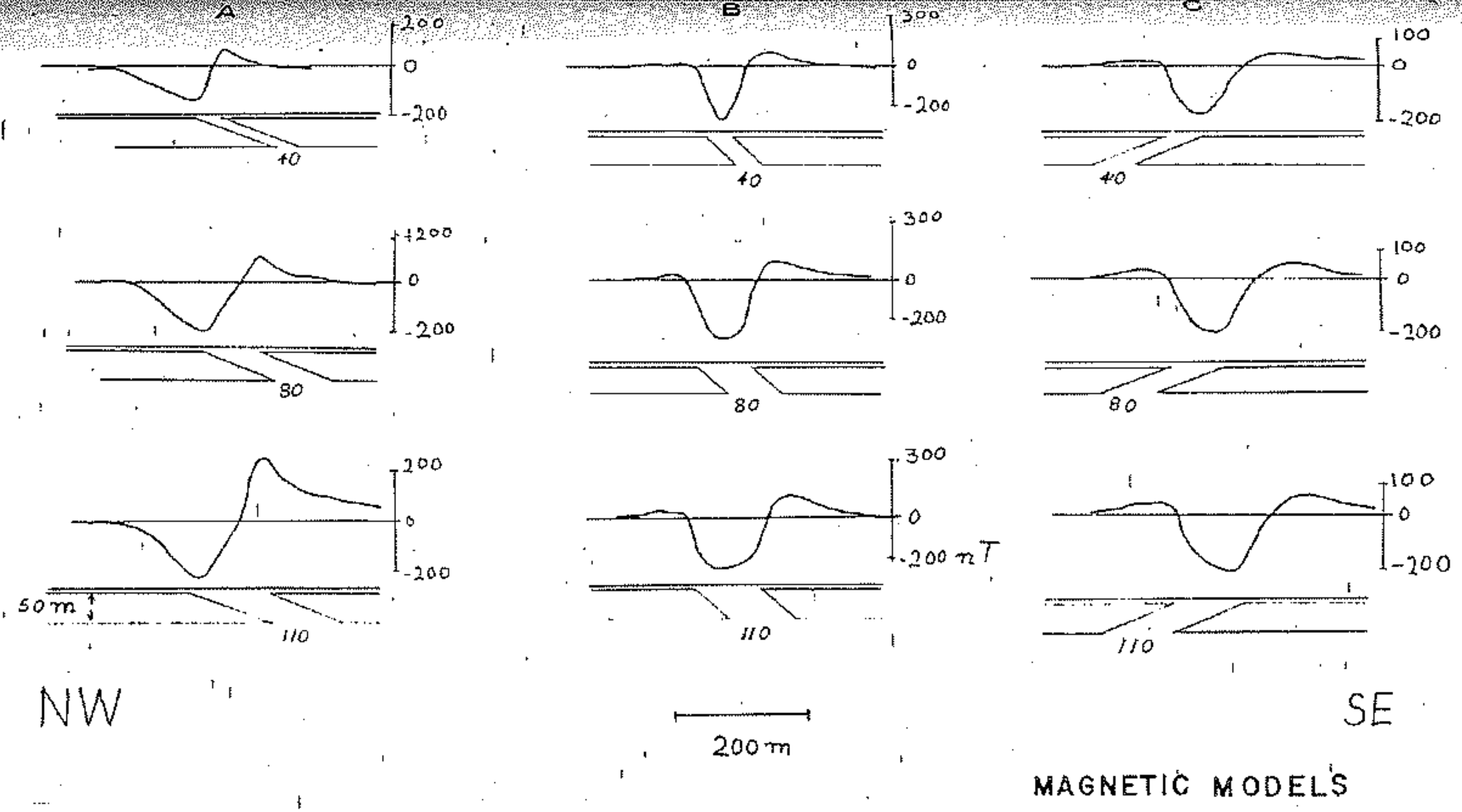


Fig. 3-5 : Groundmagnetic map, southwestern part of the Watch Hill Lineament, R.I. (contour interval: 100 nT (gamma))



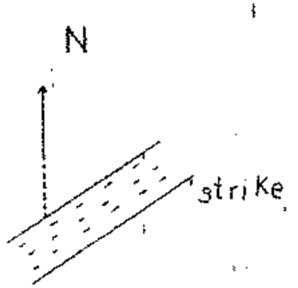
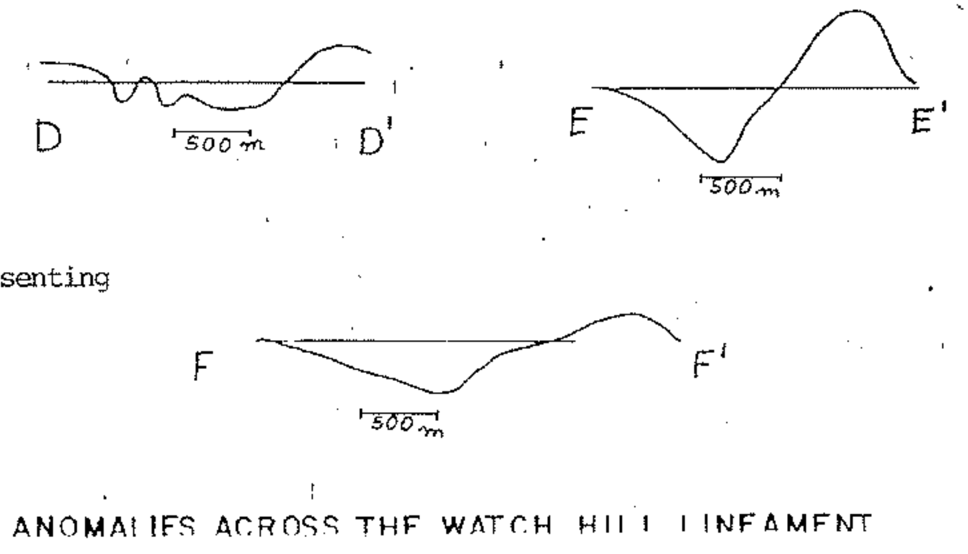


Fig. 3-6 : Magnetic models representing a fracture zone



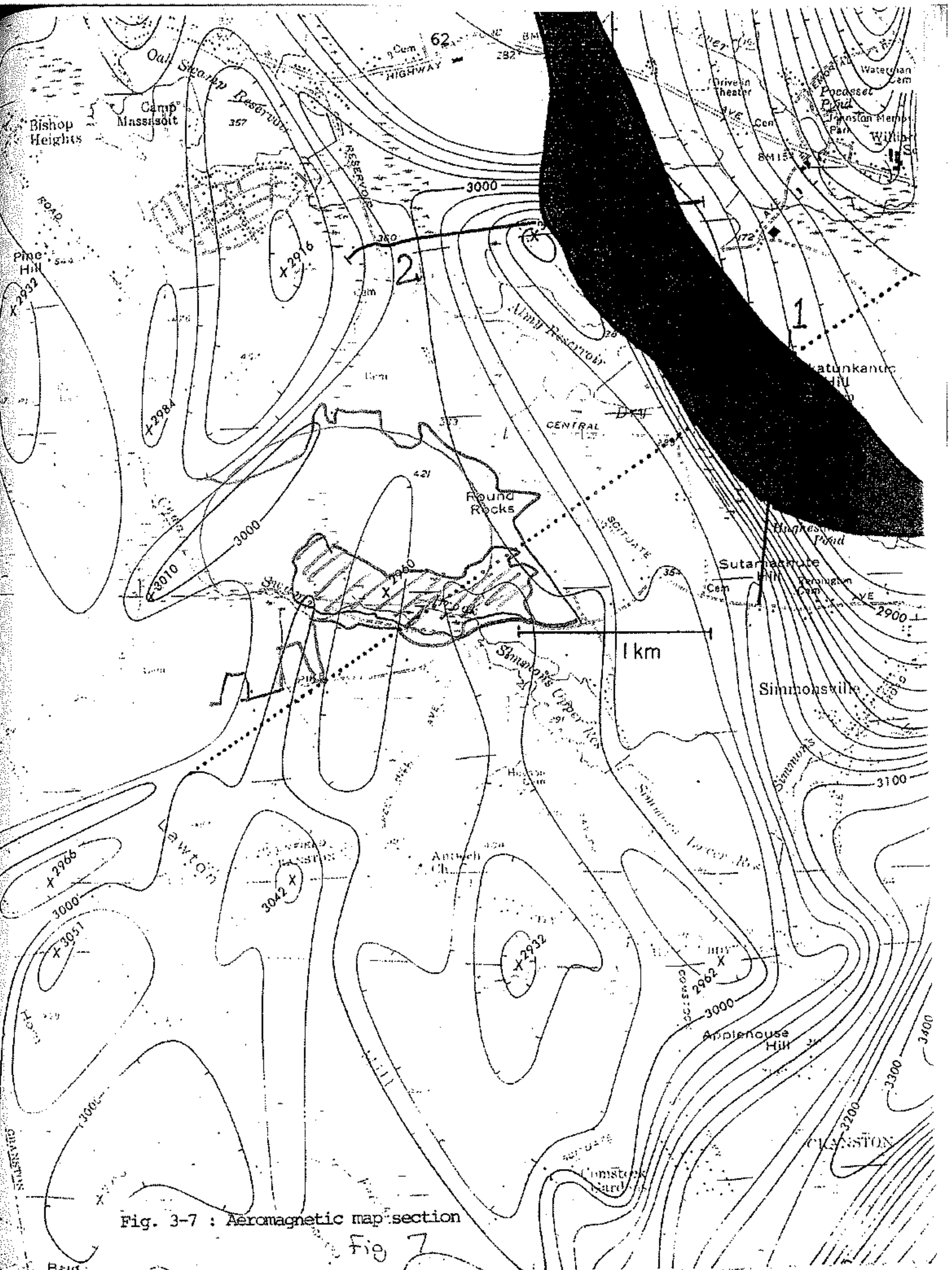


Fig. 3-7 : Aeromagnetic map section

Fig 7

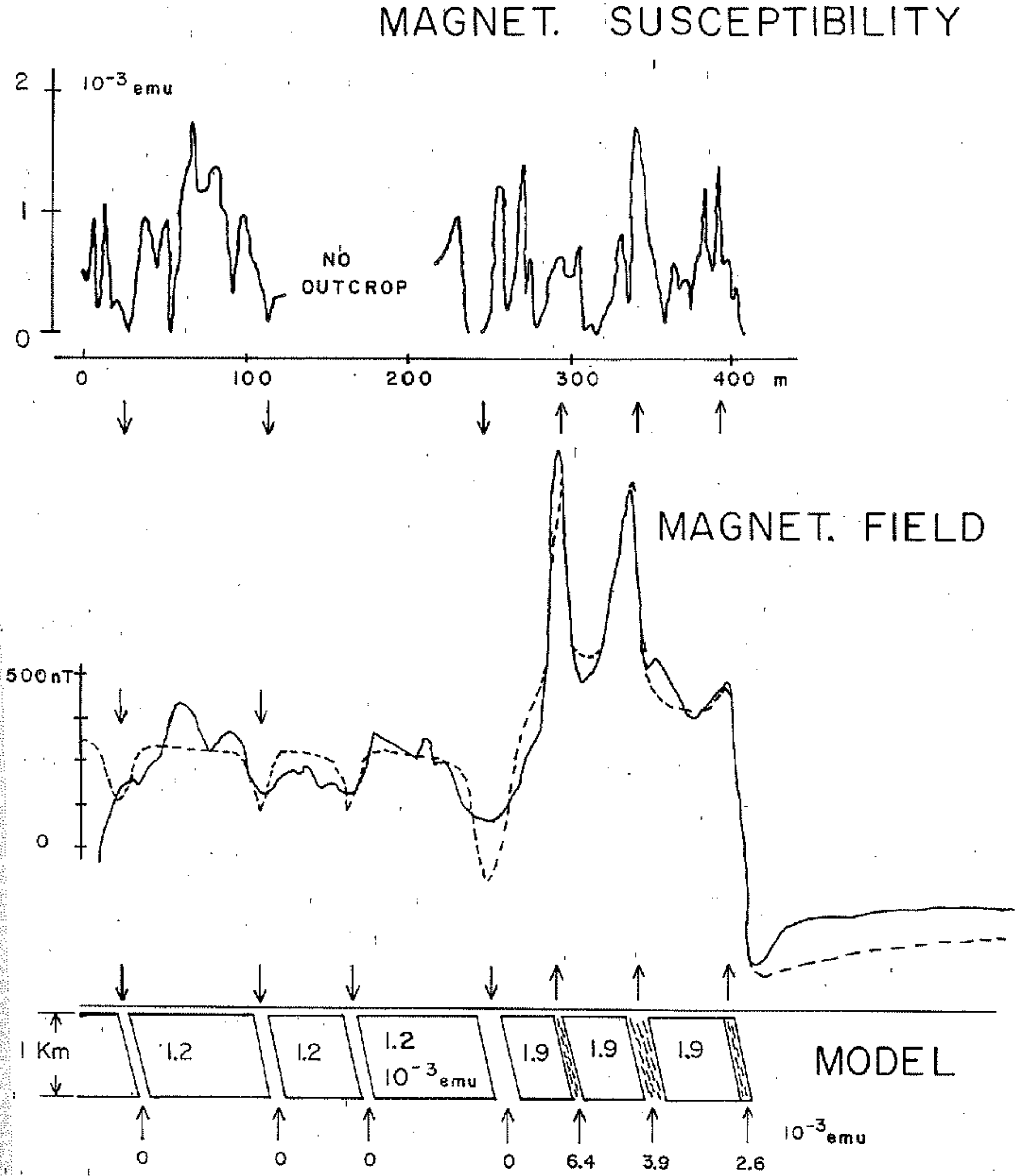


Fig. 3-8 : Groundmagnetic anomaly with model

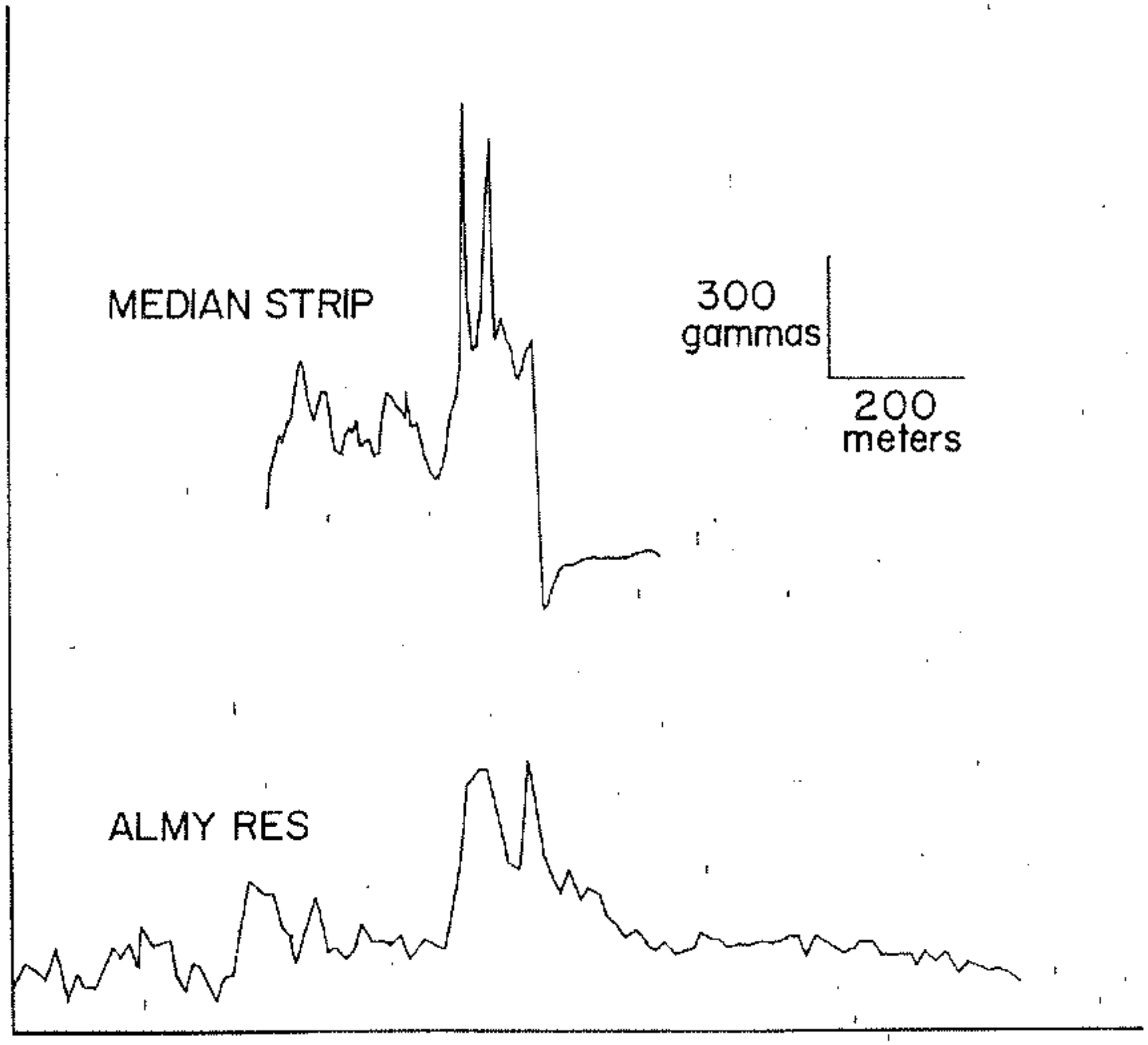


Fig. 3-9 : Groundmagnetic profiles near the Almy Reservoir, R.I.

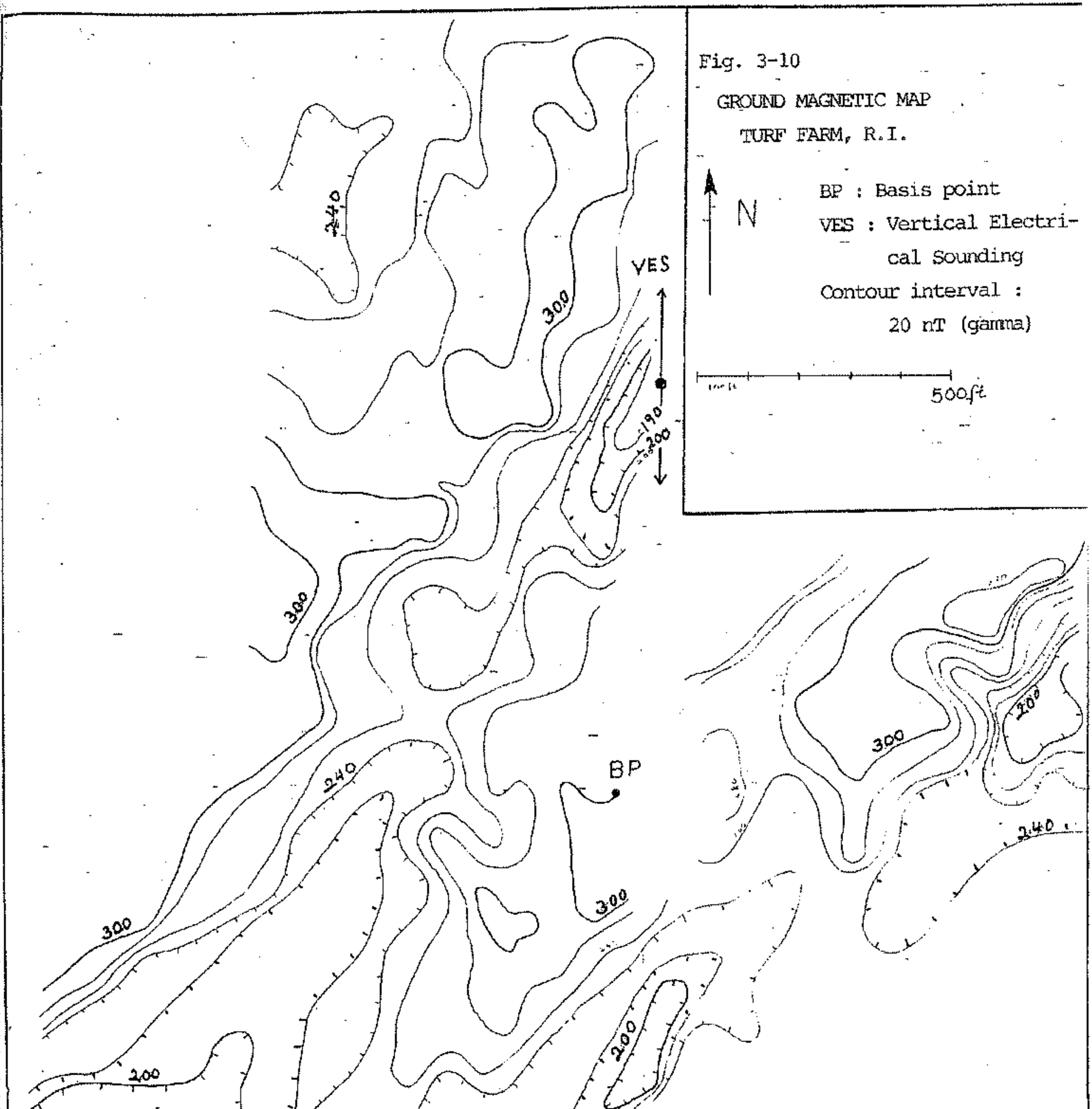


Fig. 3-10

GROUND MAGNETIC MAP

TURF FARM, R.I.

BP : Basis point

VES : Vertical Electrical Sounding

Contour interval : 20 nT (gamma)

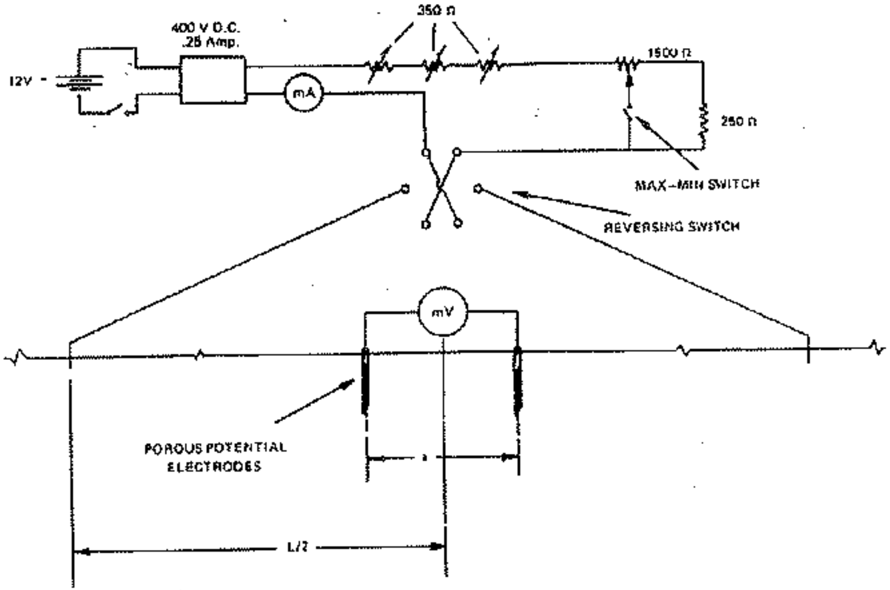


Figure 2. Schematic of equipment for geoelectrical depth sounding.

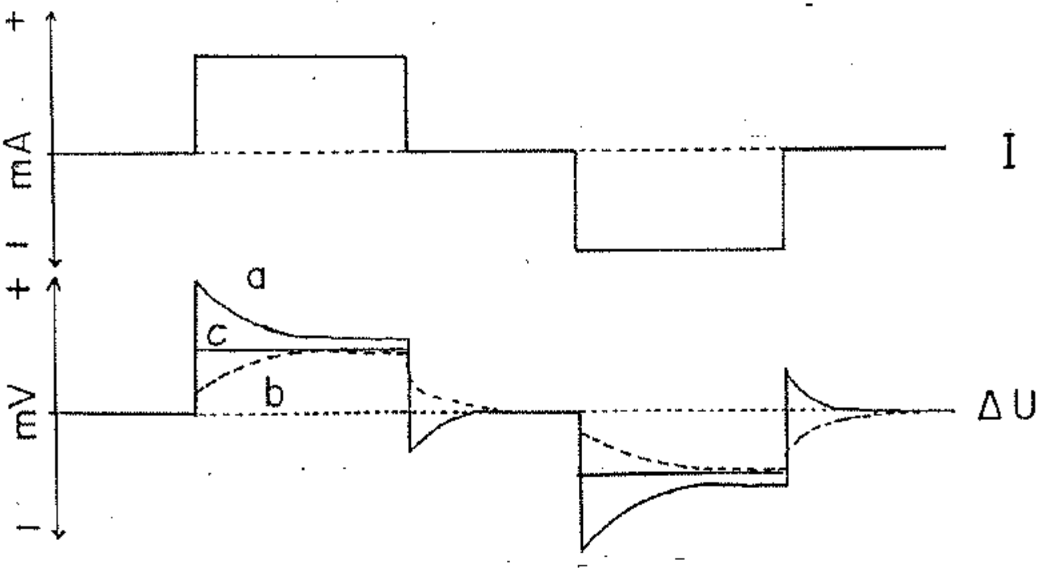


Fig. 3 - 11 : Principle of the geoelectrical resistivity method

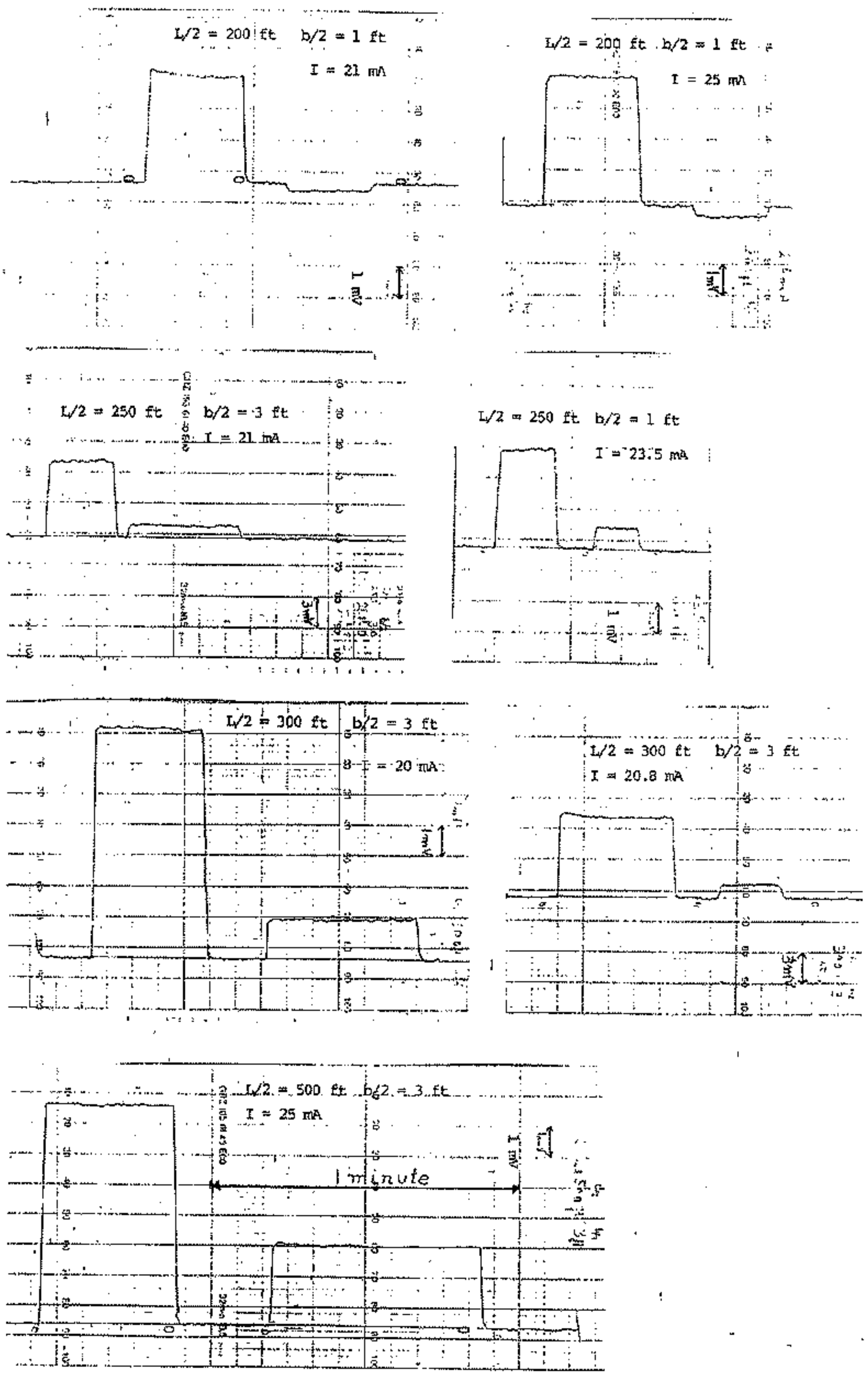


Fig. 3-12 : Voltage response of a reversed direct current over a fracture of the Turf Farm, R.I.

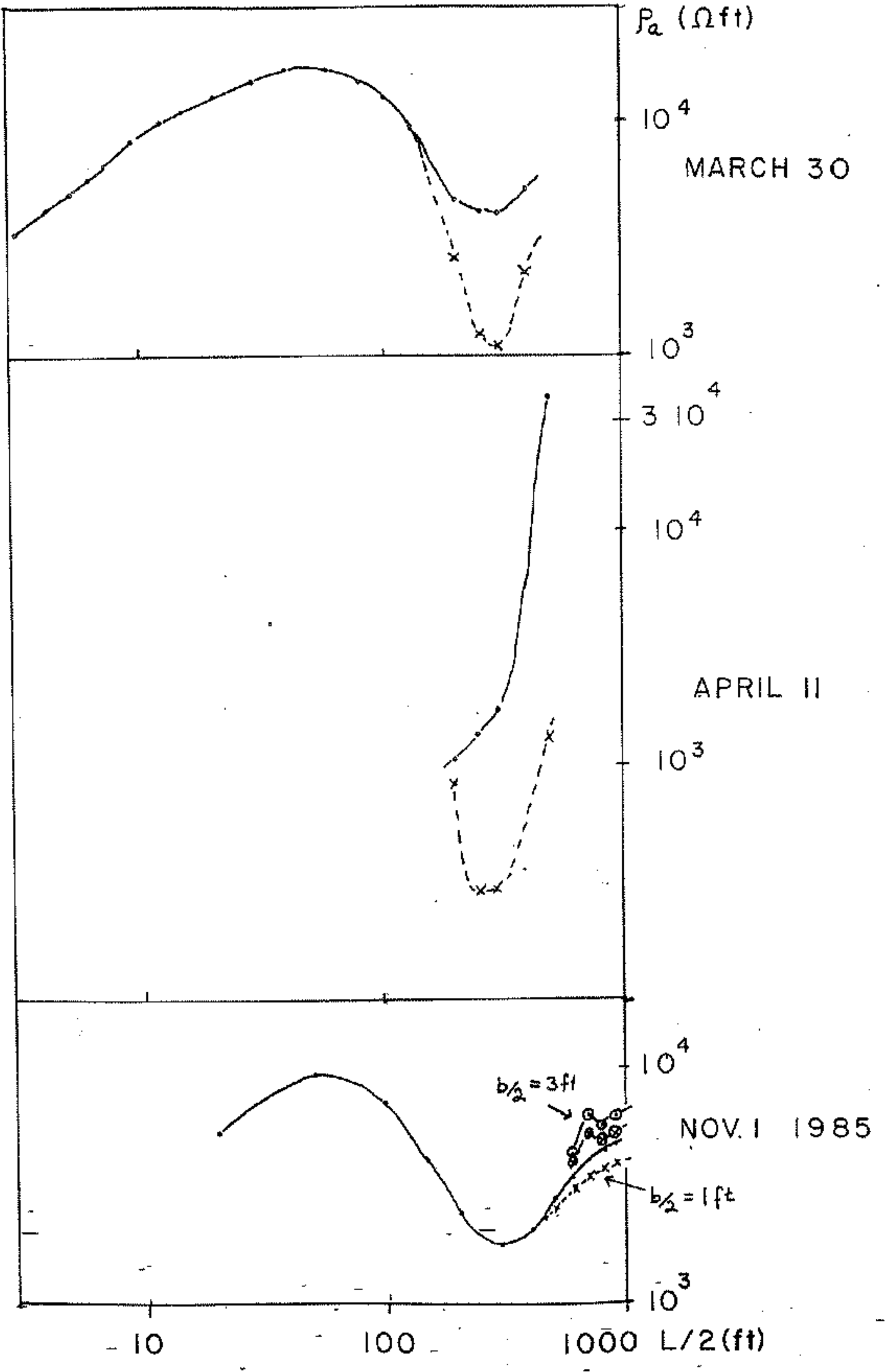


Fig. 3 - 13: Geoelectrical depth soundings with polarity-dependent resistivity over a fracture zone.

4. SUMMARY--CONCLUSIONS

Remote sensing and geophysical methods were applied and tested to locate and describe fracture zones in Rhode Island. The fracture zones are frequently not visible at the surface. Many fractures seen in outcrops often do not fully represent their characteristics at the surface, such as the fracture density and porosity. The usefulness of the methods fro fracture characterization can be categorized into three groups:

1. Cost saving reconnaissance methods that are useful to locate fracture zones but need further ground verification to identify the nature of the zones.
2. Detailed and more costly and time consuming methods that facilitate an accurate location of fractures and an estimate of their size.
3. Methods that measure physical parameters which are related to hydrological units, such as fracture porosity, permeability, and volumes.

The remote sensing method, Landsat multi-spectral lineament mapping is in the first category. Use of this method should precede any serious study of fracture zones. The magnetic methods seems to fall into the second category, particularly if short-spaced surveys are needed. Though this method is only applicable if the bedrock has a measurable magnetization, most metamorphic/granitic rocks seem to fulfill this requirement at least to some degree. For a ground magnetic survey of this kind the portable magnetometer type G856A is better suited than the one being used (Type G816A), as it has a higher resolution of 0.1 nT compared with 1 nT, which is the resolution of this survey.

A gravity survey can be useful for reconnaissance detection of fracture zones, though in most cases the station separation would be too large. Short-spaced surveys, however, can shed some light on fracture porosity and on the size of fracture zones. The accuracy depends on the knowledge of the overburden material, such as valley fills and the depth of streams and lakes. Gravity has a potential to describe the hydrological characteristics of category 3. The geoelectrical method seems to produce the most relevant information on the hydrogeology of fracture zones. The observed effects are not yet fully understood. It is recommended to intensify research in this particular field.

Isodensity satellite lineament maps produced from multi-spectral Landsat satellite imagery (MSS) can indicate areas of higher than average potential bedrock fracture zones. Detailed remote sensing analysis should also be conducted then of both specific sites, above average lineament density areas as well as high lineament intersection density. This can best be accomplished in detail by using Landsat thematic mapper imagery (TM) as well as Side Looking Airborn Radar (SLAR) together with High Altitude Photography and Aerial Photography for detail ground locations of secondary lineament.

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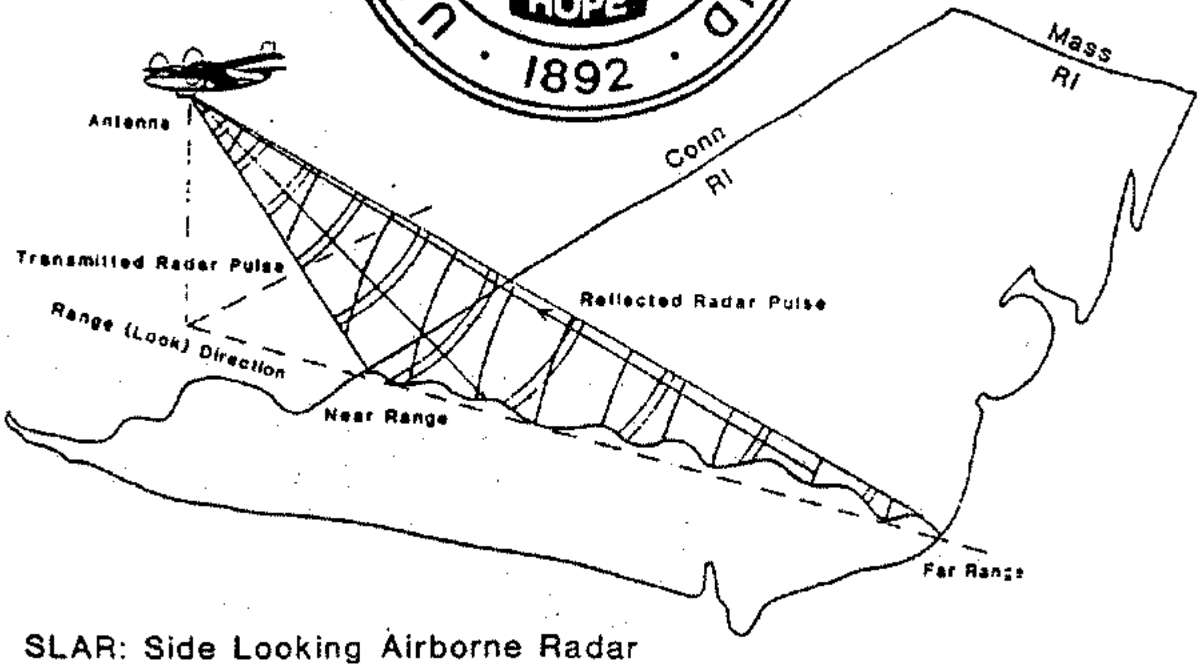

SLAR: Side Looking Airborne Radar

REPORT FY–1985 PROGRAM

GEOPHYSICAL AND REMOTE SENSING STUDIES OF BEDROCK AQUIFERS IN FRACTURE ZONES

by

R.K. Frohlich & John J. Fisher

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1. INTRODUCTION

Remote Sensing techniques were used to study groundwater in fractured bedrock. The remote sensing methods consisted of state wide and regional lineament mapping using primarily Landsat Satellite imagery and SLAR (side look airborne radar). Aerial photography of various types were used for detailed local lineament mapping. Mapping lineaments using these new remote sensing techniques have been shown to be related to bedrock fracture zones, specifically faults and joints and to 80% of known structural features (Greiling, 1981). In addition, remotely sensed lineament mapping has been shown to relate closely to geophysically mapped bedrock lineaments, specifically magnetic and gravity surveys (Gabrielsen and others, 1981). Three aspects of Rhode Island hydrology related to remotely sensed mapped lineaments were investigated in this present study at three levels; statewide, regional and local:

A. STATEWIDE: The relationship of detailed mapping and inventory of surface hydrogeologic features to these Landsat lineaments on a state-wide basis.

B. REGIONAL: The relationship and mapping of SLAR bedrock lineaments to the major subsurface glacial aquifer systems of southern Rhode Island.

C. LOCAL: The hydrogeologic relationship and remote sensing mapping of bedrock lineaments of the Tiverton area as related to bedrock residental wells and local fuel oil contamination of certain wells.

Geophysical studies concentrated on fractures related to the northeastern extension of the Watch Hill Lineament in South County and North Kingston, Rhode Island. The groundmagnetic map over the URI Turf Farm was completed and the magnetic modeling concept, demonstrated in the previous report (Frohlich and Fisher, 1985), was used to calculate the dimensions, in particular the width, of buried fracture zones. Geoelectrical depth soundings were conducted to support the magnetic fracture model and to estimate fracture porosities.

These studies were extended to a large area that includes the SODGRAS Farm on the Slocum and Wickford Quadrangles. A residual gravity map was completed and magnetic observations were completed to 90 percent.

Final resources were used to study the site of contaminated bedrock wells in Northeastern Tiverton, R.I. The site was selected with personnel from DEM, who are interested in how fast the observed well contamination can spread through the bedrock aquifer. The geophysical part was restricted to a detailed groundmagnetic survey.

Besides DEM, the R.I. Solid Waste Management Corporation was interested in this study, because of a need for methods to estimate bedrock permeabilities underneath landfill areas in general.

In pursuit of the above research projects the following were also undertaken:

1. John Fisher completed a reconnaissance map survey of the bedrock controlled glacial aquifers in Richmond for the Richmond Town Conservation Commission.

2. Joseph Savarese, graduate student under J. Fisher, was provided with a half-time internship by the RI Department of Environmental Management (DEM) Ground Water Division to work with us on the Tiverton bedrock fracture groundwater project. His thesis proposal on the same topic has been accepted in the

Department of Geology, University of Rhode Island and he delivered a seminar talk on that topic in the Dept. of Geology in the spring, 1986.

3. John Fisher participated in an International Workshop on Hydrologic Application of Space Technology sponsored by the International Association of Hydrological Sciences, 1985, Cape Kennedy, Florida. Partial costs covered by grant travel funds.

4. John Fisher investigated recent SLAR imagery techniques at the United States Geological Survey's EROS (Earth Resources Observation Systems), Sioux Falls, S.D., 1986 at no cost to the project; cost covered by J.J. Fisher.

5. Reinhard Frohlich presented a paper on "Size estimates of buried fracture zones with geophysical methods" at the 21st ann. meeting of the Geolog. Soc. of Amer., Northeastern Section, at Kiamesha Lake, New York.

6. Reinhard Frohlich was invited by the Geological Soc. of Maine to present a paper on " The location of buried fracture zones with geophysical methods ", on March 30, 1986 at Bates Coll. in Lewiston.

7. Reinhard Frohlich was invited to participate in a geophysical pilot study of aquifers in fractured bedrock near Presque Isle, Maine.

2. REMOTE SENSING (JOHN J. FISHER)

2.1 LINEAMENTS AND HYDROGEOLOGY

Lineaments are natural linear or curvilinear features that are usually detectable only on regional aerial photographic mosaics or more recently on different types of remote sensing satellite imagery. Lineaments are considered at times to reflect subsurface control and are common as anomalous trends on magnetic and gravity maps, where there is often a direct relationship between these geophysical lineaments and those mapped from satellite imagery. Lineaments often relate therefore to bedrock fracturing and the hydrogeology of subsurface groundwater. Relationships between "fracture traces" (lineaments) and groundwater was shown earlier for carbonate rock in humid areas (Lattman and Parizek, 1964). Linear features as related to ground water distribution in Texas was also later established (Finch and Wright, 1970). Use of earlier Skylab satellite imagery showed a direct relationship between lineaments and groundwater in the Suquehanna River Basin of Pennsylvania (Parizek, 1976). Lineaments mapped using later Landsat satellite imagery indicated a direct relationship between linear hydrologic features and bedrock joint systems in Texas (Finley and Gustavson, 1981). Side looking airborne radar (SLAR) was successfully used to locate potential sources of fracture-controlled groundwater in Pre-cambrian crystalline basement rocks of north-central Nigeria (Gelnett and Gardner, 1979). Twenty four of 26 wells drilled based on lineament analysis produced to maximum pump capcity. These crystalline Pre-cambrian basement rocks are similar to much of Rhode Island's bedrock.

The tectonic theory for the origin and development of lineaments is that basement regional stuctural trends, often seen in geophysical maps, are transmitted upward through overlying rocks. Surface expression of these trends are often as linear geologic featues or linear geomorphologic terrain features, "the lineaments". Lineament studies in New England have not been common. Barosh (1976) showed that various regional geophysical studies (gravity, aeromagnetic and aeroradioactivity) indicated lineament patterns that complemented those mapped by regional satellite imagery but no satellite lineaments were shown for Rhode Island. Satellite imagery mapping indicated only five lineaments ("linears") for Rhode Island in mapping conducted as part of the Preliminary Safety Analysis Report for proposed nuclear power plants at Charlestown, Rhode Island (NEPC, 1977). Preliminary Rhode Island satellite imagery mapping (Fisher and Boyle, 1982) indicated a more numerous and complex pattern of lineaments. This pattern in part may be the result of the welding of a minor continent or sub-plate (Avalon), during a plate collision with Africa (Frohlich and Fisher, 1985) as has been predicted from other geologic studies (McMaster and others, 1980).

2.2 REMOTE SENSING METHODOLOGY

2.21 MAPPING TECHNIQUES

Three different types of remotely sensed imagery were used for different aspects of the lineament mapping. This was so that the best imagery would be used for the best purpose depending on the scale of the mapping. Mapping was accomplished at three scales for three different problems:

A. Statewide lineament mapping (Rhode Island-entire state) - surface and subsurface hydrologic features

B. Regional lineament mapping (Southern Rhode Island - Washington County) - subsurface aquifer systems.

C. Local lineament mapping (Tiverton area, Rhode Island) - detailed bedrock fractures, site of fuel oil contamination.

Landsat satellite imagery were used for the statewide lineament mapping, while both Landsat and SLAR (side looking airborne radar) imagery were used primarily for the southern Rhode Island study. High Altitude Photography (HAP) was also used for this regional study. For the local detailed mapping Landsat and SLAR imagery were used to map the major lineaments while low altitude aerial phtography was used to map the remaining lineaments. Actual mapping was accomplished by transferring various geologic and geomorphic terrain linear features (lineaments) onto dimensionally stable mylar film using a Bausch and Lomb Zoom Transfer Scope. This scope is an optical anomamorphic correcting, copy ("transfer") system that allows enlargement ratios as great as 1:14. This enables direct optical overlay transferring of larger scale imagery of any scale onto smaller scale base maps. Base maps used for this study include A. Quinn's U.S. Geological Survey Map of Rhode Island (Quinn, 1971) at a scale of 1:125,000. This enabled relating lineaments to faults and geologic contacts. In addition, all satellite lineaments were transferred to the standard 1:24,000 scale U.S. Geological Survey topographic quadrangle maps. At this point, referring to these topographic maps as well as recent aerial mosaics and aerial photographs as well as HAP (High Altitude Photography), lineaments that could be related to man-made linear features such as highways, railroads, agricultural and vegetational boundaries were eliminated.

A Landsat satellite color composite print of Rhode Island at the 1:125,000 scale (same as above U.S.G.S. Geologic map) was produced using special flat-field copying lenses by J. Fisher for a previous Water Resources Project (Frohlich and Fisher, 1985).

This facilitated mapping Landsat lineaments, since the largest scale satellite imagery available for NASA is only half that size at the 1:250,000 scale. For the present study similar 1:125,000 scale Rhode Island SLAR imagery photographs were produced, both north and south looking, using the same techniques, together with available 1:100,000 SLAR mosaics.

2.22 SLAR (Side looking Airborne Radar) IMAGERY

Since SLAR (Side Looking Airborne Radar) imagery differs markedly from the more common aerial photogaphy or even Landsat satellite imagery it is necessary to describe those features of SLAR imagery that area applicable to the present hydrogeology and lineament study. In 1980, the U.S. Geological Survey began this SLAR program to evaluate geologic, cartographic and hydrologic application of SLAR imagery (Southworth, 1984) with emphasis on the Appalachian Mountains of West Virginia,, (Pohn and others, 1984). In addition to use in geologic analysis the U.S. Geologic

Survey has indicated that SLAR imagery can be useful for petroleum and mineral exploration, land use mapping and groundwater studies (U.S. Geological Survey, 1985). Lineament analysis of SLAR imagery has proved useful in groundwater exploration for wells in igneous fractured bedrock in West Africa (Gelmett and Gardner, 1979) and it is expected that similar fractured bedrock in Rhode Island exhibits similar groundwater hydrology.

SLAR is an electronic image-producing system whose name indicates that the radar beam is transmitted at an angle to the surface but perpendicular to the aircraft or spacecraft acquiring the data (Fig. 2.1). It is thus similar in principal to the side-scanning sonar used in oceanographic work which operates in a different frequency in a different manner. Airborne SLAR also differs from spaceborne radar, called synthetic-aperture radar (SAR) which requires spacecraft motion to imitate a larger antenna but at greater heights (Elachi and Granger, 1982). Seasat radar imagery and space shuttle imaging radar (SIR) were both SAR systems. In a comparison study in Virginia (Moore and Sheehan, 1981), the Seasat data appeared to have poorer resolution than Landsat images because of radar image speckle. The result, in the case of SLAR, is an obliquely apparently "illuminated" view of the terrain which can pick out subtle surface featues, such as folds and faults (Banks, 1975). In addition, it appears that cetain lineaments are also emphasized. It is actually a radar signal or pulse which is transmitted from the aircraft and reflected from the terrain which is the apparent "illumination" (Fig. 1).

Greater reflectivity can be indicated as greater "illumination". The azimuth is the direction of flight while the range refers to the "look" direction of the radar pulse. A factor of interpretation is the change of shadow length across this look direction from the near (less shadow) to far (greater shadow) range.

SLAR products are avialable as image strips of the flight line and as mosaics of several flight lines and in a very few special cases as computer compatible tapes (not New England). Positive transparencies are considered superior to photographic paper for analysis and that form was ordered for the present project. SLAR imagery was acquired by the U.S. Geological Survey using a digital high resolution synthetic aperture STAR-1 radar system at flight altitude of 33,000 feet. Look direction was east, average depression angle was 22 degrees and date flown was May 25, 1984. Black and white near and far range paper print mosaics (1:100,000) and black and white film strip positives (1:250,000) were used. A combination of SLAR imagery and aerial photography has been found best for geologic analysis (Gelnett, 1975) and that technique was used for the detailed Rhode Island contamination study (see aerial photographs below).

2.23 LANDSAT SATELLITE IMAGERY

The special aspects of Landsat satellite imagery that applies to this study has been discussed in an earlier Water Resources Report (Frohlich and Fisher, 1985). Both false color composite and individual multi-spectral bands (Bands 4, 5, 6, and 7) were available from that study as positive transparencies for May 5, 1976. For the present study, the most recent imagery from Landsat 5 on January 18, 1985 was acquired. To complement the early summer imagery of the previous study, winter imagery was specially requested and prepared for this study at special handling additional cost. It has been shown (Caran and others, 1982) that winter imagery, when the angle of solar elevation is least, emphasizes low-relief topographic features. Rhode Island lineaments have been found to be of low relief topography in several cases. In addition, the imagery was snow and cloud free and with a minimum of foliage. Most satellite imagery used for land-use or vegetation mapping are from summer months and the foliage can obscure the subtle topographic and geologic features necessary for lineament and other hydrogeologic features necessary for lineament and other hydrogeologic analysis.

In addition to acquiring winter season imagery, newly available spectral bands of the thermatic mapper system were acquired. These included the mid-infrared reflectance (Band 5 -TM) as well as Band 1 (Blue-Green) and False Color Composites (Bands 2,3,4). The thematic mapper (TM) in addition to an extended spectral sensitivity has twice the resolution (40m vs 80m) of the earlier and still available multi-spectral sensor (MSS).

2.24 AERIAL PHOTOGRAPHY

Aerial Photography has been considered the standared for remote sensing for detailed geologic studies for several decades and has been shown to still be the best medium for detailed geologic mapping in association with SLAR radar imagery (Gelnett, 1975). For the present study three different types of aerial photography were used, each chosen for a specific purpose:

A. - Large scale recent aerial photography April, 9, 1985: Black and white contact print paper prints, 9 inches by 9 inches were ordered for the Tiverton aspect of the study from Aerial Data Reduction Inc., Pensauken, NJ. Detailed lineament mapping on these photographs were necessary to supplement those mapped from Landsat satellite and SLAR imagery. The greater resolution of these aerial photographs of better than 10 feet, is several times that of the other imagery.

B. Early Archival Aerial Photography:

In order to map lineaments before commercial and residential development in the Tiverton area, the earliest aerial photographs of the area (January 26, 1939) were acquired from the National Archives of the Library of Congress, Washington. These 9 inch by 9 inch black and white contact print paper photographs at an original scale of 1:24,000 were also ordered as enlargements to a scale of 1:5,000 to match the recent photography.

C. High Altitude Aerial Photography:

In addition, National High Altitude Photography (NHAP) was acquired of the area west of Narragansett Bay as 9 inches by 9 inches color film transparencies at a scale of 1:100,000. The advantage of NHAP imagery is that it is available as both color infrared imagery and natural aerial ektachrome color. The resolution of this imagery lies between Landsat satellite-SLAR imagery and aerial photography.

2.3 HYDROGEOLOGY OF RHODE ISLAND LINEAMENTS

2.31 LINEAMENT HYDROLOGY

It is now believed that lineaments are the surface expression of deep-seated basement rock fractures often propagated upward through overlying consolidated rock and even unconsolidated geologic materials, such as sediments and glacial material (Gay, 1972). While there is yet no agreement on the exact mechanism for the origin of lineaments, some workers (Gelnet and Garner, 1979) consider that they are initally tensional fractures extending to great depths. These lineaments mapped fractures are not necessarily normal faults nor does the scale and length reflect joints directly.

Regional tensional lineaments however would have associated open joints which would strongly influence the overall fracture controlled surface and subsurface hydrogeology. Various surface geomorphologic terrain drainage features would develop (Fig. 2.2) influenced by these dominant joint sets as would be the ground water reservoir capacity especially of the normally low porosity and low permeability crystalline rocks.

2.32 SURFACE LINEAMENT HYDROLOGY

Regional lineaments in the Arctic coastal plain on Landsat satellite imagery has been found to be related to surface hydrological features such as lakes and their orientations (Fischer and Latham, 1973). The lineaments were alignments of small lakes, distortions in the shorelines of large lakes, linear areas between groups of lakes and curvilinear alignments of small lakes. Geological and geophysical studies show that these lineaments are features of the underlying geologic structure. Surface drainage hydrogeology patterns have also been shown related to underlying structures. Drainage patterns as mapped on Landsat imagery in five areas of North America (Saunders and Thomas, 1973) were related to the fracture patterns. In some cases, fracture patterns formed lineaments that extended up to a hundred miles. Analysis of Landsat imagery in Texas (Finley and Gustavson, 1981) indicate linear hydrogeologic surface featues including stream channels, stream valleys and aligned lake depressions which form lineaments which relate to joints mapped in the field and regional structural trends. Since there were few faults in the area, joints were the structural geologic control. Joints provide paths along which surface drainage will develop preferentially and joint intersections provide sites for downward percolation of water.

2.33 SUBSURFACE LINEAMENT HYDROGEOLOGY

Zones of enhanced hydraulic conductivity have been shown to be associated with large scale structural "mega-lineaments" as mapped from Landsat imagery in the karst plateau region of Kentucky (George, 1984). Lineaments mapped as related to surface hydrologic karst features such as sinkholes (Allison, 1980) were shown to be also directly related to fractures and fracture intersections in the bedrock. Relationship of lineaments to subsurface hydrogeology is indicated from a recent detailed unpublished study (Heller, 1980) in West Virginia. Bedrock wells with a high yield-to-depth ratio were found in areas of high photolineament density. Although these were limestone rocks and secondary karst premeability is a factor, the high lineament density also indicates a higher fracture density which would allow increased development of secondary karst porosity and pemeability. This would lead to an increase in yield from the bedrock wells. In Rhode Island, there was little glacial erosion since the continental glacial was mainly melting in southern Rhode Island. Therefore, the bedrock fracture zones, even in crystalline rocks, beneath the surface lowland hydrological features are probably highly weathered, that is pre-glacially weathered in time, and thus highly porous and permeable.

2.34 RHODE ISLAND LINEAMENT HYDROGEOLOGY

Relationship of mapped Landsat satellite lineaments (Boyle, 1980) to surface hydrogeologic features were determined for the entire state (Fig. 2.3). These features were established from analysis of lineaments plotted on thirty 1:24,000 topographic maps as well as aerial mosaics, HAP (high altitude photogrpahy) and individual aerial photographs as available. Six linear hydrogeologic features are probably related to subsurface bedrock fractures such as primarily joints and secondarily faults as diagrammed schematically in Fig. 2.2. The following classification, in order of importance, of surface hydrologic features was developed:

1. ALIGNED DRAINAGE: relatively short, straight drainage channel reaches commonly connecting at right angles. Stream segments were included only if they form a sequence of linear channels along a lineament.

2. LINEAR STREAM SEGMENTS: long, linear reaches of a stream either in a narrow valley or a wide floodplain lowland. Again several linear stream segments were necessary in a series along a mapped linear lineament.

3. ALIGNED LAKES: lakes or ponds of differing shapes but forming a linear series of three or more along a mapped lineament, some lakes maybe also elongated.

4. ELONGATED LAKES: lakes or ponds of distinctly linear shape with the linearity aligned in the direction of a mapped lineament.

5. SWAMPS OR WETLANDS: wetland terrain as indicated on the topographic maps by the marsh symbol. Considered to be standing water beneath grass or shrub vegetation. A minimum of three or more wetlands and swamps were included which fell along a mapped lineament trend.

6. LINEAR LOWLANDS: long, linear valleys, lowlands or negative terrain. Always in these lowlands would be examples of the above linear hydrogeologic features. Those lowlands were included which fell along a mapped lineament trend.

An inventory of these hydrogeologic surface features as related to the lineaments (Fig. 2.3) also indicates the percent of these features along the lineament by Roman number I-IV:

I - 100 to 90 percent of the lineament follows or closely parallels this hydrogeologic features.

II - 90 to 50 percent of the lineament follows or closely parallels this hydrogeologic features.

III - 50 to 10 percent of the lineament follows or closely parallels this hydrogeologic feature.

IV - 10 to 0 percent of the lineaments follows or closely parallels this hydrogeologic feature.

As tabulated from Table 2A and 2B, there are 136 mapped Landsat satellite imagery lineaments with 446 mapped hydrologic linear features. The greatest number of lineament associated hydrogeologic features are those of linear valleys and lowlands which represent 30 percent. Although many of these lowlands are the result of selective fluvial erosion along fractured bedrock joint systems, the larger, more extensive lineament valleys probably have developed along a normal fault system, tensional in nature.

Interestingly, the second most common lineament associated hydrogeologic feature are swamps and wetlands at 24 percent. These swamps are often associated with the above linear valleys and it is probably daming by glacial deposits that developed these particular swamps. Elongated lakes make up 15 percent of the features and they are usually in the lowlands in the glacial material and appear to be indirectly bedrock fracture control but at depth. Aligned drainage features at 13 percent are more likely to be bedrock controlled while aligned lakes at 10 percent are usually located in glacial material and bedrock fracture control would be at depth. Straight stream segments make up less than 10 percent of the hydrogeologic features and this is due to extensive glacial material in most large valleys which allows the stream to meander on the surface.

As discussed in the previous report (Frohlich and Fisher, 1985) some of these major lineaments pass through significant hydrogeological features through the state. The longest lineament (21 miles) lying wholly in Rhode Island (lineament #26, Fig. 2.3) passes through the east, dam, end of the Scituate Reservoir along streams and ponds and then to the Central Landfill site and Almy Reservoir in Johnson. In southern Rhode Island a parallel set of four lineaments (numbers 21, 64, 135, 136) pass through the Great Swamp on the west and extend to Narrow River on the east. In fact, along Narrow River is another lineament which trends north-south, paralleling other north-south lineaments in southern Rhode Island. This is not meant as an extensive description of all the satellite lineament hydrogeologic features listed on Table 1A and Fig 2.3 but just a representative sampling.

2.4 SOUTHERN RHODE ISLAND AQUIFERS AND MEGA-LINEAMENTS

2.41 MEGA-LINEAMENTS OF SOUTHERN RHODE ISLAND

Numerous northeast-southwest parallel trending lineaments were mapped (Frohlich and Fisher, 1985) for southern Rhode Island using Landsat satellite imagery (see Fig. 2.3). However SLAR (side looking airborne radar) imagery lineament mapping for this study revealed the existence of another lineament system. This system trends primarily northwest-southeast and is not apparent on Landsat imagery but only the SLAR imagery. The reason that these lineaments are not apparent on Landsat imagery is that the Landsat imagery is taken at about 9:00 am and at that time the sun is in the southeast and hence it's rays will parallel the northwest-southeast trending terrain features and not highlight them. In contrast the northeast-southwest lineament features are highlighted by the sun's rays as well as producing neccessary terrain shadowing. It is necessary to point out that the Landsat satellite system will always image the Rhode Island area at 9:00 am since it's orbit is designed to repeat every 18 days at the same time. Since it is in a near-polar north-south orbit (Landsat Data Users Handbook, 1979) areas to the south and north of Rhode Island will be imaged slightly later and earlier but still in the morning. Since the earth is revolving on its axis beneath the satellite's orbit, the satellite on its next orbit will image the region west of Rhode Island, at the same latitude, again at 9:00 am their time, and again the same illumination pattern.

In a geologic fracture mapping remote sensing study of the western overthrust belt in Montana (Moore and Sheehan, 1981) an area of northwestern trending faults were investigated. Because this trend also parallels the solar azimuth of the Landsat system, faults were not obvious. The only way to overcome this limitation in geologic terrain or fracture pattern mapping is to use another imaging system. In this case of the above Montana study SLAR imagery was used to indicate these solar-azimuth trending faults. Since SLAR aircraft can fly any azimuth but usually will fly either north-south or east-west, the look direction will then be either east-west or north-south (Fig. 2.1) and illuminated these northwest-southeast trends. For Rhode Island, recent SLAR has an east look direction.

Large scale mega-lineaments were mapped using SLAR imagery in southern Rhode Island (Fig. 2.4). These lineaments trend northwest-southeast and form a parallel system extending 6 to 10 miles across Washington County from the

Connecticut border almost to the west shore of Narragansett Bay. Separation between the lineaments is only 1 to 2 miles. A second lesser northeasterly trend occurs in the eastern half of Washington County. Some of these, trending NNE by SSW, are equally long but more widely separated. A third trend is more ENE by WSW. While it occurs in both North and South Kingstown nearer the Bay it may be related to the trend of the Watch Hill fault in the Westerly area (Frohlich and Fisher, 1985). There are a few long NS widely spaced lineaments in the western half of Washington County. This NS trend parallels the similar trend of the Lake Char Fault, just west of the Rhode Island border in Connecticut. About 40 percent of this mega-lineament system was mapped from Landsat imagery and 60 percent from SLAR imagery.

Regional fracture patterns appear to be the explanation of this lineament pattern. One of the major northwest-southeast trending lineaments follows the trend of the mapped Hope Valley shear zone (Gromet and O'Hara, 1985). In general, the west part of southern Rhode Island exhibits a northwest-southeast trending pattern. While for the eastern half of southern Rhode Island, the lineament pattern exhibits a northeast-southwest trend. Dividing these two regions is a distinctive set of north-south trending lineaments. According to the Bedrock Geologic Map of Rhode Island (Quinn, 1971) this lineament trend divides the Ten Rod granite gneiss on the east from the Scituate granite gneiss on the west. Differences in structure including fracture patterns of the two large rock bodies probably account for the different lineament pattern trends. The northeast-southwest lineament trend in the east has previously been related to fracture systems relating to a rifting of Narragansett Basin (Frohlich and Fisher, 1985). An unusual step-like pattern of the aquifer near the junction of Richmond, Exeter and Hopkinton (A, Fig. 2.5) suggest a series of local left lateral strike-slip faults, as does the trend of the major NS aquifer in this area (B, Fig.2.5).

2.42 RHODE ISLAND AQUIFERS AND MEGA-LINEAMENTS

Realization that the major aquifers of southern Rhode Island was related to satellite lineaments patterns was while constructing a general location map of the glacial aquifers for the Richmond Town Conservation Commission (Fisher, 1986). The aquifers of southern Rhode Island are important present and potential water supply systems and since they are subsurface it would be useful to develop a model to predict their geologic patterns. The hydrogeology of these aquifers is principally river valleys underlain by sand and gravel of glaciofluvial origin with adjacent till covered bedrock hills 200-500 feet above sea level (Gonthier, et al, 1974). Significant to the mega-lineament pattern of these aquifers are these deep buried bedrock valleys (Fig. 2.5). Although not always apparent on the surface, these bedrock valleys exist throughout the coastal zone of New England. Along the coastal region of Connecticut, Rhode Island, Massachusetts, New Hampshire and Maine these glacially filled buried bedrock valleys are the most important aquifers. Hydrogeologic development of these valleys is related to fluctuations of sea level (Upson and Spencer, 1964) with the valleys eroded subaerially during a period of lower sea level. This relatively lower sea level was perhaps the result of the readvance of ice of Late Wisconsian time or earlier. The water necessary to develop this additional ice had to come from the oceans and thus lower its level. However, during this time, the subaerial fluvial erosion drainage patterns were guided by pre-existing fracture patterns in the bedrock.

Relationship of bedrock fractures in valley development is seen in a hydrogeologic study in West Virginia (Wyrick and Borcher, 1981). Fracture systems affected both the occurrence and movement of groundwater in a typical Appalachian valley. These stress-relief fracture systems underlying the valleys constituted the most transmissive part of the regional aquifer and further affect surface water hydrology. Although this fracture system is in sedimentary rock it indicates that erosion of bedrock is related to fracture systems located in valley situations. Recently, E-an Zen, U.S. Geological Survey geologist mentioned that he felt that almost all valleys in the Appalachians were underlained by a greater number of fractures than the adjacent hill tops (Talk, Washington Geological Society, Winter, 1986).

Drainage courses in the Northern Coast Ranges were mapped as large scale lineament systems using both Landsat and SLAR imagery (Gelnett, 1974). The lineament pattern was related to both local faulting as well as a regional conjugate shear or fracture pattern resulting from a triple plate junction at Cape Mendocins. Thus there is the possibility that a conjugate shear fracture pattern or other tectonic stress system influenced the early drainage pattern in southern Rhode Island. Minor lineament patterns may be rlated however to joint systems as in Norway (Greiling, 1981) where most of the Landsat mapped lineaments represent normal joints. However, in Norway, it was suggested that glacial erosion the joint system was accentuated, a possibility also for the small streams in Rhode Island.

It is apparent that the pre-glacial or late glacial fluvial streams eroded valleys into the bedrock following one or more different fracture systems in southern Rhode Island (Fig. 2.5). During retreat of the last continental glacier, these valleys were filled with glaciofluvial sands and gravels which are highly permeable and porous (Gonthier et al, 1974). The greatest thickness of these aquifer deposits also occur in these buried valleys (Allen et al, 1966). There can also be seen a difference in the pattern of western aquifers of the lower Pawcatuck River basin which trends northwest-southeast, with a secondary intersecting north-south trend. In contrast, the eastern aquifers of the upper Pawcatuck River basin trend northeast-southwest, with a secondary northwest-southeast trend. As mentioned earlier, these are areas of two different rock types of different ages (Ten Rod granite gneiss to the east and Scituate granite gneiss to the west) so it could be expected that each was subjected to different tectonic stresses. From a hydrogeologic aspect, it is expected that the maximum ground water yield would be found at the intersection of the lineaments with supplemental water from increased bedrock fractures in these intersection areas. In addition, the pattern of the buried valleys and the associated aquifers to the south beneath the Charlestown recessional moraine can be predicted based on the regular patterns developed to the north.

2.5 FIGURE CAPTIONS CHAPTER 2

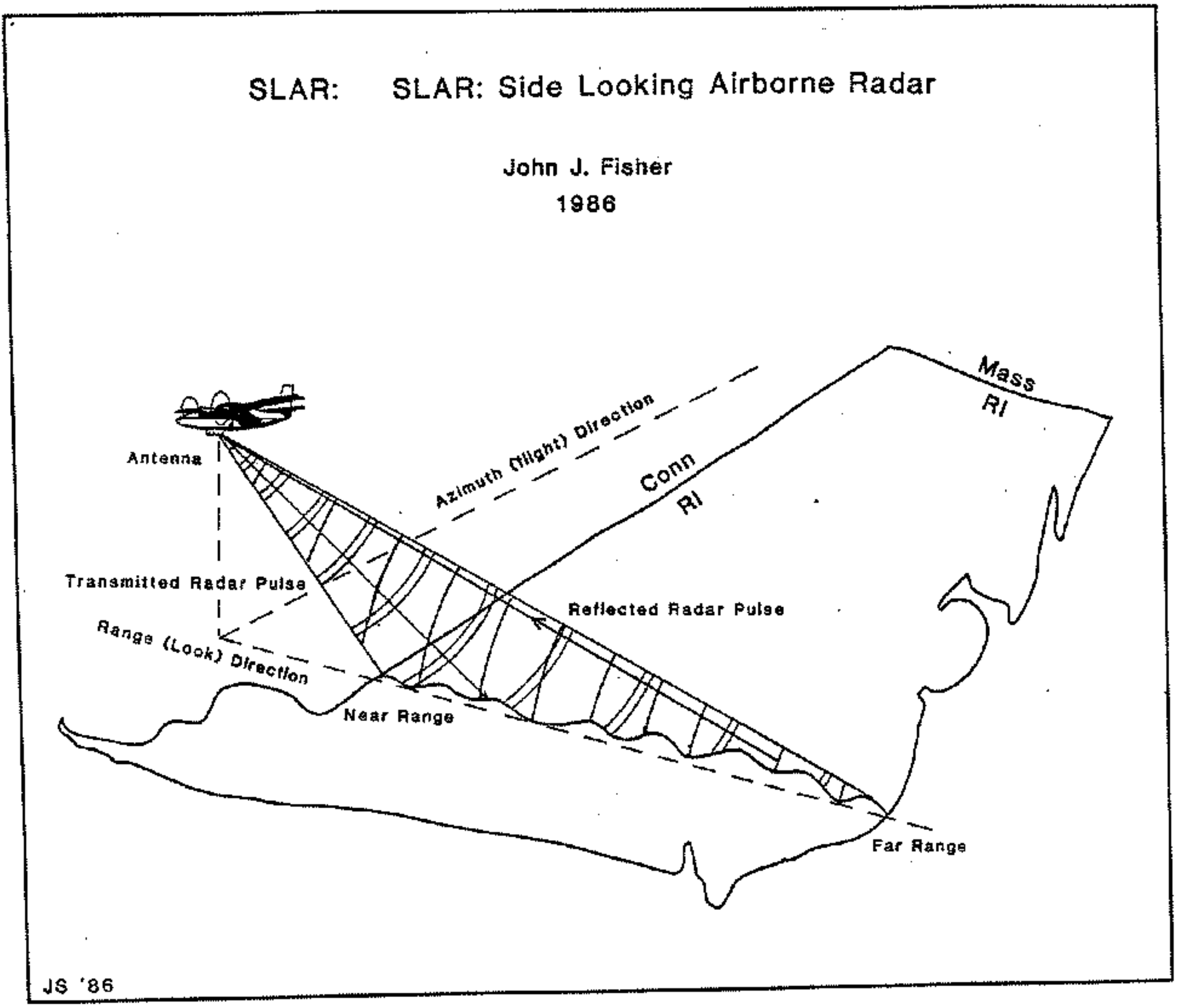
Fig.2.1: Features of side looking airborne radar (SLAR) available for Rhode Island as related to hydrogeologic lineament mapping. Flight direction (azimuth) is in a north-south direction and the transmitted radar pulse is in an eastward looking direction (range). Reflected radar pulses from topographic surfaces "illuminate" the terrain.

Fig.2.2: Relationship of Rhode Island hydrogeologic lineament "trace" features as related to bedrock fractures. Hydrogeologic features include: elongated lakes, aligned lakes, linear swamps, aligned drainage, straight streams and linear lowlands. Bedrock fractures would be joints, sheeting and faulting and zones of fracture concentration and intersection.

Fig.2.3:Distribution of Rhode Island hydrogeologic features related to Landsat satellite lineaments. Of 136 mapped lineaments with 446 mapped hydrogeologic features as follows: linear valleys or lowlands 30% , swamps and wetlands 24% , elongated lakes 15% , aligned lakes 10% , and straight stream segments 8% . The largest lineament (21 miles) passes through the Scituate Reservois (#26).

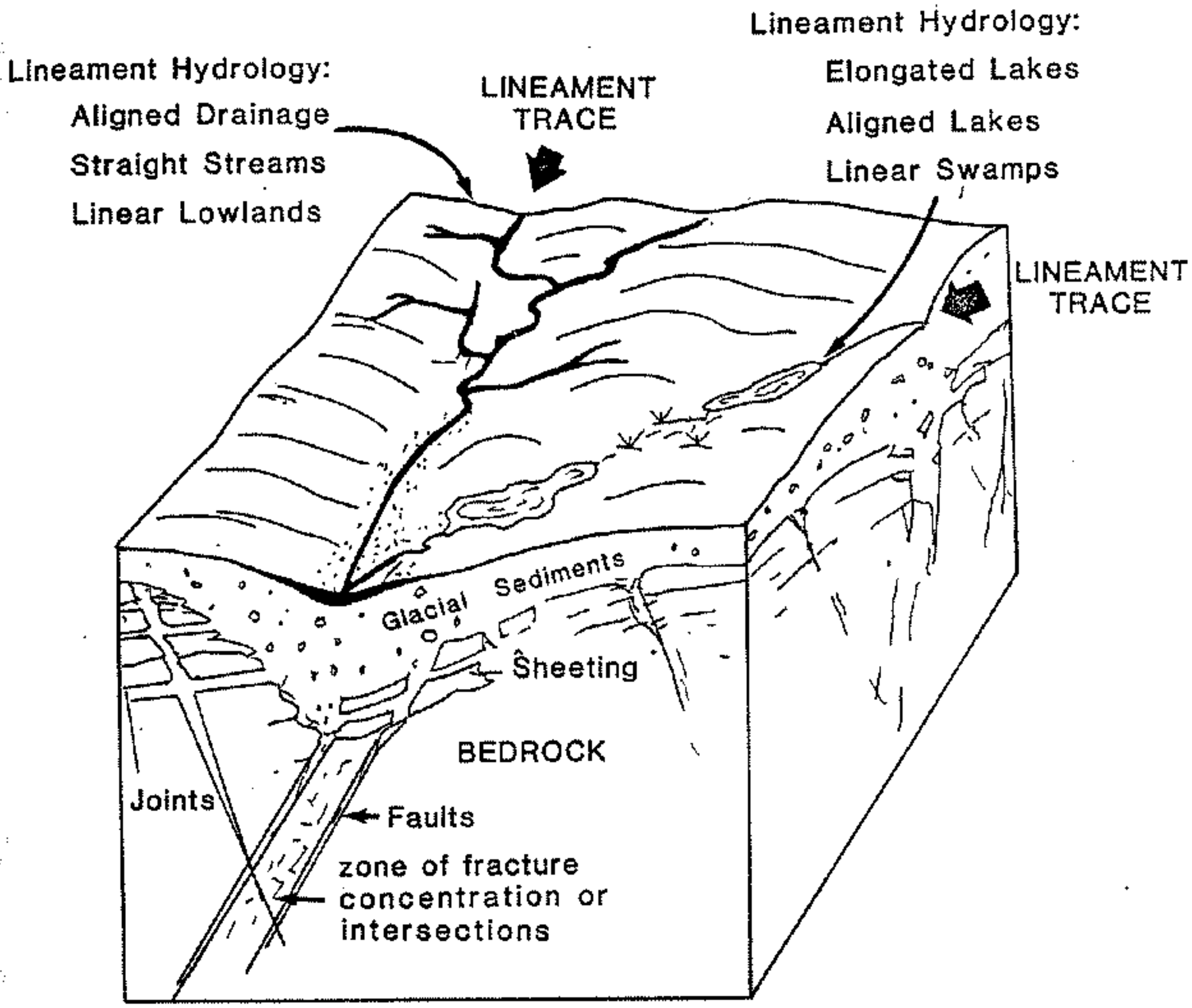
Fig.2.4: Distribution of SLAR mapped lineaments of southern Rhode Island (Washington County). Western Washington Co. lineaments trend primarily in a northwest to southeast trend. Eastern Washington Co. has two lineament sets, one trends NNE by SSW and the other trends ENE by WSW. This latter trend connects with the Watch Hill Fault trend in southwestern Rhode Island.

Fig.2.5: Southern Rhode Island glacial aquifers as related to large-scale lineament bedrock fractures mapped using SLAR and Landsat Imagery. The distribution patterns of these important water supply aquifers can be predicted by analysing the different fracture patterns using remote sensing methods. The northeast section of this pattern (box) in the University of Rhode Island area was further studied in detail with geophysical methods, such as magnetics, gravity and geoelectrics.



SLAR: SLAR: Side Looking Airborne Radar
John J. Fisher
1986
Antenna
Azimuth (flight) Direction
Conn
RI
Mass
RI
Transmitted Radar Pulse
Reflected Radar Pulse
Range (Look) Direction
Near Range
Far Range
JS '86

FIGURE 2.1



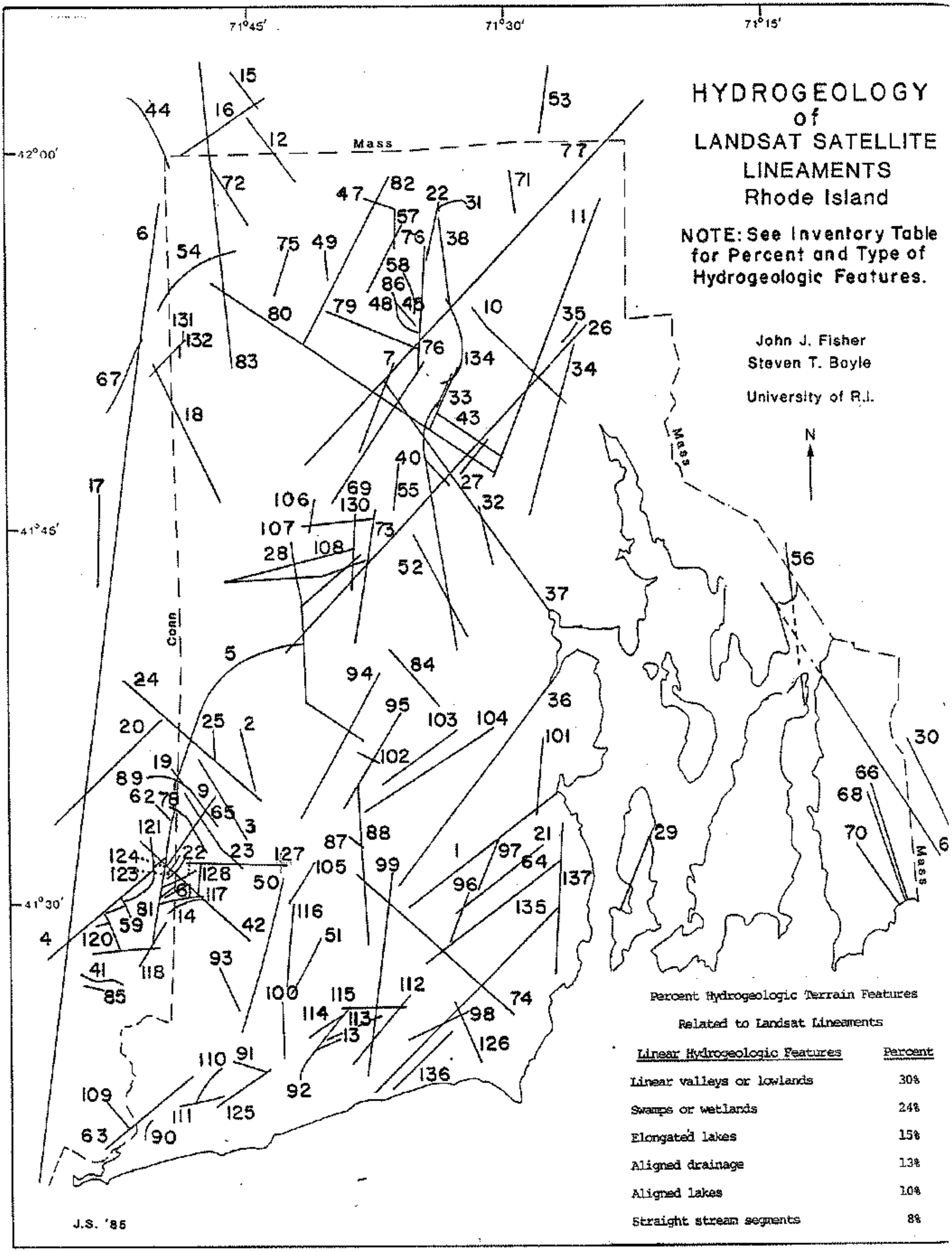
Relationship of Rhode Island Hydrogeologic Lineament Trace Features to Bedrock Fractures

John J. Fisher

1986

JS '86

FIGURE 2.2



Percent Hydrogeologic Terrain Features
Related to Landsat Lineaments

Linear Hydrogeologic Features	Percent
Linear valleys or lowlands	30%
Swamps or wetlands	24%
Elongated lakes	15%
Aligned drainage	13%
Aligned lakes	10%
Straight stream segments	8%

FIGURE 2.3

MEGALINEAMENTS

LINEAMENTS OF SOUTHERN RHODE ISLAND

John J. Fisher

Andrew Ross

1986

(Lineaments mapped from Landsat Thematic Mapper and North, South and East look SLAR)

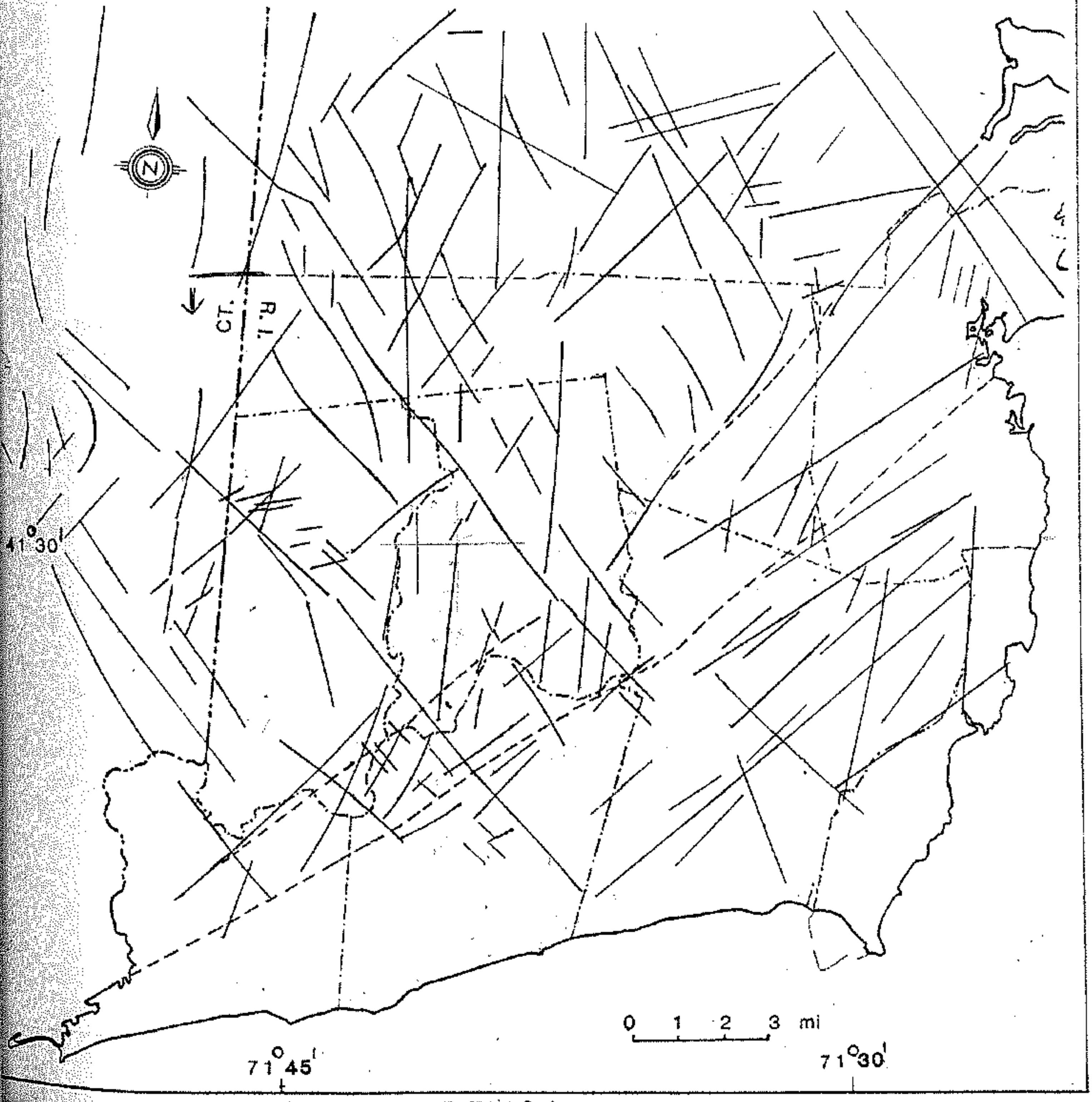


FIGURE 2.4

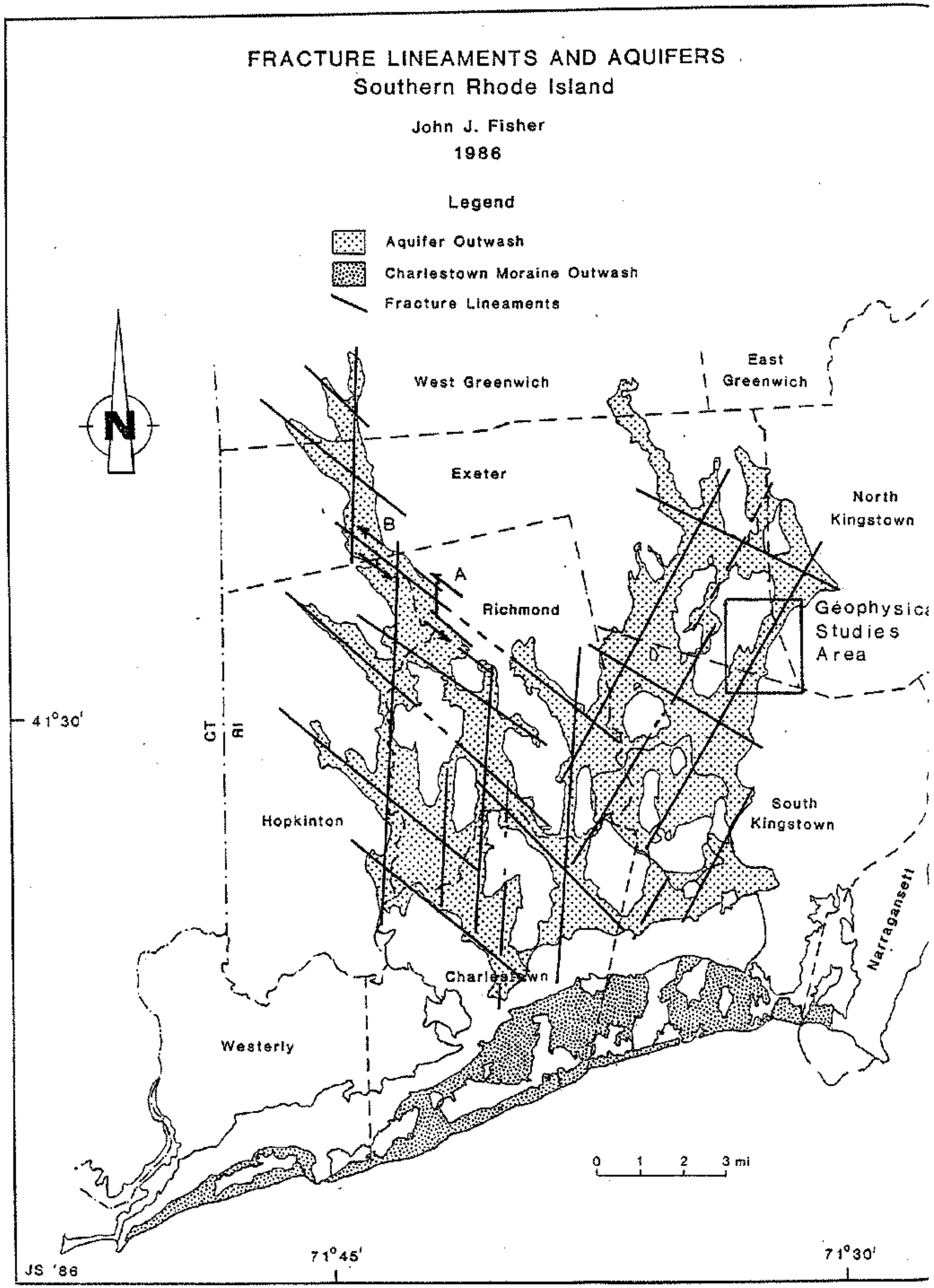

FRACTURE LINEAMENTS AND AQUIFERS
Southern Rhode Island
John J. Fisher
1986
Legend
Aquifer Outwash
Charlestown Moraine Outwash
Fracture Lineaments
N
West Greenwich
East Greenwich
Exeter
North Kingstown
B
A
Richmond
Geophysica
Studies
Area
D
41°30′
CT
RI
Hopkinton
South Kingstown
Narraganset
Charlestown
Westerly
0 1 2 3 mi
71°45′
71°30′
JS '86

FIGURE 2.5

TABLE 2A

Percent Hydrological Terrain Features
Related to Landsat Lineaments

	Aligned Lakes	Elongate Lakes	Linear Streams	Swamps or Wetland	Linear Terrain	Aligned Drainage
1	III	III	III	II	II	III
2	--	--	--	IV	III	--
3	--	--	II	III	I	III
4	--	IV	III	III	II	--
5	III	IV	II	III	II	--
6	III	III	III	III	II	III
7	--	--	--	III	IV	--
8	--	IV	--	--	II	III
9	--	--	--	II	II	II
10	II	III	I	III	I	--
11	III	III	--	III	IV	--
12	II	--	--	--	II	III
13	--	--	--	--	IV	--
14	--	--	--	--	II	--
15	III	III	--	III	I	IV
16	III	III	--	II	I	IV
17	II	II	--	--	I	II
18	--	III	--	II	II	III
19	--	--	--	--	III	--
20	II	--	--	II	I	--
21	III	III	I	II	III	III
22	--	--	--	II	III	--
23	--	III	III	II	I	--
24	III	III	II	I	I	--
25	--	III	II	III	I	--
26	III	IV	--	III	IV	IV
27	--	III	--	--	IV	III
28	--	--	II	III	I	II
29	III	--	--	II	I	II
30	--	--	--	II	I	II
31	--	--	--	III	IV	--
32	--	--	--	II	I	I
33	III	III	--	II	III	IV
34	III	IV	III	III	--	--
35	--	III	--	--	II	III
36	--	IV	III	II	II	--
37	III	III	III	II	II	II
38	IV	III	II	II	I	--
39	III	III	--	III	II	II
40	--	--	--	III	I	--
41	--	--	--	--	IV	--
42	--	--	--	II	II	III
43	I	II	--	III	I	III
44	--	--	--	IV	I	--
45	--	--	--	I	I	III
46	--	--	III	III	I	--
47	--	--	III	--	I	--
48	III	--	II	II	I	II
49	I	I	--	--	I	--
50	IV	IV	III	III	I	--
51	--	IV	I	--	I	--
52	--	--	II	IV	I	--
53	III	III	--	II	I	II
54	III	III	--	III	II	II
55	--	I	--	--	--	--
56	--	IV	--	III	II	III
57	II	III	--	III	II	II
58	III	III	--	--	II	II
59	--	--	I	III	I	--
60	--	--	III	II	II	II
61	--	--	--	--	III	--
62	--	--	--	IV	IV	--
63	--	III	--	II	IV	--
64	III	--	III	II	III	III
65	--	--	--	--	II	--
66	--	--	--	II	I	II
67	--	--	I	IV	I	--
68	II	II	--	III	I	II
69	--	--	--	III	IV	--
70	III	--	--	II	I	II
71	--	--	I	--	I	--
72	--	III	II	II	I	III
73	--	III	--	III	II	IV
74	--	IV	--	II	II	--
75	--	I	--	--	I	--
76	II	II	--	II	I	--
77	II	IV	--	III	III	--
78	--	--	--	III	II	II
79	III	III	--	--	III	III
80	III	III	--	III	III	II
81	--	--	--	--	II	IV
82	--	III	II	III	I	--
83	II	III	--	II	III	--
84	II	II	--	III	II	IV
85	--	--	--	--	IV	--
86	--	--	--	II	I	--
87	--	--	--	I	II	II
88	--	--	II	II	I	--
89	--	--	--	--	I	II
90	--	--	--	--	IV	--
91	II	--	--	--	IV	--
92	--	--	--	III	III	--
93	--	IV	--	III	I	IV
94	III	III	--	--	II	III
95	III	III	--	--	II	--
96	II	II	II	--	I	--
97	--	III	I	III	I	--
98	--	--	--	IV	II	--
99	III	IV	--	III	I	--
100	--	--	--	III	IV	--
101	III	II	--	II	II	--
102	--	--	--	--	IV	--
103	--	--	--	III	IV	--
104	--	--	--	III	IV	--
105	--	--	--	III	II	III
106	--	I	--	--	I	--
107	III	III	--	II	I	II
108	--	IV	--	III	II	III
109	--	--	--	--	IV	--
110	--	--	--	II	II	III
111	--	--	--	I	I	--
112	--	III	--	II	II	--
113	--	--	--	III	IV	--
114	III	--	--	III	IV	--
115	--	--	--	II	IV	--
116	--	IV	II	III	II	--
117	III	II	--	IV	II	--
118	II	III	--	--	IV	--
119	--	III	--	IV	IV	--
120	--	--	--	III	II	II
121	--	--	--	III	III	III
122	--	III	--	--	--	III
123	--	--	--	II	--	II
124	--	--	--	--	II	II
125	--	--	III	II	IV	--
126	I	I	--	--	IV	--
127	--	IV	IV	IV	IV	--
128	I	III	--	--	IV	--
129	--	--	--	III	II	III
130	--	IV	--	III	I	--
131	--	II	--	III	I	I
132	--	--	--	III	II	II
133	--	--	--	II	I	II
134	II	II	--	II	I	III
135	II	III	III	II	--	II
136	III	III	IV	—	IV	III
137	II	II	III	III	I	IV

Percent of lineament that parallels feature: I = 90-100%,
II = 50-90%, III = 10-50%, IV = 0-10%.

TABLE 2B

TOTAL
Percent Hydrogeologic Terrain Features

Related to Landsat Lineaments

Linear Hydrogeologic Features	Percent
Linear valleys or lowlands	30%
Swamps or wetlands	24%
Elongated lakes	15%
Aligned drainage	13%
Aligned lakes	10%
Straight stream segments	8%

3. GEOPHYSICAL STUDIES (Reinhard K. Frohlich)

Besides the magnetic studies in Northeastern Tiverton, geophysical studies concentrated along the northeastern extension of the Watch Hill Lineament on the Quadrangles of Kingston, Slocum and Wickford (see Fig.3-1).

3.1 MAGNETIC STUDIES OVER THE URI TURF FARM

Airborne- and groundmagnetic surveys are frequently used to locate and trace structural elements, including faults and folds. Large-scale tectonic units show magnetic anomaly patterns that can be traced over several hundreds of miles (Higgins and Zietz, 1983). Less known is the direct relationship between faults and fractures and their magnetic signatures. Magnetic anomaly patterns can be interrupted and offset across shear faults (Schwab and Frohlich, 1976), as it is most likely the case northeast of the contaminated well site in Northeastern Tiverton (see chapter 4.4). Henkel and Guzman (1977) correlated fracture zones with trends of subdued magnetic anomalies. The partial extinction of magnetic anomalies is caused by a decrease of the magnetic susceptibility within the fracture zone. Thinsection analysis suggests an oxidation of magnetite to hematite, named "martitization", which is a process believed to originate from solutions that circulate within the fractures. Frohlich (1982) showed that this concept , if applied to a uniformly magnetized sheet, can produce elongate magnetic lows over a nonmagnetic gap that represents a "martitized" fracture zone. In the following magnetic models are compared with the magnetic anomaly map over the URI Turf Farm to determine the width of the fracture zone.

The magnetic anomaly map over the URI Turf Farm was further expanded and completed. This location is ideally suited for geophysical surface studies, as the bedrock is covered by glacial outwash, which presents an almost level surface. Fig. 3-2 shows the extended magnetic anomaly map. Magnetic stations were established on a two-dimensional grid at station intervals of 100 ft. Each station reading presents the average of three adjacent readings obtained with a proton precession magnetometer, model Geometrix G816 and G856. Observations were rejected if the three adjacent readings differed substantially from each other (>30 nT). Steel fences, landfill (northeastern part), pipes and railroad tracks prevented a further expansion of this map.

The magnetic anomaly map with 20 nT contour intervals shows three northeast trending relative magnetic lows, characterized by hatchured contours. The northwestern anomaly low A is parallel to the railroad tracks (see Fig.3-3), which may have influenced the magnetic anomaly pattern. The southeastern anomaly low C shows some irregularities, possibly caused by some man made structures along the road. The anomaly low B in the center shows the most regular anomaly pattern and was reproduced with a magnetic model.

Profile A' - A in Fig.3-4 shows a center anomaly of - 80 nT. It is compared with two model anomalies with a computer program described in Appendix A. The width of the fracture zone is between 90 and 120 m. The relatively small magnetic susceptibility of 0.0004 emu is an average value observed on outcrop samples further south (Frohlich, 1982). The amplitude of the magnetic low is strongly dependent on the magnetic susceptibility and the inverse to the depth of the magnetic layer. The value of 15 m is in agreement with wells that penetrated the glacial deposits. Variations to the depth of the bottom of the sheet (=500 m) have a relatively small influence on the amplitude of the anomaly. Further changes of the model anomaly with changes in the model parameters are shown in Appendix A. It is important to note that this relatively simple geological model concept is based on induced magnetization only which is the major component of granite magnetization.

3.2 GEOELECTRICAL STUDIES

3.21 INTERPRETATION OF DEPTH SOUNDINGS BASED ON HORIZONTAL LAYERING

In the absence of bedrock outcrops at the URI Turf Farm the interpretation concept for magnetic lows was confirmed with geoelectrical depth soundings. Should magnetic lows indicate bedrock fractures, one would expect low bedrock resistivities over magnetic lows and high bedrock resistivities over magnetic highs. Three geoelectrical depth soundings after Schlumberger were conducted parallel to the northeastern trend of the anomalies (see Fig. 3-3). The first depth sounding, VES#1 (Vertical Electrical Sounding), is parallel to the railroad tracks over anomaly low A; the second sounding VES#2 was located over a magnetic high; and the third sounding VES#3 is over the magnetic low B. As the base lines, the spread of the current electrodes, is parallel to the magnetic anomaly trend, lateral inhomogeneities in resistivity, caused by the fractures, are optimally suppressed.

The depth soundings were interpreted by comparison with multilayer model curves derived from a horizontally layered resistivity depth model. The computer program and the interactive modeling procedure are described in Appendix B.

The three depth sounding curves are shown in Fig. 3-5. The apparent resistivity is plotted versus the half electrode separation L/2 on double logarithmic coordinates. The depth to which the apparent resistivity, , corresponds, increases with an increase in L/2. The models derived from the best fitting model curve are shown at the top of Fig.3-5, where the horizontal axis is used for the depth on the same logarithmic axis. All curves represent four-layer cases. A shallow low-resistivity surface layer is underlain by the highly resistive unsaturated zone that causes the maximum on all curves, while the saturated zone causes the minimum. This zone is particularly thick underneath VES#2, over the center of the glacial stream channel. The ascending limbs for large electrode separations, from L/2 = 200 to 800 feet, are controlled by the resistivity of the bedrock. At a slope of 45 degrees with the horizontal axis the bedrock resistivity is infinitely high. This slope is approached with VES#2 at large electrode separations. Bedrock resistivities obtained from the other two depth soundings (VES#1 and 2) are below 10,000 Ohmfeet. This is satisfactory evidence that the magnetic lows occur over fracture zones, while relative highs are over compact bedrock.

A bedrock resistivity of 8000 Ohmfeet can be compared with the water conductivity measured in the URI-well near the northwestern edge of the map shown in Fig.3-3. The conductivity was 150 mhos/cm. Archies Law (1943) allows an estimate of the rock porosity with the simple relationship:

$$\rho_b = \rho_w \cdot \phi^{-n}$$

ρ_b is the bulk resistivity of the bedrock (compact or fractured) that is derived from geoelectrical depth soundings.

ρ_w is the resistivity of the water in the pores and joints.

ϕ is the porosity

n is a constant known as the "cementation factor".

For ρ_b a value of 8000 Ohmfeet (=2440 Ohmm) was used. The water resistivity was calculated from the observed water conductivity. For n a low value of 1.5 seems to be appropriate, which is similar to the values used for unconsolidated sand (Frohlich, 1976). For a comparison, a higher value for σ_w (=300 μmhos/cm) was used, since the nearby landfill may have lowered the water resistivity in the fractures (Kelly, 1977 and Sanders, 1982). Table 1 shows ranges for the porosity ϕ in % derived from Archie's Law.

	μmhos/cm	
σ_w	150	300
n	ϕ %	ϕ %
1.4	7.6	4.7
1.5	9.1	5.7
1.6	10.5	6.8

Table 1: Fracture porosities derived
from Archie's Law.

An estimate of the fracture porosity in the range between 5 and 10 % is in excellent agreement with fracture porosities derived from gravity profiles across the Narrow River (Frohlich and Fisher, 1985). The gravity-derived fracture porosities ranged between 2.5 and 3.7 % as a minimum estimate and an average for a fracture zone of at least 1 km depth. The values derived from the geoelectrics at the URI Turf Farm correspond to the upper part of the bedrock, where fractures are expected to be more abundant than at depth.

3.22 EVIDENCE OF LATERAL INHOMOGENEITIES RELATED TO BEDROCK FRACTURES

Generally, irregular and nonsteady geoelectrical depth sounding curves are observed if the structure of the substratum deviates substantially from a horizontal layer case. On the other hand, a steady field curve is not necessarily evidence for a horizontally layered substratum. Other criteria were observed that indicated the presence of lateral inhomogeneities as they are expected over fractured bedrock. One important indicator of lateral inhomogeneities is a substantial change of the apparent resistivity if the potential electrodes are expanded while the current electrodes remain stationary. For a horizontally layered substratum the apparent resistivity, obtained with different potential electrode spacings, b, should be small to negligible if b is less than 5% of L, the current electrode spacing. Most depth soundings were conducted with a b=2, 6, and 8 feet. The depth soundings over magnetic lows,(VES#1 , 3, and 4) show substantial differences between readings taken at different values for b. It was also apparent that the values did not converge for larger L, as it is the case over horizontal layers.

David Owen, graduate student, worked on a computer program using the finite difference method to estimate lateral inhomogeneities caused by conductive fracture zones. The method of flow nets, described by Freeze and Cherry (1979), is also applicable to the flow of an electrical current, as the differential equations and boundary conditions for water and electrical current flow are analogous. This technique, while tedious, is very useful for illustrating the concept of current flow constrained by geometries associated with a conductive fracture zone in nonconductive bedrock. Application of the finite difference method after Mufti (1976) showed no significant change ($\leq$ 5%) of the equipotential lines (perpendicular to the lines of current flow) if the width of a fracture zone is smaller than the depth of the homogeneous overburden. In this model the resistivities of the overburden and the fracture zone are the same. Multiple layer cases with different resistivities have not yet been considered, but are expected to enhance rather than to subdue the effect from the fracture zones. If the potential electrodes are over the center of the fracture zone, an expansion of the potential electrodes will result in larger apparent resistivities. This effect has been observed over fractures.

3.23 NONLINEAR CURRENT-VOLTAGE RELATIONS OVER FRACTURES

A new geoelectrical phenomenon was observed over the fracture zone associated with the magnetic anomaly low B. Repeated geoelectrical depth soundings over the same location were conducted to observe these effects (VES # 4, see Fig.3.3). The effects occur at large electrode separations L/2 and originate from the saturated zone and the bedrock. The most frequently reoccurring events are:

(1) The apparent resistivity changes if the current is reversed, i.e. the reversed current produces a different voltage at the potential electrodes.

(2) With increasing L/2 the difference of the apparent resistivities, observed for both polarities, increases.

(3) At large L/2 the voltage may not reverse with the current, but will show a polarity that is opposite to the electrical current (see Fig. 3-12 in Frohlich and Fisher, 1985).

(4) The value of the apparent resistivities, observed with both current polarities, will change with the size of the current.

(5) The intensity of the above-mentioned nonlinear effects is small during the winter and early spring. They build up during late spring and last until the late fall. There seems to be a dependence of these abnormal effects on the amount of precipitation, which controls the water pressure in the fracture zone.

Because of the influence of precipitation, a series of depth soundings was repeated over VES#4 to study the change of these effects with time. In 1985, after a very dry winter, the nonlinear effects were observed as early as April 1st. In 1986, during a rainy spring and summer, the effects were observed for the first time as late as June 30. Prior to this date four successive depth soundings showed systematic changes in the unsaturated and saturated zones. Fig. 3.6 shows the four depth sounding curves and the best fitting resistivity depth models. The results of the interpretation are summarized in table 2, which also shows the transverse resistance of the unsaturated zone ($T_2 = \rho_2 \cdot D_2$) and the conductance of the saturated zone ($S_3 = D_3 / \rho_3$). They are the Dar Zarrouk parameters that describe the electrical properties of a high- and low-resistive layer, respectively.

Date	D_2	$\rho_2(\Omega ft)$	D_3	$\rho_3(\Omega ft)$	$T_2(10^2)$	$S_3(10^{-2})$
4/18/86	29	40,000	165	2,300	11,600	7.17
4/25/86	24	44,000	165	800	10,560	20.63
5/16/86	22	52,000	120	900	11,440	13.33
6/4/86	18	68,500	60	400	12,330	15.00

Table 2: Change of geoelectrical parameters of the saturated and unsaturated zone over a fracture.

Most significant is a decrease of the resistivity in the unsaturated zone from 4/16/86 to 6/4/86. This strongly suggests an abnormal increase of the pore water salinity over the fracture zone before the nonlinear resistivity effects occured. On June 30, the reversal effect was observed for the first time in 1986. On July 8-86 the effect has decreased in intensity due to renewed rainfall. The repeated depth soundings that show the nonlinear effects are shown in Fig.3.7. It appears that the salinity of the pore water in the fracture zone does not only change considerably with time but also has a controlling influence on the occurrence and intensity of nonlinear resistivity effects. During periods of high precipitation the pressure of fresh water seems to be dominant. During dry periods water of higher salinity seems to migrate towards the center of the fracture zone.

Nonlinear current-voltage effects are not unknown to physicists. They occur as boundary effects in semiconductors and are utilized in the transistor. They were also observed across membranes that separate high- from low-concentration saline solutions. Kobatake and Fujita (1964) investigated these effects on charged membranes and suggested that similar processes are associated with membranes in the nerve system. Though such phenomena have never been described in the geophysical or hydrogeological literature, it is very likely that similar membrane effects are the cause of the observed phenomena. Since these effects were observed on many other locations, it is believed that further details of these effects may finally lead to a more complete understanding and characterization of the hydraulic behavior of fracture zones. Observations over a hydrogeologically tightly controlled fracture zone should also include well observations.

3.3 GRAVITY STUDIES

The gravity map of Rhode Island showed evidence of a potential gravity low on the quadrangle of Slocum. A glacial stream channel intersects the northeastern extension of the Watch Hill Lineament. Detailed gravity observations were conducted at this intersection. A similar condition was expected, which exists further south on the Carolina Quadrangle. A glacial stream channel underneath the Lower Wood River intersects the Watch Hill Lineament. A local gravity low suggests an extensive deposition of glacial deposits at the intersection forming a high yield aquifer. The site on the Slocum Quadrangle at the SODGRASS Turf Farm is also located over the intersection of a glacial stream channel with a fracture system.

The Bouguer Gravity (see Fig.3.8) shows a strong gravity gradient of the regional field. This may have subdued the more local effect of glacial stream channels and fractures. The regional field was separated with a least squares two-dimensional plane (see Appendix C). Fig. 3.9 shows the residual gravity map which emphasizes the local anomalies. To the southwest of the map a northeast striking gravity low is parallel to a fracture- related surface depression (see Fig.3.1). The large closed gravity low in the northern part of the map is exactly at the intersection of both lineaments, i.e. the glacial stream channel and the Watch Hill Lineament. The cause of the gravity low is believed to be related to a large deposition of glacial outwash.

3.5 FIGURE CAPTIONS CHAPTER 3

Fig. 3.1: Location of geophysical survey in South County, R. I.

Fig. 3.2: Groundmagnetic map over the URI Turf Farm at 100 ft station intervals with 20 nT contour intervals. Anomaly lows depict buried fracture zones.

Fig. 3.3: Groundmagnetic map with location of geoelectrical depth soundings.

Fig. 3.4: Comparison of a magnetic profile across the URI Turf Farm with model anomalies derived from a fracture model.

Fig. 3.5: Geoelectrical depth soundings after Schlumberger over fracture zones (VES # 1 and 3) and over compact rock (VES # 3).

Fig. 3.6: Geoelectrical depth soundings over the same location (VES # 4) conducted at different times during the spring of 1986. Changes of the resistivity in the saturated zone suggest an increase in pore water salinity in the fracture zone prior to the occurrence of nonlinear geoelectrical effects.

Fig. 3.7: Geoelectrical depth soundings over VES # 4 at different times of the year showing nonlinear resistivity effects. For large electrode separations the resistivity changes with a change of current polarity. Circles indicate voltage reading that is opposed to the electrical current.

Fig. 3.8: Bouguer gravity map over the SODGRAS Turf Farm, Slocum Quadrangle.

Fig. 3.9: Residual gravity over the SODGRAS Turf Farm showing a NE striking fracture-related gravity low. A closed NNW trending gravity low in the northern part indicates an increase in the thickness of high porosity glacial outwash.

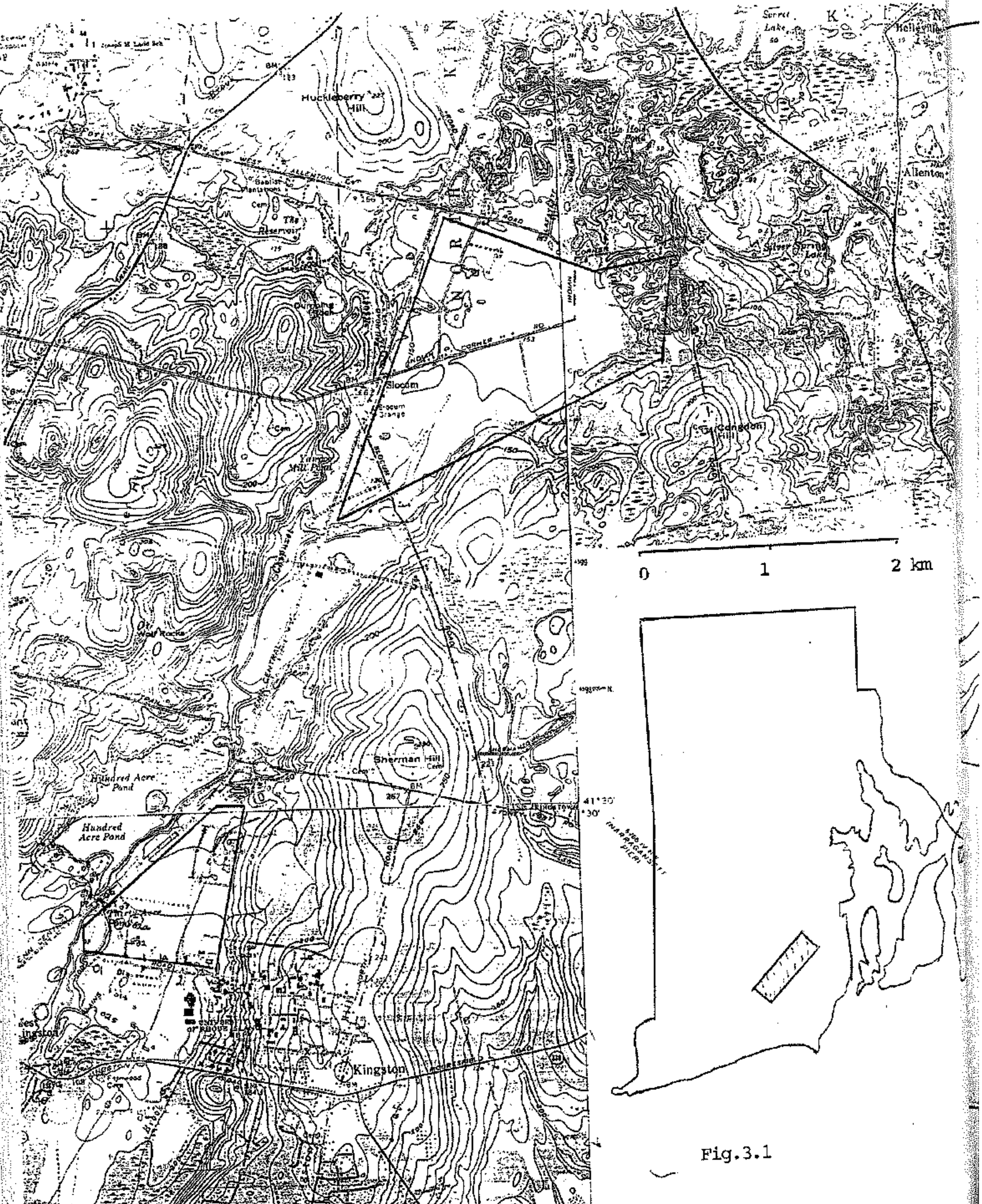

Huckleberry Hill
The Reservoir
Slocum
Yawgoo Mill Pond
Wolf Rocks
Sherman Hill
Hundred Acre Pond
Kingston
Silver Spring Lake
Allenton
Congdon Hill
0
1
2 km

Fig.3.1

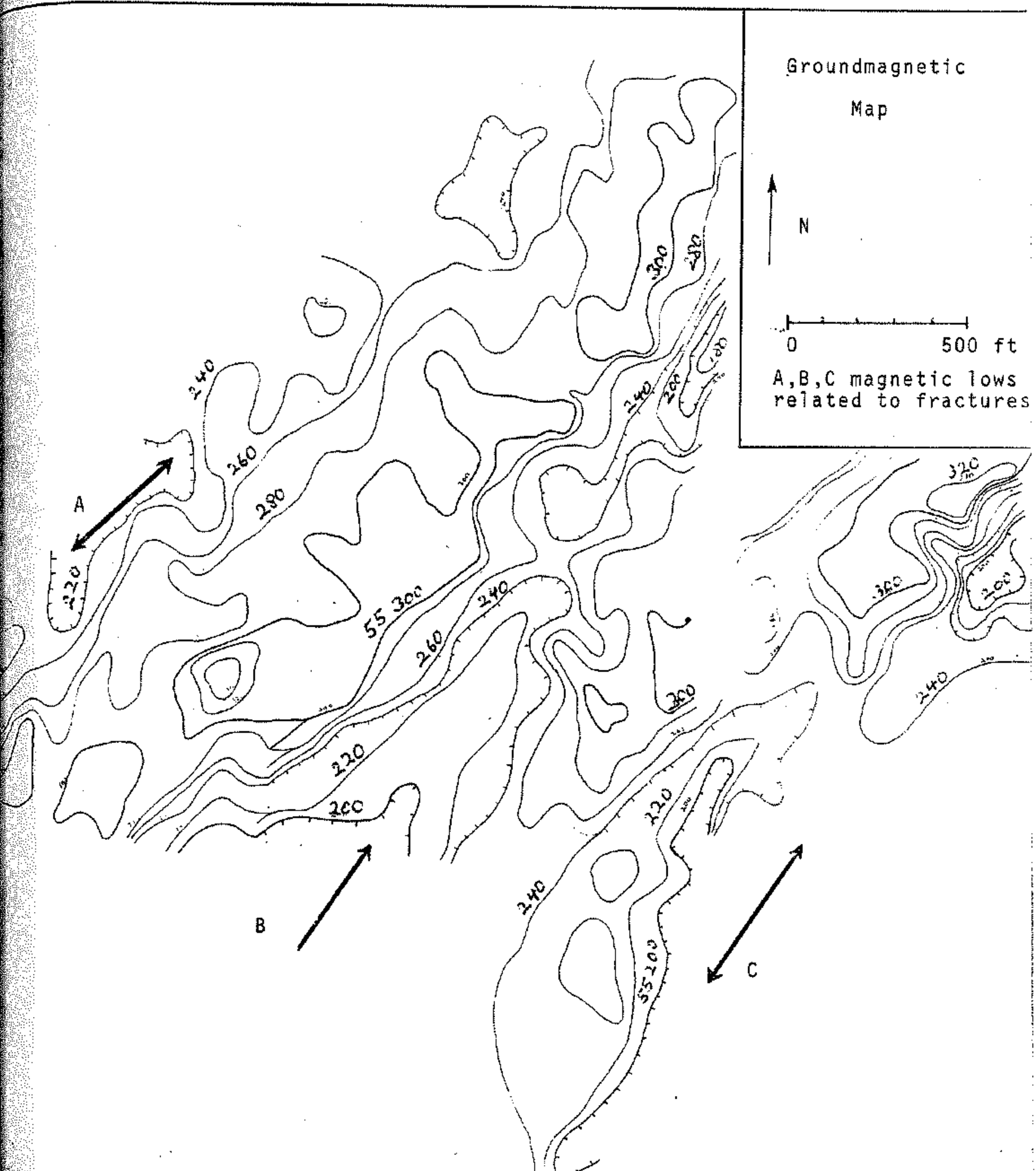
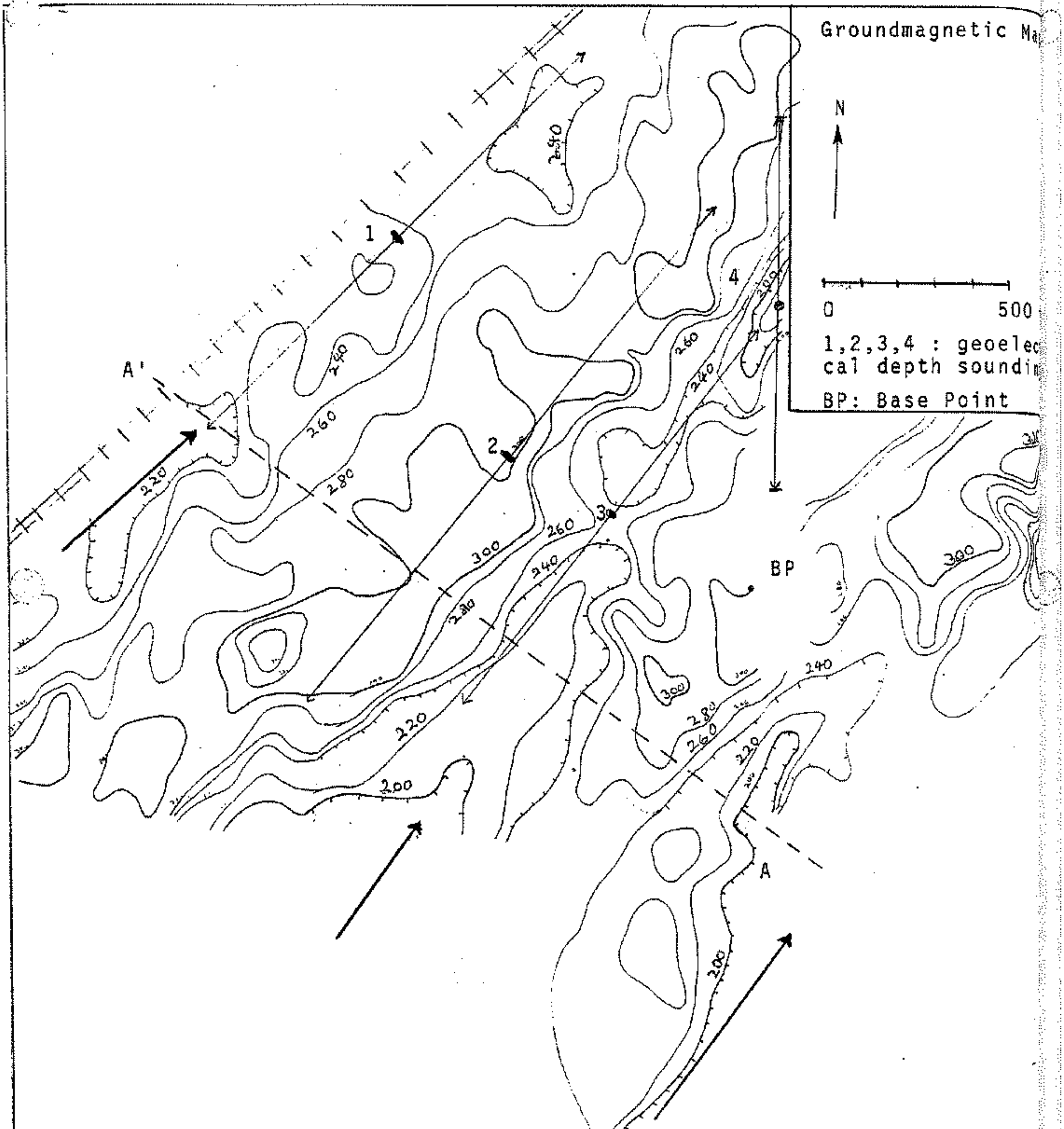

Groundmagnetic
Map
N
0
500 ft
A,B,C magnetic lows related to fractures
A
B
C
240
260
280
220
55 300
240
260
220
200
300
280
240
200
180
320
300
200
240
300
240
220
55 200
240

Fig. 3.2


Groundmagnetic Ma
N
0
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1,2,3,4 : geoelec
cal depth soundin
BP: Base Point
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1
2
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220
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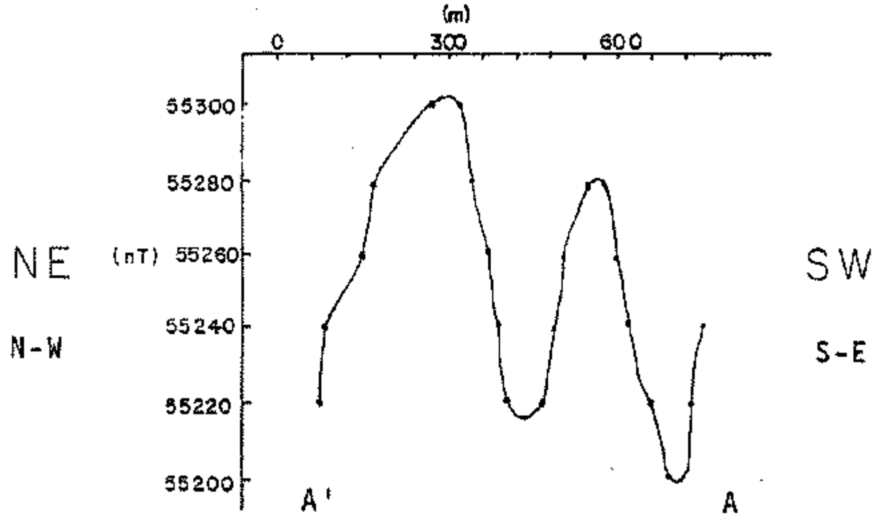
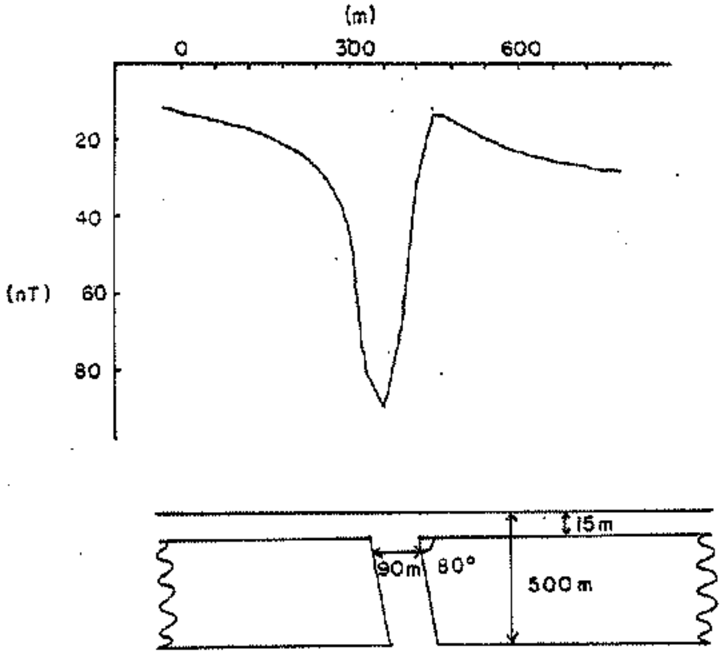
260
280
300
200

Fig. 3.3



Observed Total Magnetic

Field



M O D E L S

Su: 0.0004 emu

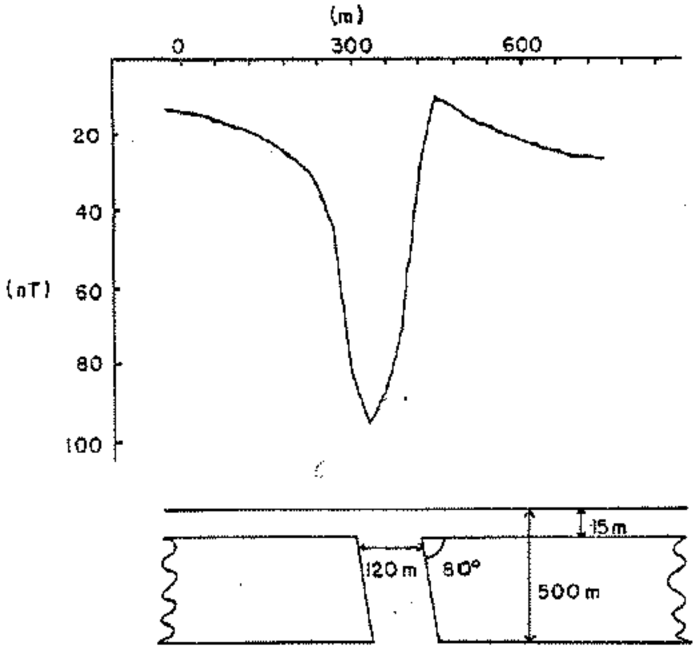
T: 56,000 nT

I1: 72°

A1: 80°

L: N 45° E

Width of nonmagnetic
gap: 90 m (N=3)



Width of nonmagnetic

gap: 120 m (N=4)

Fig. 3.4

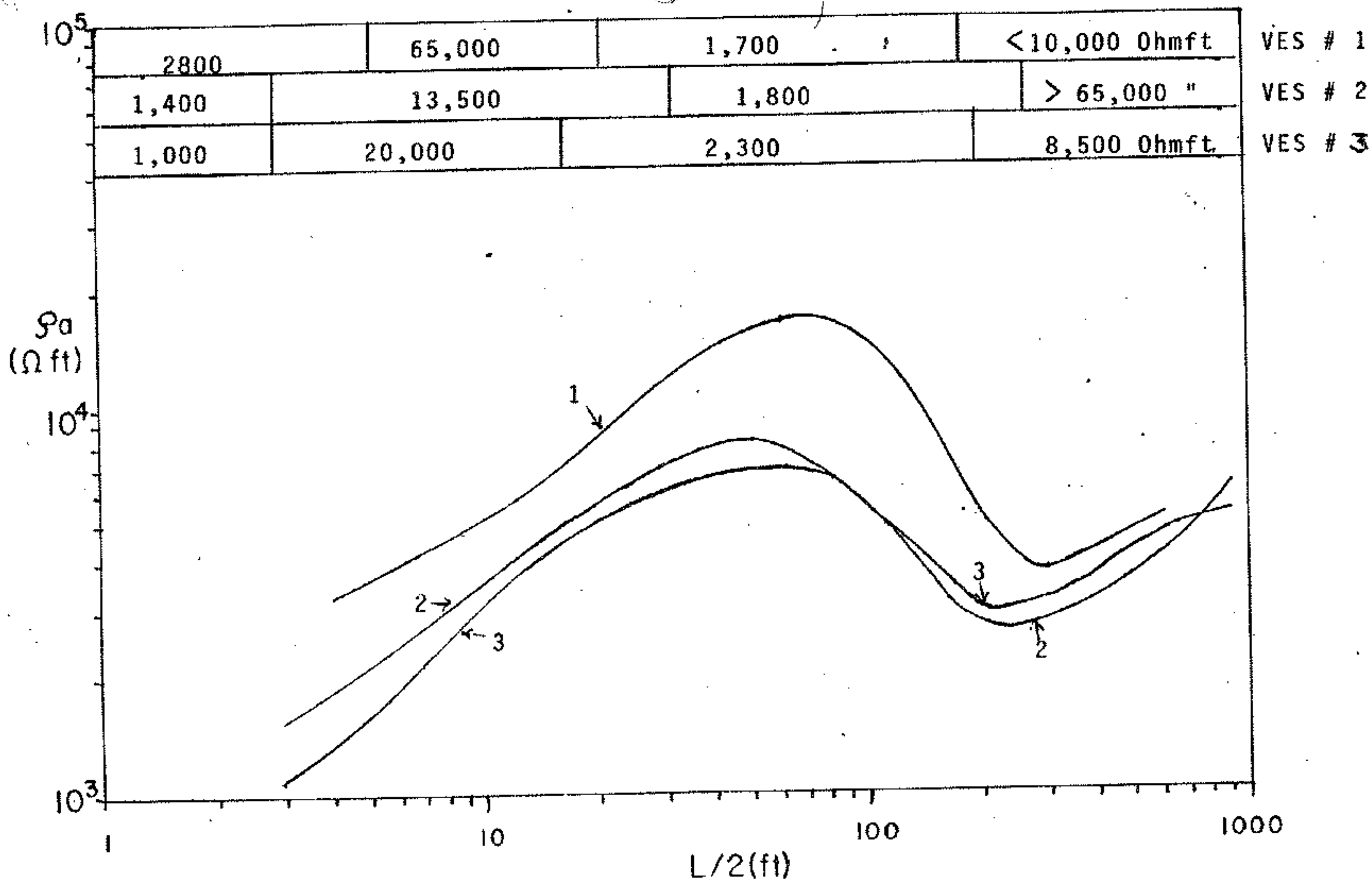

2800
65,000
1,700
<10,000 Ohmft
VES # 1
1,400
13,500
1,800
> 65,000 "
VES # 2
1,000
20,000
2,300
8,500 Ohmft
VES # 3
10^5
10^4
10^3
ρa
(Ω ft)
1
2
3
1
10
100
1000
L/2(ft)

Fig. 3.5

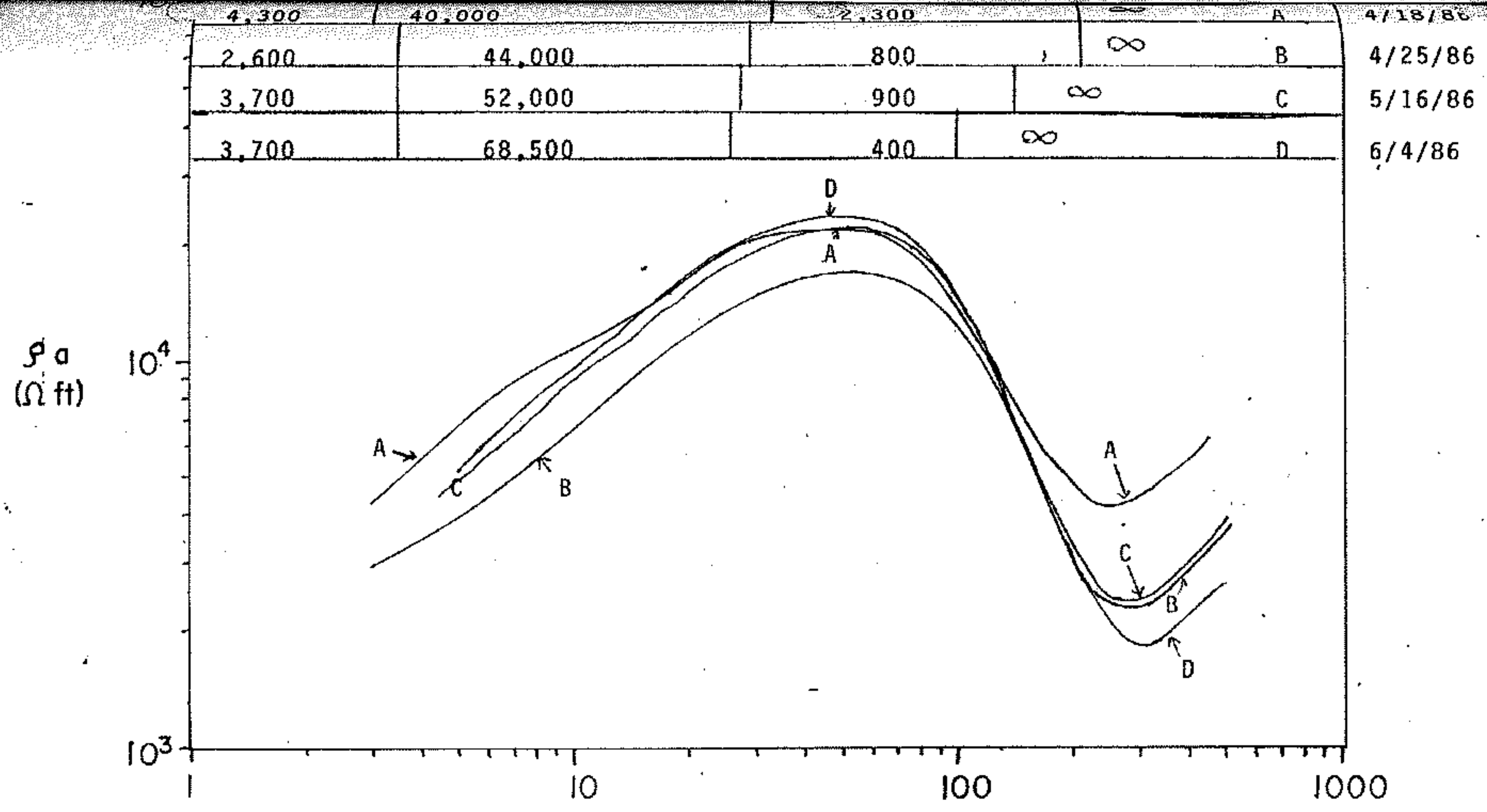
4,300
40,000
2,300
∞
A
4/18/86
2,600
44,000
800
∞
B
4/25/86
3,700
52,000
900
∞
C
5/16/86
3,700
68,500
400
∞
D
6/4/86
ρa
(Ω ft)
10^4
10^3
A
B
C
D
1
10
100
1000
L/2 (ft)

Fig. 3.6

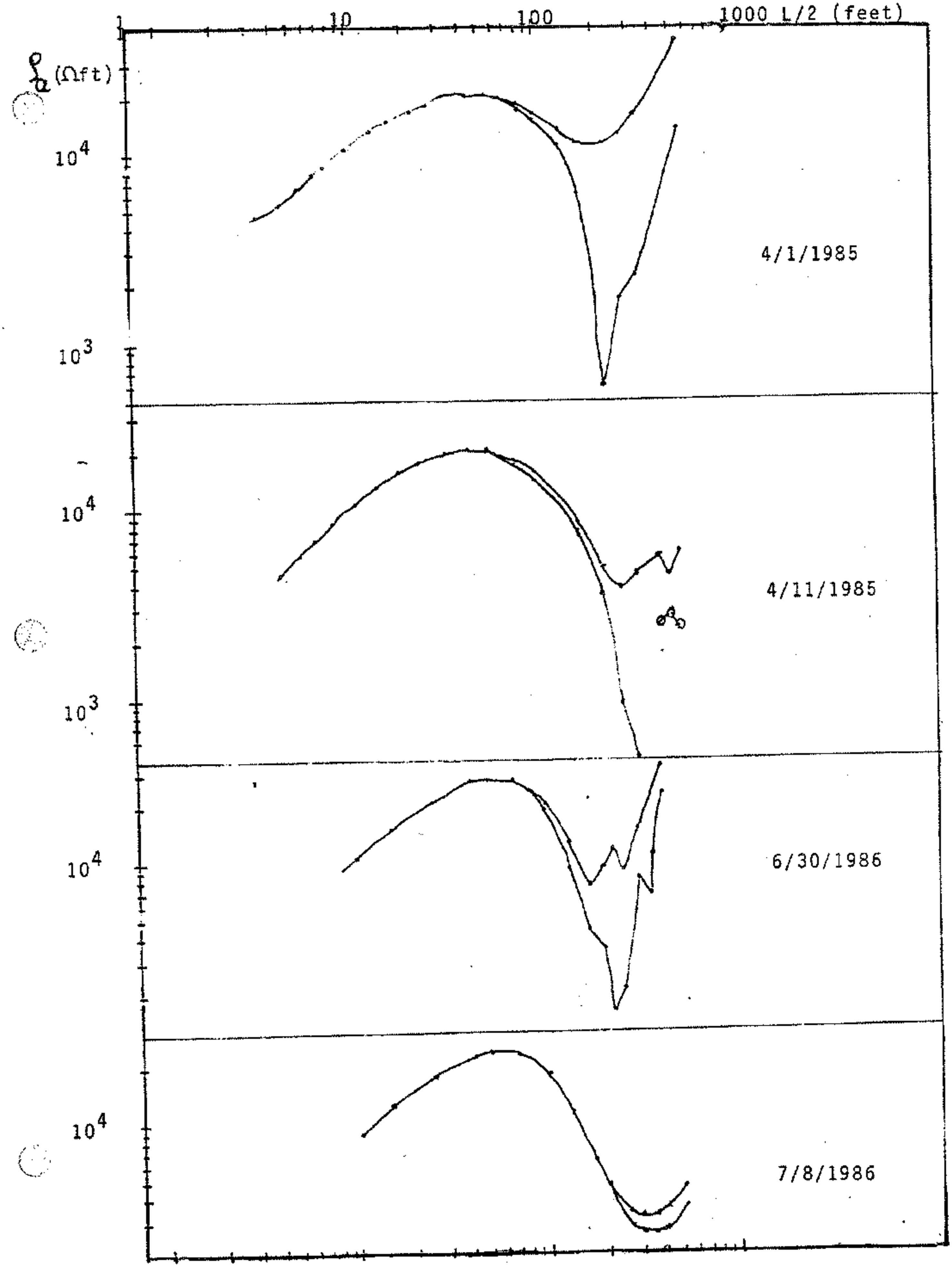

10
100
1000 L/2 (feet)
ρa (Ωft)
10^4
10^3
4/1/1985
10^4
10^3
4/11/1985
10^4
6/30/1986
10^4
7/8/1986

Fig. 3.7

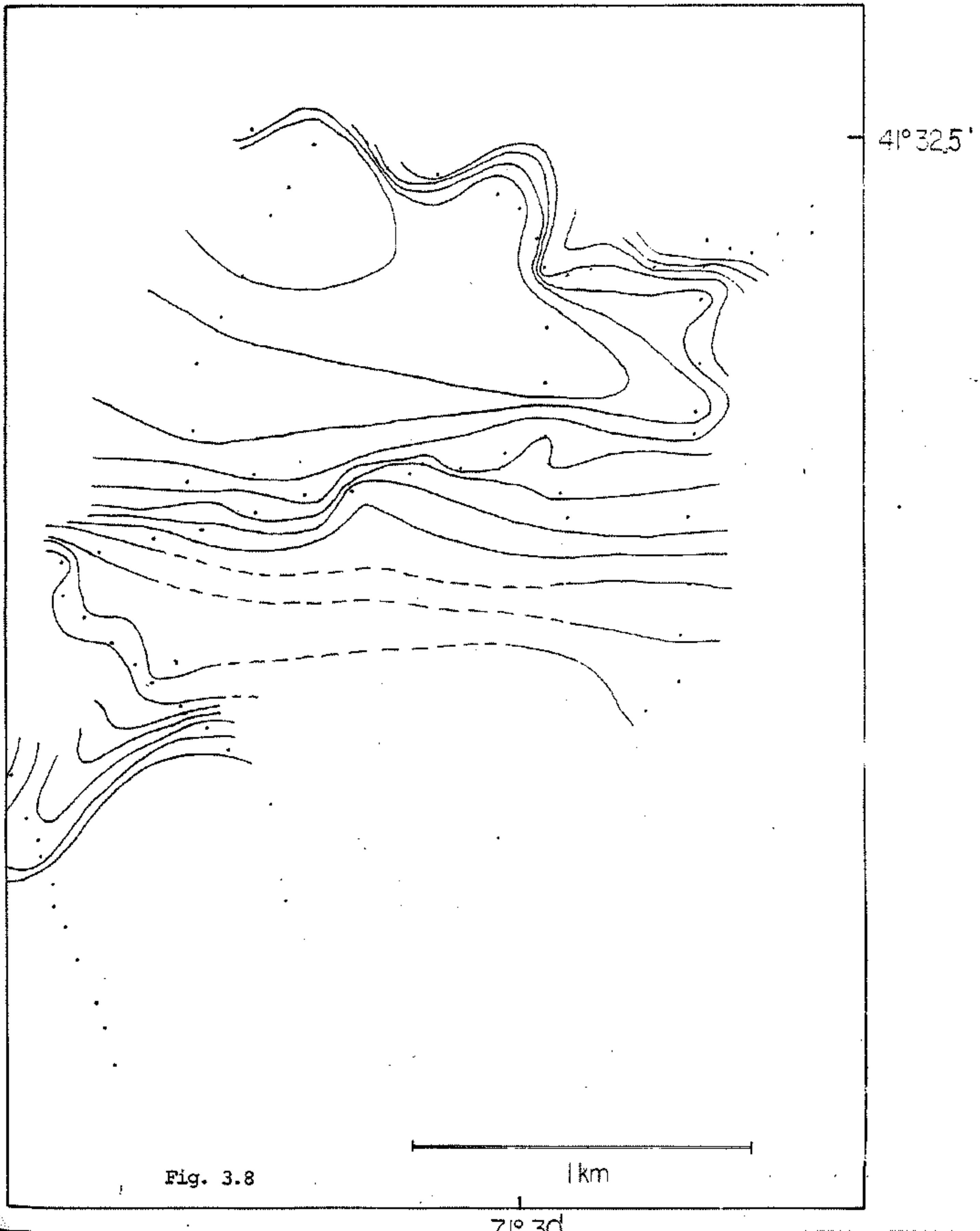


Fig. 3.8

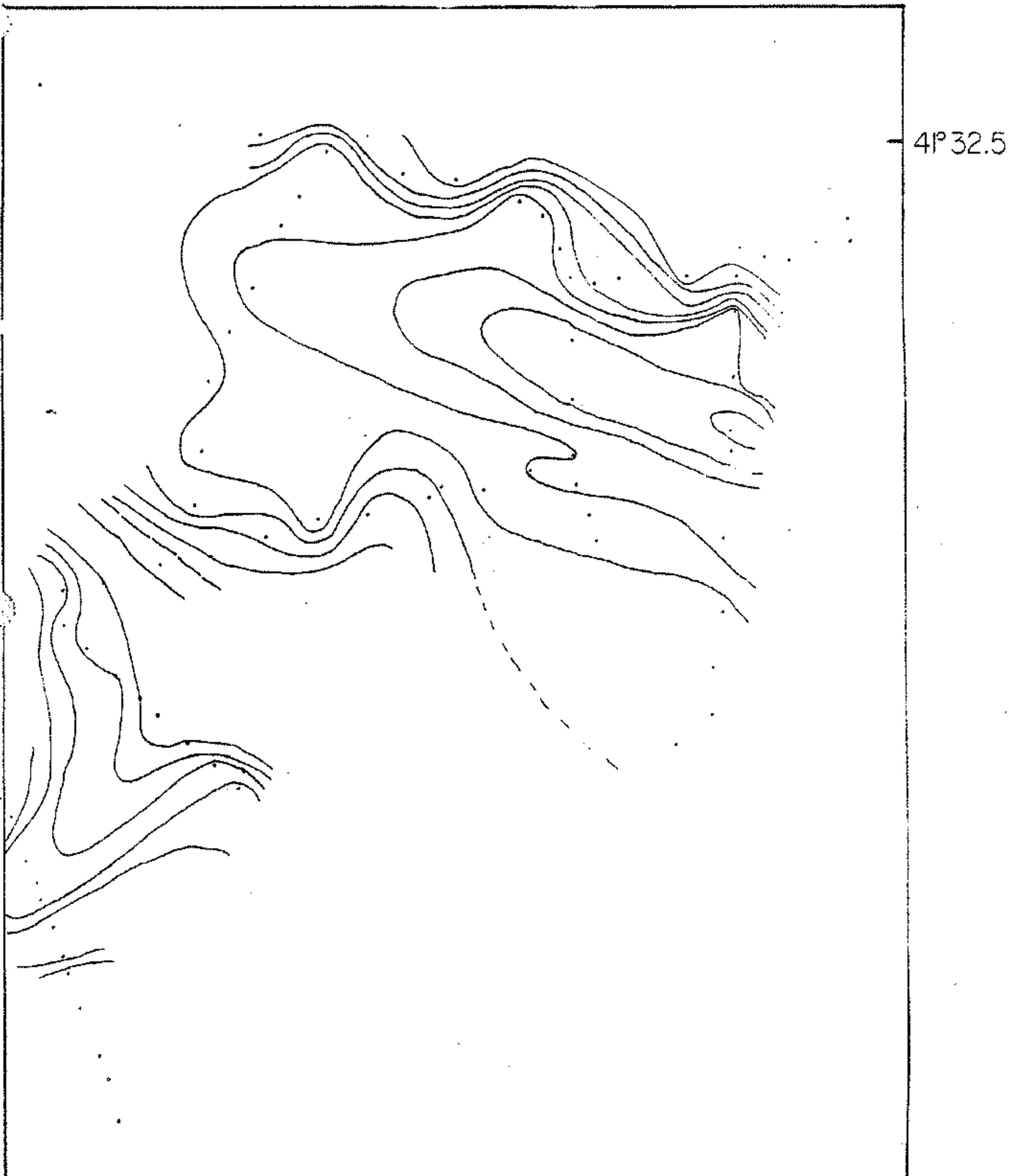


Fig. 3.9

4. TIVERTON BEDROCK WELL CONTAMINATION (Fisher, J.J., R.K. Frohlich, J. G. Savarese)

4.1 REMOTE SENSING, HYDROGEOLOGIC AND GEOPHYSICAL APPROACH:

Seven private wells in Northeastern Tiverton have been contaminated with fuel oil, as reported by the Rhode Island Department of Environmental Management's Ground Water Section. Since the contamination is located in buried bedrock wells, the aquifer is the fracture zone of the granitic bedrock. A common procedure for determining fracture zones in bedrock is to use a step-wise approach of interpreting lineaments derived from aerial photography, satellite and radar imagery, and topography to determine their location. Interpretation of well records would then be necessary for construction of hydrogeologic models. The use of ground geophysical methods would then allow the determination of more specific hydraulic characteristics of the fracture zones, such as: porosity, permeability and fracture density.

Investigation of this area is important due to the potential rapid movement of contaminated water in fractured bedrock. The threat of contaminated water flowing to additional private wells in addition to the possible impact on nearby Stafford Pond, a municipal source of public water supply.

The remote sensing methods are used to determine the location and pattern of lineaments. Once lineaments have been mapped, results from ground magnetic geophysical surveys can verify the presence of the subsurface fracture zone from which the lineaments were formed. Similar types of investigations undertaken in Rhode Island have been conducted for subsurface interpretations. Previous geophysical studies include those by Frohlich, 1982; Frohlich and Barosh, 1982; Frohlich and Fisher, 1985; and Sanders, 1983. Magnetic surveys were intially conducted in the proposed area of research. This technique has been used specifically for location of fracture zones (Henkel and Guzman, 1977). Hence, direct correlation of hydrogeological and remote sensing analysis with geophysical results allow refinement of the hydrogeologic model using knowledge of subsurface conditions and hydraulic characteristics of fracture zones.

4.2 LINEAMENT ANALYSIS

Delineation of lineaments in Tiverton help determine areas of highly fractured bedrock through which a considerable amount of groundwater flows. Many investigators have studied and evaluated the importance of fractured rock located by lineaments as an important ground water resource (Lattman and Parizek, 1964; LeGrand, 1949, and Parizek, 1976). Major lineaments in Tiverton and the surrounding area: Little Compton, RI; Fall River and Westport, MA; were mapped from aerial photography (1985, 1939), SLAR (Side Looking Airborne Radar) and Landsat Satellite Imagery and projected to a 1:100,000 U.S.G.S. topographic base map using a Bausch and Lomb Transfer Scope and Art-O-Graph Image Projector.

Lineaments in the Tiverton area trend predominantly north-north-west by south-south-east (Fig. 4.1). The system of lineaments are parallel to subparallel. Significant parallel systems occur between Sakonnet Point and Little Compton (A, Fig. 4.1) and just south of Davol Pond, just east of the Rhode Island border (B, Fig. 4.1). The parallel lineament systems near Sakonnet Point are more widely separated (0.5 -0.7 mi), although the same length (2.0 mi) and control the development of the step-wise pattern of the shoreline east of Sakonnet Point. The parallel lineament system south of

Davol Pond although 2.0 miles in length are only 0.2 miles apart but appear to be an extension of a similar parallel lineament system in northeast Tiverton (C, Fig. 4.1). Just to the west of this trend between Stafford Pond and South Watuppa Pond are the contaminated bedrock wells in Tiverton. In fact, Sawdy Pond and Davol Pond are probably the result of a bedrock fracture system being eroded out by glacial erosion of pre-glacial fluvial erosion at depth. Just to the south-west of the contamination site (0.5 mi) along Cornell Road there is a prominant Landsat lineament 2.0 miles long (D, Fig. 2.6) and also trending NNW - SSE. Immediately NE of Stafford Pond several short 1.0 mile lineaments (E, Fig. 4.1) are trending directly towards the contamination site.

All these three lineament systems bracket the contamination site and suggest that NNW - SSE trending bedrock fractures exist in the contamination site. The similarity in lineament trend throughout the Tiverton-Little Compton area is probably due to the fact that one rock type, Bulgarmarsh granite underlies almost the entire area (Quinn, 1971). The border of Narragansett Bay is bordered by Pennsylvanian sedimentary rocks and lineaments of a different trend, northeast by southeast, occur in this area (F, 4.1) around Nannaquaket Pond in Tiverton.

4.3 HYDROGEOLOGICAL ANALYSIS

Collection of Well Completion Reports, 1972-1985, from the Rhode Island Water Resources Board and Well Inventory Forms from the U.S.G.S. was necessary to obtain subsurface geologic and hydrologic data. Research of well owners and use of 1:400 aerial plat/lot maps at the Tiverton Town Hall Tax Assessor's Office was required to locate and plot well locations on a topographic base to supplement limited data of the Fall River (Allen and Ryan, 1960) and Tiverton (Schiner and Gonthier, 1965) U.S.G.S Groundwater Maps. Well records provided data to produce maps of the contoured piezometric surface of bedrock wells; and superposition of potential flow directions on piezometric surface (Fig. 4.2).

Evaluation and interpretation of the lineament map and water record data from well logs provide the information from which the hydrogeologic conditions may be appraised. Subsequently, preliminary interpretation of potential groundwater movement may be documented.

The above hydrogeologic evaluation and remote sensing analysis can be correlated with geophysical results; i.e., magnetic surveys available in this area. Use of geologic and hydrologic data from well records aid in determination of: hydrologic conditions; groundwater flow potential; and subsequent potential for the spread of contaminated groundwater.

Evidence from remote sensing analysis and geophysical surveys for location of fractures constrain groundwater movement within these fracture zones further define the proposed hydrogeologic model, helping to indicate areas susceptible to present and future contamination.

Water table contours trend north and south indicating a uniform slope from the higher terrain on the west down to South Watuppa Pond on the east. However, in the contamination study area there is a complete closure of the water table contours. This indicates a higher than average water table which can occur only if the bedrock has a higher porosity and permeability. Bedrock fractured more than the immediate surrounding area is how this higher porosity/permeability developed. The north-south elongation of the water table contour closure indicates that the zone of higher fractured bedrock follows the same trend indicated by the remote sensing lineament study (see section 4.2).

Flow lines of subsurface water indicates a flow primarily from west to east down the hydraulic gradient. However in the area of greater fractured bedrock there are local zones of both north and south groundwater flow. This is because the high fracture zone can even act as a recharge area to the surrounding less fractured bedrock. In fact, subsurface water will mound up in this recharge area and flow out in an outward direction in a pattern that will deform the normal flow patterns.

4.4 MAGNETIC STUDY

A short-spaced magnetic survey was conducted over an area that includes the site of contaminated bedrock wells in Northeastern Tiverton. A total of 150 magnetic stations were established along EW profiles at an average spacing of 100 m . Two groundmagnetometers of the proton precession type, model Geometrics G816 and G856, were used with resolutions of 1.0 and 0.1 nT, respectively. Each magnetic station was based on the average of three adjacent readings taken at the corners of an equal-sided triangle with 5 to 10 m sidelength. Many stations had to be abandoned and relocated because of large differences between the three readings, caused by buried pipes of iron. Large parts of this area are characterized by housing and uncontrolled dumping which includes magnetic iron scraps.

The groundmagnetic map, presented at 100 nT contour intervals (see Fig.4.3), shows two dominant NNW to SSE striking anomaly trends. The first, in the northeastern part of the map, suggests a shear zone with possible left-lateral shear faulting. Less distinctive NNE to NE striking anomaly trends are interrupted along this suggested shear zone and appear to be offset in a left-lateral sense. The second anomaly trend is a NNW to SSE striking magnetic low which extends across the site of contaminated bedrock wells (Florence Str.). This anomaly can be interpreted as direct evidence of a fracture zone. It appears to be limited in width and length .The trend of both dominant anomalies is parallel to the most prominent lineament orientation found with remote sensing methods.

In addition to the 150 magnetic stations, two short-spaced profiles at 5 to 15 m spacings were conducted over potential fracture zones. One, profile A, extends over the southern tip of the magnetic anomaly low related to the fracture zone underneath Florence Street (see Fig.4.4). The second magnetic profile (B) extends over a second magnetic low at the southern margin of the survey, where a natural spring suggests another fracture zone (see Fig.4.5). The magnetic models underneath the observed profiles suggest a width of the fracture zones of 30m (profile A) and 40 m (profile B), respectively. The concept and justification for this model is described in chapter 3 and in Appendix A.

This magnetic survey over the area of contaminant bedrock wells in Northeastern Tiverton is a typical example of urban geophysics. Man made structures and extensive dumping presents serious problems for the interpretation of geophysical observations. It is therefore surprising to obtain useful and precise results from the magnetic survey which are applicable towards locating the bedrock aquifer. This was possible, since the observations had to pass two criteria for final acceptance. First, the three adjacent readings were not to show large differences. Second, the average of the three readings was accepted if the value would fit into a consistent anomaly pattern. It is imperative that these results should be supported and augmented with gravity and geoelectrics. The detailed profiles A and B at 5 - 15 m spacings provide an accuracy for the location of the contaminated aquifer that would be needed for engineering purposes. This would include the optimal location of a pumping well for remedial action. Whether this accuracy can be obtained in the vicinity of Florence Street remains to be seen; but sofar the results are better than expected. Additional gravity and geoelectrical surveys would add to the required precision. BGesides, both methods would provide different hydrogeological information related to porosity and permeability of the fracture zone. Such information is needed for reliable groundwater flow modeling in the fracture zone.

4.5 FIGURE CAPTIONS CHAPTER 4

Fig. 4.1: Lineament map of the Tiverton, R.I. area, site of present fuel oil contamination of bedrock fracture wells (circled). Primary lineaments were mapped using landsat satellite imagery with detailed mapping of secondary and tertiary lineaments using aerial photography (recent and archieval). The dominant lineament trend is NNW by SSW with trends passing through the contaminated area (C and E).

Fig. 4.2: Detailed water table contours of Tiverton fuel oil contamination site developed from well records and hydrogeologic developed flow directions. Closure of water table contours indicates greater bedrock fracturing and the north-south closure indicates a zone of higher fractured bedrock following the remote sensing lineament trend.

Fig. 4.3:Magnetic anomaly map of the Tiverton, R.I. area including the site of bedrock well contamination. The contaminated zone is over a N 30 W striking magnetic low that indicates a buried fracture zone. A left-lateral strike slip fault is suggested due to the offset of magnetic anomalies further northeast.

Fig. 4.4: Micromagnetic profile across anomaly A south of the site of contaminated bedrock wells. The comparison with a model anomaly suggests a 30 m wide fracture zone.

Fig.4.5: Micromagnetic profile B. The magnetic low and the spring suggest a different fracture zone of 40 m width.

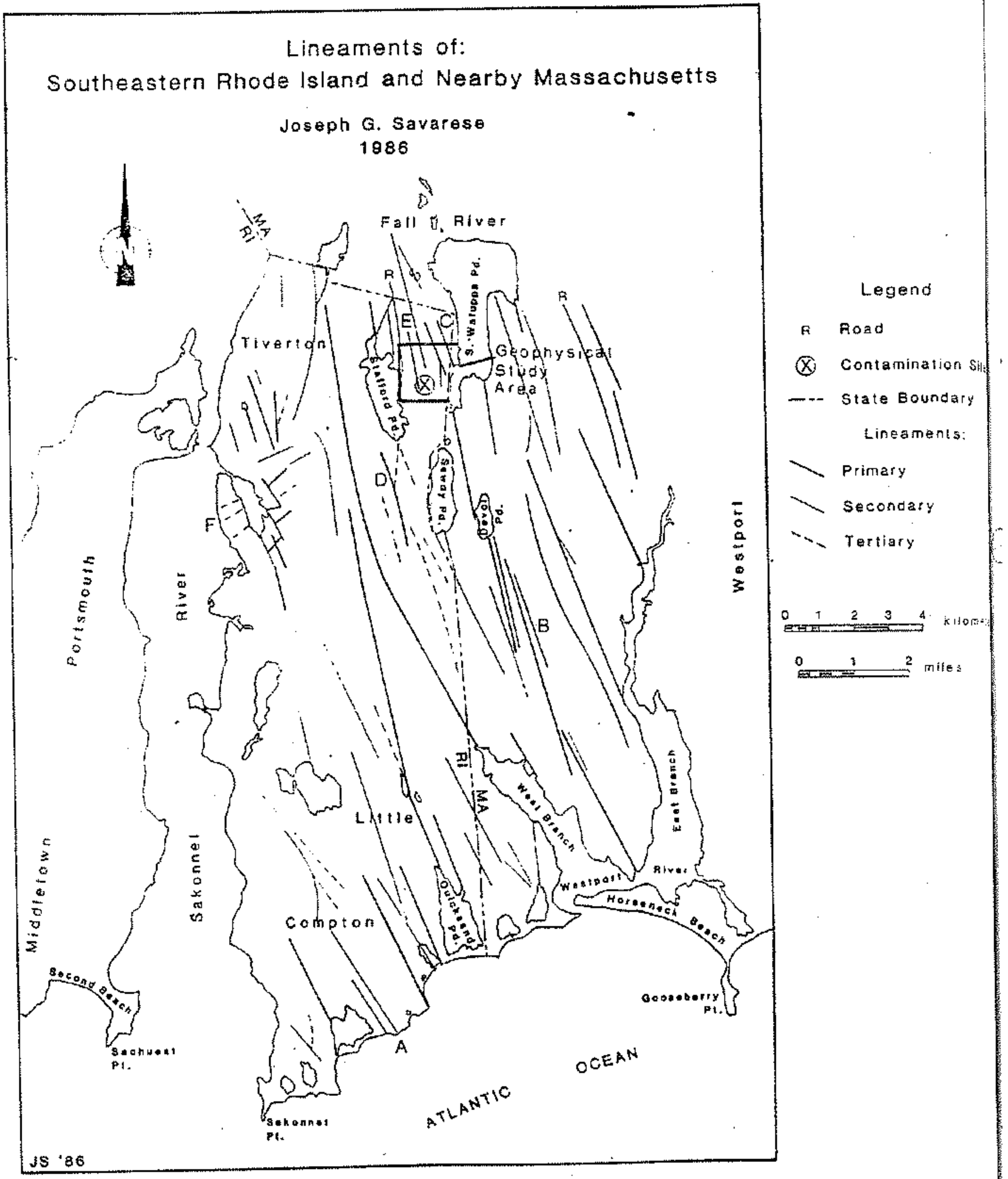

Lineaments of:
Southeastern Rhode Island and Nearby Massachusetts
Joseph G. Savarese
1986
MA
RI
Fall
River
R
R
E
C
S. Watuppa Pd.
Tiverton
Geophysical Study Area
Stafford Pd.
Sawdy Pd.
Devol Pd.
D
F
B
Portsmouth
River
Westport
RI
MA
West Branch
East Branch
Little
Middletown
Sakonnet
Compton
Quicksand Pd.
Westport
River
Horseneck Beach
Second Beach
Sachuest Pt.
Gooseberry Pt.
A
OCEAN
ATLANTIC
Sakonnet Pt.
JS '86
Legend
R Road
Contamination Si
State Boundary
Lineaments:
Primary
Secondary
Tertiary
0 1 2 3 4 kilom
0 1 2 miles

FIGURE 4.1

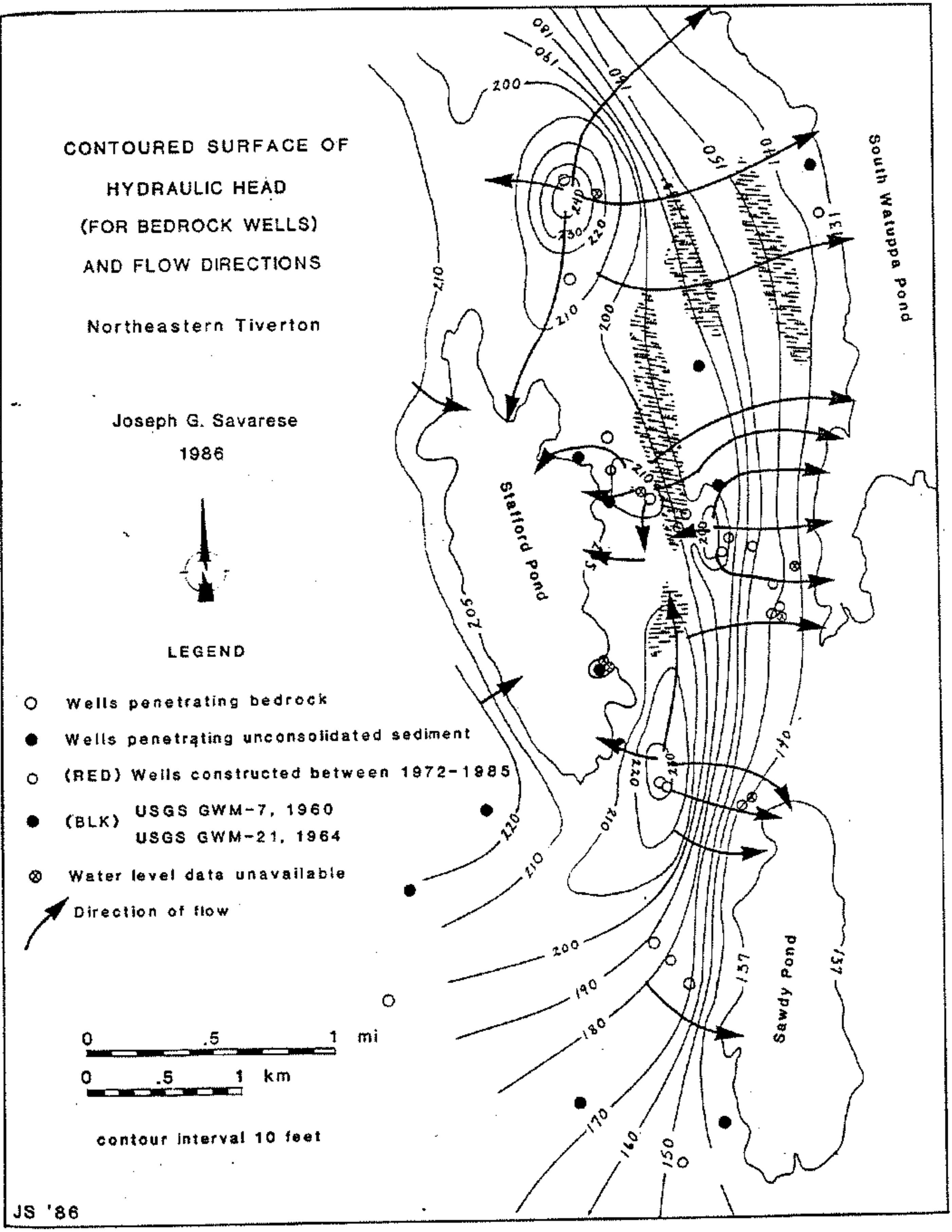
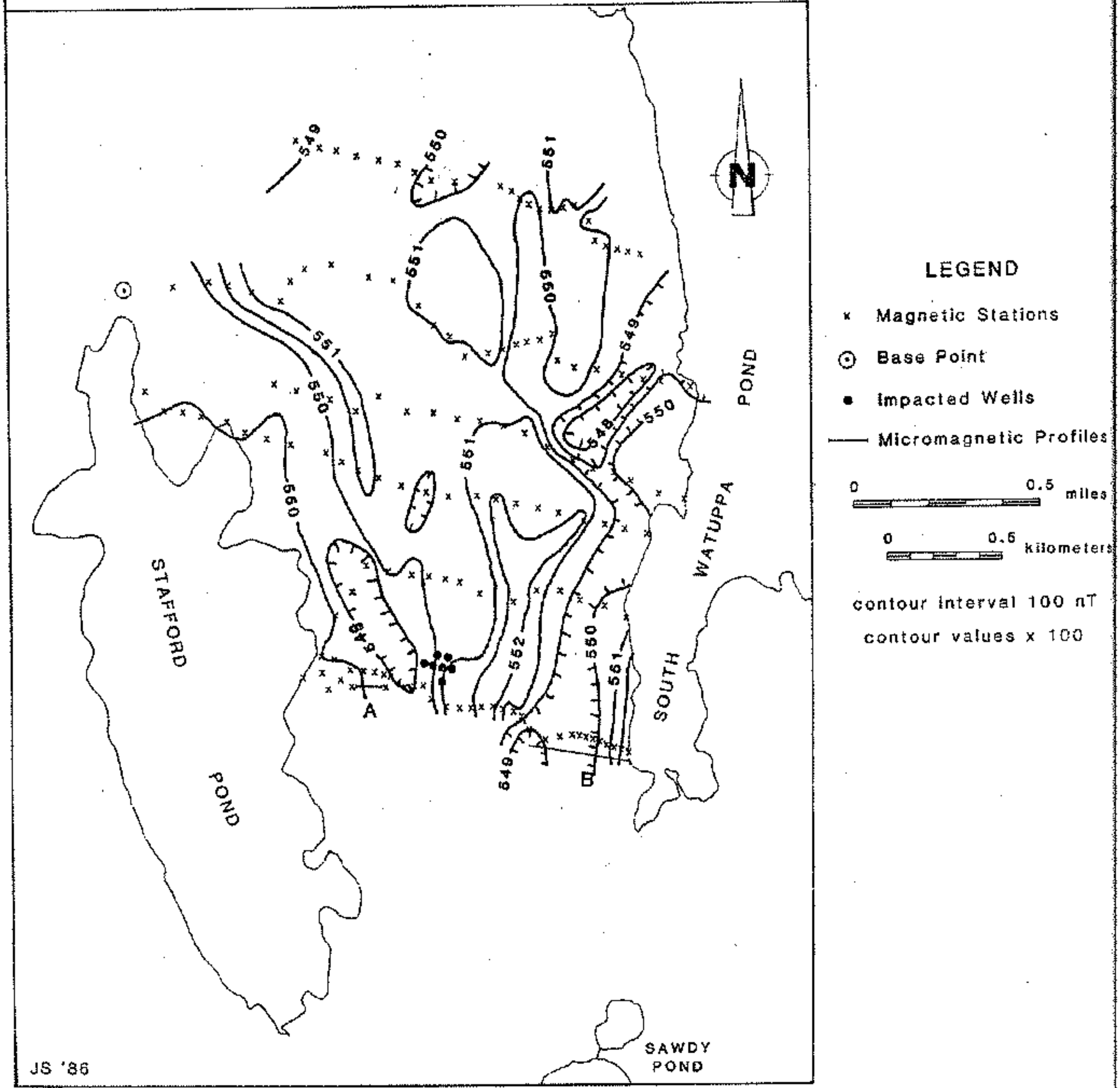

CONTOURED SURFACE OF
HYDRAULIC HEAD
(FOR BEDROCK WELLS)
AND FLOW DIRECTIONS
Northeastern Tiverton
Joseph G. Savarese
1986
LEGEND
○ Wells penetrating bedrock
● Wells penetrating unconsolidated sediment
○ (RED) Wells constructed between 1972-1985
● (BLK) USGS GWM-7, 1960
USGS GWM-21, 1964
⊗ Water level data unavailable
Direction of flow
0 .5 1 mi
0 .5 1 km
contour interval 10 feet
JS '86
Stafford Pond
South Watuppa Pond
Sawdy Pond
240
230
220
210
205
200
190
180
170
160
150
140
137

FIGURE 4.2

Ground Magnetic Map of Northeastern Tiverton

Reinhard K. Frohlich
Joseph G. Savarese

1986



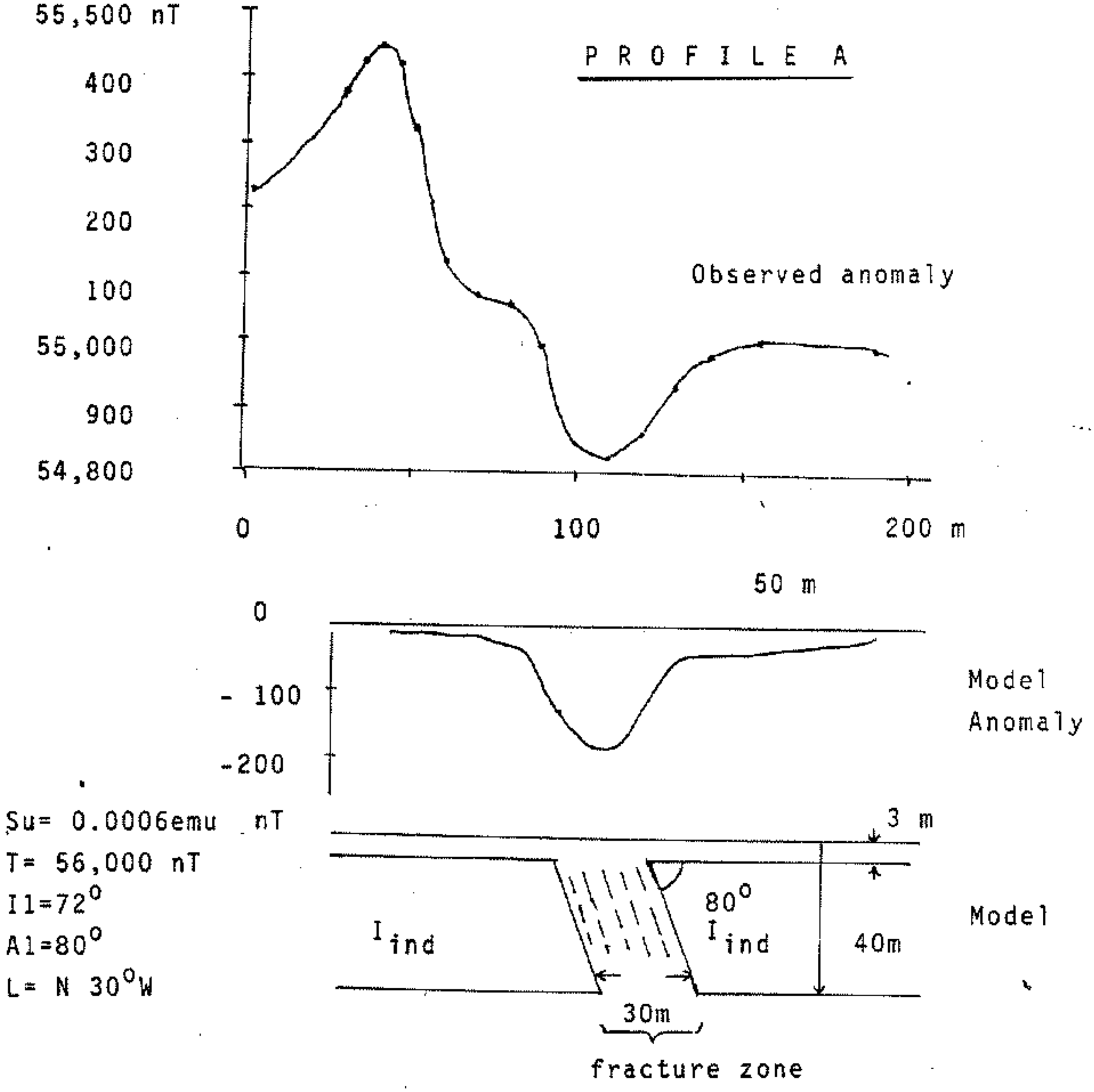

55,500 nT
400
300
200
100
55,000
900
54,800
0
100
200 m
PROFILE A
Observed anomaly
50 m
0
- 100
-200
nT
Model
Anomaly
Su= 0.0006emu
T= 56,000 nT
I1=72°
A1=80°
L= N 30°W
3 m
80°
I ind
I ind
40m
Model
30m
fracture zone

Fig. 4.4

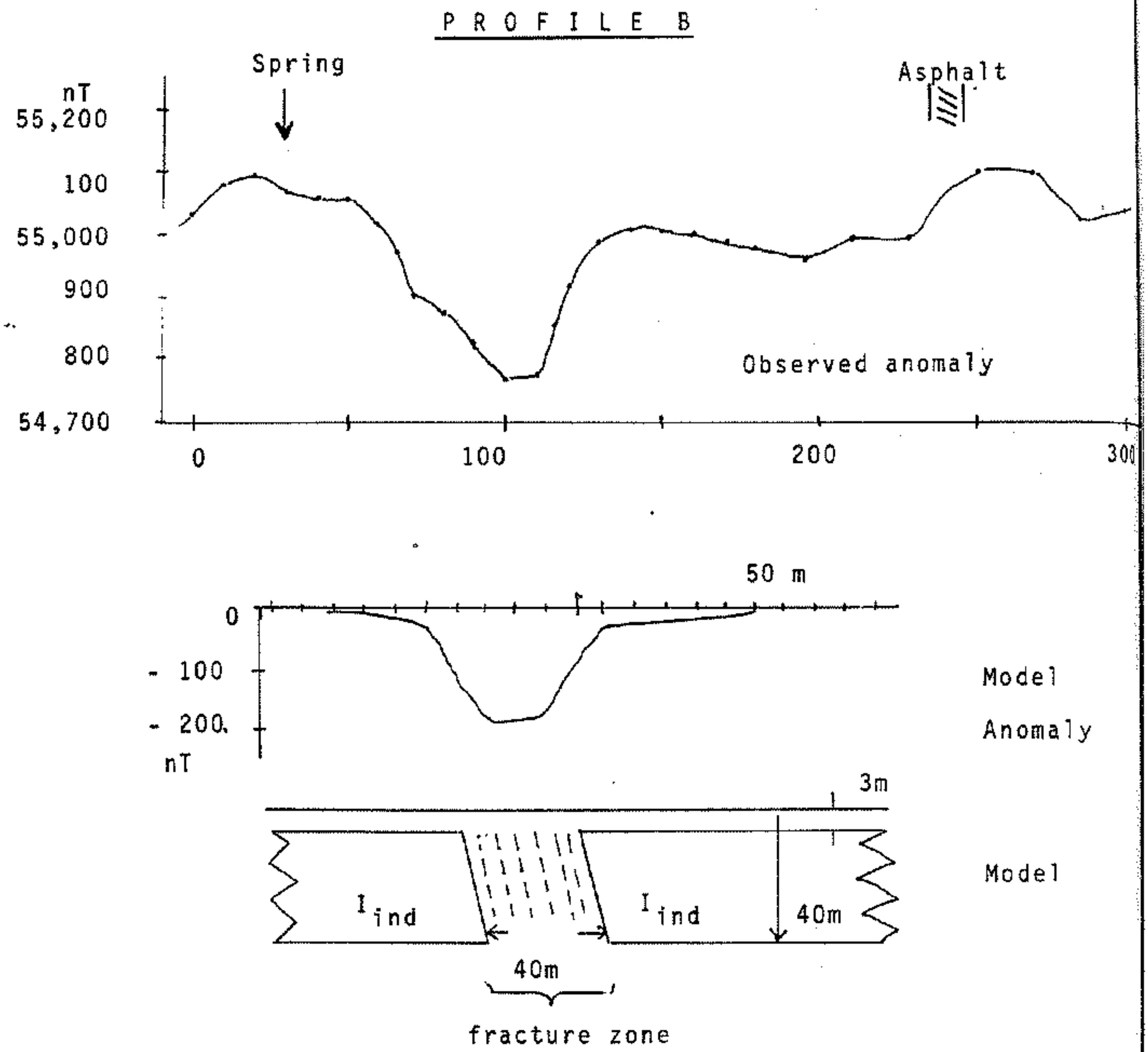

PROFILE B
Spring
Asphalt
nT
55,200
100
55,000
900
800
54,700
0
100
200
300
Observed anomaly
50 m
0
- 100
- 200
nT
Model
Anomaly
3m
I_{ind}
I_{ind}
40m
Model
40m
fracture zone

Fig. 4.5

5. SUMMARY - CONCLUSIONS

5.1 REMOTE SENSING

1. New Landsat Satellite 5 imagery from January 1986 showed bedrock lineament fracture zones more clearly because of the lack of vegetation and lower sun angle. Thematic mapper imagery (TM) with improved 20 m resolution from that flight enabled more precise and detailed lineament mapping than earlier multispectral imagery (MSS).

2. SLAR (Side look airborne radar) imagery proved most useful for regional and detailed mapping. It showed geologic features, including fracture lineaments, in more detail than satellite imagery beacuse it has greater resolution and the active radar ray enhances finer terrain relief features.

3. Additional imagery used for detailed lineament fracture mapping included: a) space shuttle large format camera imagery (LFC); b) high altitude color and color infrared photography (HAP); c) low altitude large scale recent and archive (Library of Congress) aerial photography.

4. An inventory and mapping of the hydrogeologic features related to the mapped Landsat lineaments was completed. Of 136 mapped lineaments, 446 surface hydrogeologic related features were mapped on thirty state-wide 1:24,000 topographic maps. These features included: a) linear stream segments, b) aligned drainage, c) elongated lakes, d) aligned lakes, e) swamps or wetlands and f) linear valleys.

5. Groundwater aquifer systems in the buried river valleys of southern Rhode Island have now been found to be related toi large-scale lineament

bedrock fracture systems as mapped on both Landsat satellite and SLAR (radar) imagery. The major fracture pattern trends northwest in western Rhode Island and northeast in eastern Rhode Island. This fracture system underlies all thue major aquifer in southern Rhode Island and the lineament maps can predict their subsurface location.

6. Remote sensing mapping has indicated a north-north-west trend of bedrock lineaments passing through the fuel oil bedrock well contamination site in Tiverton, RI. This indicates increased bedrock fracturing in the immediate area. Preliminary hydrogeologic analysis of the water table in the area also indicates an elongated trending closure, the result of higher porosity and permeability. This anisotropic groundwater condition will stongly affect ground water flow direction and velocity.

Future areas of investigation based on these studies within Rhode Island should include:

a) Investigate SPOT (French) satellite imagery with its greater resolution (and greater cost) for RI water resources surface and subsurface hydrogeologic applications;

b) Use SLAR (radar) imagery for a more detailed mapping and inventory for planning purpose of hydrogeologic features related to bedrock fracture lineaments especially in the environmentally hydrologically sensitive southern and western RI areas;

c) Use SLAR (radar) imagery for lineament mapping of suggested bedrock fracture control of buried glacial deposit aquifers in central and north Rhode Island and used recent large scale aerial photographs for detailed mapping of mega-lineament system of southern Rhode Island's buried glaical aquifers.

d) Computer analysis of digitized imagery would enable detailed and rapid mapping of the above hydrogeologic research areas in Rhode Island. It would also enable tranferring all the lineament fracture data, developed to date as well as future data, to the R.I. Dept. of Envir. Management G.I.S. (Geographical Information System). This computerized data system is housed at the University of Rhode Island. The base map for the DEM/URI GIS is the 1:24,000 topographic map, which is the same base for the remote sensing lineament maps. Landsat Satellite Imagery data is available in digitized form. However, the accuracy of this imagery system, as shown in this study, is low if compared with SLAR and aerial photography. It is suggested that these latter two imagery systems should be digitized both for computer quantitative analysis and for the GIS data base.

5.2 GEOPHYSICS

1. The magnetic map at short station spacings was completed. It could be shown that fractures in crystalline bedrock can produce isolated elongate magnetic lows in the northern hemisphere. Magnetic modeling can accurately locate and estimate the width of fracture zones. This method does not seem to be affected by overburden effects.
2. Geoelectrical studies confirmed the magnetic interpretation concept. Bedrock porosities in the fractured zones were estimated to be between 5 and 10 percent. This is consistent with porosities derived from gravity data. Again, estimates of bedrock porosities from geoelectrics are not affected by overburden effects.
3. Lateral effects expected over fracture zones were observed and methods were developed to distinguish them from vertical resistivity changes.
4. Nonlinear current-voltage effects were further observed over a selected fracture zone. A strong dependence of these effects on precipitation and the water salinity in the fracture zone was established. It is believed that a fracture zone acquires properties of a membrane system under above conditions.

Further studies are needed to establish the usefulness of this newly discovered effect for the hydrogeological characterization of buried fracture zones.

5. The gravity method yields usefull additional and complimentary information of the fracture porosity. This method can be used in populated areas, i.e. it is not affected by man made constructions. This method, however, also responds to lateral changes in density due to glacial deposits.

5.3 COMBINED METHODS FOR THE CHARACTERIZATION OF FRACTURED BEDROCK AQUIFERS.

This study has shown the usefulness of remote sensing and geophysical methods for solving water resources management problems. It was shown that groundwater pollution from fuel oil contamination affects the bedrock fractures.

While crystalline bedrock is commonly thought to be impermeable to groundwater movement, this cannot generally be accepted for the crystalline bedrock of Rhode Island. Further evidence was gathered that fractures are particularly abundant in valleys.

The study in Northeastern Tiverton found that crystalline bedrock of granitic composition was sufficiently fractured to supply water for domestic needs. Therefore the bedrock is sufficiently permeable to facilitate the migration of fuel oil. Although these rocks are normally thought to be useful for locating landfill and hazardous waste sites, the study showed the limitations of this concept. The most significant difference between aquifers in fractured bedrock and unconsolidated material, such as glacial outwash, is a strong azimuthal anisotropy. This puts considerable constraints on groundwater flow models, since water flow is primarily confined by the dimensions of the fracture zone.

By combining geophysical with remote sensing methods for the analysis of bedrock fractures, the usefulness of this approach can be summarized as follows.

Remote sensing methods, such as Landsat Satellite Imagery, can identify patterns related to bedrock fractures and is useful for an intensity assessment. The methods allow for a coverage of large areas at minimal costs, once the maps are available.

More local detailed bedrock fracture mapping is possible with SLAR, because of greater resolution and fidelity. Detailed photo analysis of present and past aerial photos allows for more local detail.

All geophysical methods require more effort for the field work and interpretation. There seems to be a direct relationship between the properties of the fracture zone and the geophysical anomalies. The model concepts for interpreting geophysical anomalies relate directly to the material difference between fractured and compact bedrock. These differences cause a change in magnetic susceptibility, density and electrical resistivity.

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APPENDIX: COMPUTER PROGRAMS

The programs used for this study are written in BASIC for the HP-85 personal computer.

A. The Magnetic Anomaly Over A Nonmagnetic Fracture Zone.

The magnetic anomaly-lows observed over fracture zones are explained by the magnetic edge-effect over two juxtaposed horizontal slabs of infinite extend. They are separated along their edges by a nonmagentic gap which represents the fracture zone. The anomalies are caused by induced magnetization only.

The magnetic anomaly over a magnetized horizontal sheet is:

$$T(x) = SU \cdot T \cdot C \cdot \sin(A1) *$$

$$\left\{ C1 \cdot \ln\left(\frac{\left[X - \frac{D2 - D1}{\mathrm{tg}\, A1}\right]^2 + D2^2}{x^2 + D1^2} \right) + C2 \cdot \left[\mathrm{tg}^{-1} \frac{\left[X - \frac{D2 - D1}{\mathrm{tg}\, A1}\right]}{D2} - \mathrm{tg}^{-1}\left(\frac{x}{D1}\right) \right] \right\}$$

With the following constants:

$$C = 1 - [\cos(I1) * \cos(L)]^2$$

$$B = \mathrm{tg}^{-1}[\mathrm{tg}(I1)/\sin(L)]$$

$$C1 = \cos(A1 - 2 \cdot B)$$

$$C2 = 2 * \sin(A1 - 2B)$$

The model parameters are:

Su: magnetic susceptibility

T: intensity of the total magnetic field

I1: inclination of the magnetic field

L: strike direction of the edge with respect to magnetic north

X: field points along a profile across the edge of the slab

D1: depth to the top

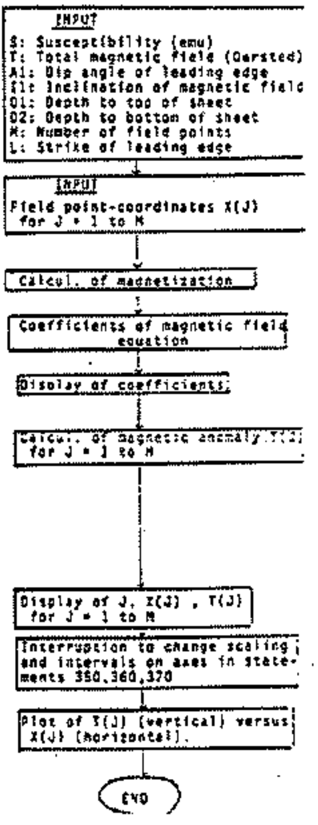
D2: depth to the bottom

A1: dip angle of the termination of the slab.

The following program "MAG1" calculates and plots the anomaly of a single buried magnetic slab. Fig. A-1 shows the plot of two slabs.

The magnetic anomaly over a buried magnetized sheet

```
  Program "MAGI"
 10 OPTION BASE 1
 20 DIM X(50),T(50)
 30 READ S,T,A1,I1,D1,D2,M
 35 DATA .0003,56000,51,72,40,20
    0,31
 36 DISP USING 38 ; S,T,I1,D1,D2
    ,M
 38 IMAGE D 5D.6Z,2(4D.2D),2(4D
    2D),M
 40 INPUT L
 50 DISP "STRIKE L=";L;"DEG  A
    1=";A1
 60 FOR J=1 TO M
 70 READ X(J)
 80 DATA -300,-270,-240,-210,-18
    0,-150,-120,-90,-60,-30,0,30
    ,60,90,120,150,180,210,240,2
    70,300
 90 NEXT J
100 P=S*T
110 DEG
120 C=1-(COS(I1)*COS(L))^2
130 B=ATN(TAN(I1)/SIN(L))
140 C1=COS(A1-2*B)
150 C2=SIN(A1-2*B)
155 DISP "     C      B        C1
      C2"
160 DISP USING 165 ; C;B,C1,C2
165 IMAGE 2D.2D,2X,4D.2D,X,2(2D
    .2D,X)
170 FOR J=1 TO M
180 RAD
190 P1=ATN((X(J)-(D2-D1)/TAN(A1)
    )/D2)-ATN(X(J)/D1)
200 DEG
210 T(J)=P*C*SIN(A1)/A*(C1*LOG(((X
    (J)-(D2-D1)/TAN(A1))^2+D2^2)
    /(X(J)^2+D1^2))+C2*P1)
215 NEXT J
218 DISP
219 DISP " J      X(J)          T(J)
    "
220 DISP
221 FOR J=1 TO M
222 DISP USING 224 ; J,X(J),T(J)
224 IMAGE 2Z,2X,2(5D.2D,2X)
226 NEXT J
240 PAUSE
340 PEN 1 @ GCLEAR
350 SCALE X(1),X(M),-50,50
360 XAXIS 0,30
370 YAXIS 0,10
380 FOR J=1 TO M
390 PLOT X(J),T(J)
400 NEXT J
1000 END
```



INPUT

S: Susceptibility (emu)

T: Total magnetic field (Oersted)

A1: Dip angle of leading edge

I1: Inclination of magnetic field

D1: Depth to top of sheet

D2: Depth to bottom of sheet

M: Number of field points

L: Strike of leading edge

INPUT

Field point-coordinates X(J) for J = 1 to M

Calcul. of magnetization

Coefficients of magnetic field equation

Display of coefficients

Calcul. of magnetic anomaly T(J) for J = 1 to M

Display of J, X(J), T(J) for J = 1 to M

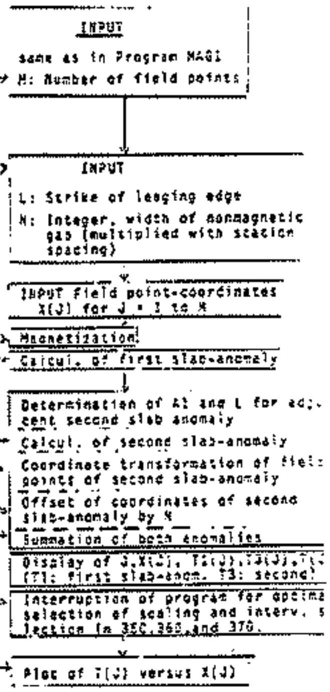
Interruption to change scaling and intervals on axes in statements 350,360,370

Plot of T(J) (vertical) versus X(J) (horizontal).

END

PROGRAM :MAGSTF

```
 10 OPTION BASE 1
 20 DIM X(50),T(50),T1(50),T2(50
    ),T3(50)
 25 FOR J=1 TO 50
 26 T2(J)=0 @ T3(J)=0
 27 NEXT J
 30 READ S,T,A1,I1,D1,D2,M
 35 DATA .0003,56000,80,72,20,50
    0,31
 36 PRINT USING 38 ; S;T;I1;D1,D
    2,M
 38 IMAGE D 5D.6Z,2(4D.2D),2(4D
    2D),M
 40 INPUT L,N
 50 PRINT "STRIKE L=";L;"DEGR A1
    =";A1;"N=";N
 60 FOR J=1 TO M
 70 READ X(J)
 75 DATA -450,-420,-390,-360,-33
    0
 80 DATA -300,-270,-240,-210,-18
    0,-150,-120,-90,-60,-30,0,30
    ,60,90,120,150,180,210,240,2
    70,300
 85 DATA 330,360,390,420,450
 90 NEXT J
100 P=S*T
110 GOSUB 1100
112 FOR J=1 TO M
114 T1(J)=T(J)
116 NEXT J
120 A1=180-A1
130 L=L+180
140 GOSUB 1100
145 FOR J=1 TO M
147 T2(J)=T(M+1-J)
148 NEXT J
170 FOR J=1 TO M
172 T3(J)=T2(J+N)
174 NEXT J
180 FOR J=1 TO M
190 T(J)=T1(J)+T3(J)
195 DISP USING 196 ; J,X(J),T1(J
    ),T3(J),T(J)
196 IMAGE 2Z,4(4D.2D)
200 NEXT J
300 PAUSE
340 PEN 1 @ GCLEAR
350 SCALE X(1),X(M),-80,20
360 XAXIS 0,30
370 YAXIS 0,10
380 FOR J=1 TO M-N
390 PLOT X(J),T(J)
400 NEXT J
1000 END
1100 DEG
1200 C=1-(COS(I1)*COS(L))^2
1300 B=ATN(TAN(I1)/SIN(L))
1400 C1=COS(A1-2*B)
1500 C2=SIN(A1-2*B)
```



INPUT

same as in Program MAGI

M: Number of field points

INPUT

L: Strike of leading edge

N: Integer, width of nonmagnetic gap (multiplied with station spacing)

INPUT field point-coordinates X(J) for J = 1 to M

Magnetization

Calcul. of first slab-anomaly

Determination of A1 and L for adjacent second slab anomaly

Calcul. of second slab-anomaly

Coordinate transformation of field points of second slab-anomaly

Offset of coordinates of second slab-anomaly by N

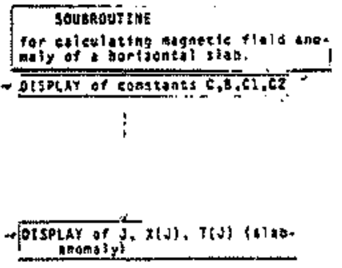
Summation of both anomalies

Display of J,X(J), T1(J),T3(J),T(J) (T1: first slab-anom. T3: second)

Interruption of program for optimal selection of scaling and interv. selection in 350,360,and 370.

Plot of T(J) versus X(J)

```
1550 DISP "     C      B        C1
       C2"
1600 DISP USING 1650 ; C;B;C1;C2
1650 IMAGE 2D.2D,2X,4D.2D,X,2(2D
     .2D,X)
1700 FOR J=1 TO M
1800 RAD
1900 P1=ATN((X(J)-(D2-D1)/TAN(A1
     ))/D2)-ATN(X(J)/D1)
2000 DEG
2100 T(J)=P*C*SIN(A1)/A*(C1*LOG(((
     X(J)-(D2-D1)/TAN(A1))^2+D2^
     2)/(X(J)^2+D1^2))+C2*P1)
2110 DISP USING 2120 ; J,X(J),T(
     J)
2120 IMAGE 2Z,2X,2(5D.2D,2X)
2130 NEXT J
2200 RETURN
```



SOUBROUTINE

for calculating magnetic field anomaly of a horizontal slab.

DISPLAY of constants C,B,C1,C2

DISPLAY of J, X(J), T(J) (slab-anomaly)

```
       SU    T       I1        D1      D2
    .00030056000   72.00   20.00  500
 00   31.00
 STRIKE L= 45 DEGR A1= 80 N= 3


  J   X(J)        T1(J)    T3(J)    T(J)
 01 -450.00      -7.24     -.09    -7.33
 02 -420.00      -7.07     -.51    -7.59
 03 -390.00      -7.13    -1.02    -8.16
 04 -360.00      -7.16    -1.63    -8.79
 05 -330.00      -7.15    -2.38    -9.53
 06 -300.00      -7.00    -3.38   -10.38
 07 -270.00      -6.94    -4.45   -11.39
 08 -240.00      -6.69    -5.84   -12.53
 09 -210.00      -6.29    -7.93   -14.22
 10 -180.00      -5.69   -10.75   -16.44
 11 -150.00      -4.78   -15.20   -19.98
 12 -120.00      -3.39   -23.72   -27.11
 13  -90.00      -1.19   -43.36   -44.54
 14  -60.00       2.62   -52.84   -50.22
 15  -30.00      10.50   -51.72   -41.23
 16    0.00      29.48   -49.74   -20.26
 17   30.00      39.22   -47.79    -8.57
 18   60.00      36.56   -46.23    -9.67
 19   90.00      33.96   -44.76   -10.80
 20  120.00      31.50   -43.43   -11.94
 21  150.00      29.32   -42.27   -12.95
 22  180.00      27.27   -41.11   -13.84
 23  210.00      25.47   -40.07   -14.61
 24  240.00      23.82   -39.09   -15.27
 25  270.00      22.33   -38.15   -15.82
 26  300.00      20.97   -37.24   -16.27
 27  330.00      19.72   -36.35   -16.63
 28  360.00      18.59   -35.48   -16.89
 29  390.00      17.54     0.00    17.54
 30  420.00      16.59     0.00    16.59
 31  450.00      15.71     0.00    15.71
```

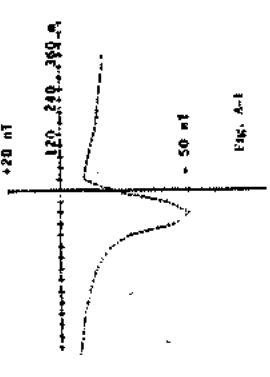


Fig. A-1

The anomaly of the earth's magnetic field over a non-magnetic gap in a magnetized slab is calcualted with the same equation applied twice to magnetic slabs that face each other. The program "MAGSTF" needs as an additional parameter "N" the width of the non-magnetic gap. Figs. A-2, A-3, A-4 show examples of different models.

The intensity of the magnetic lows is controlled by the size of SU, T, and D2 and by the inverse of D1 and the width of the nonmagnetic gap N. Most of the angles control mainly the shape of the anomaly, though a clear distinction between shape- and amplitude controlling parameters is not possible. Most important is the fact that these anomalies depend not only on the strike of the fracture zone but also on the magnetic latitude.

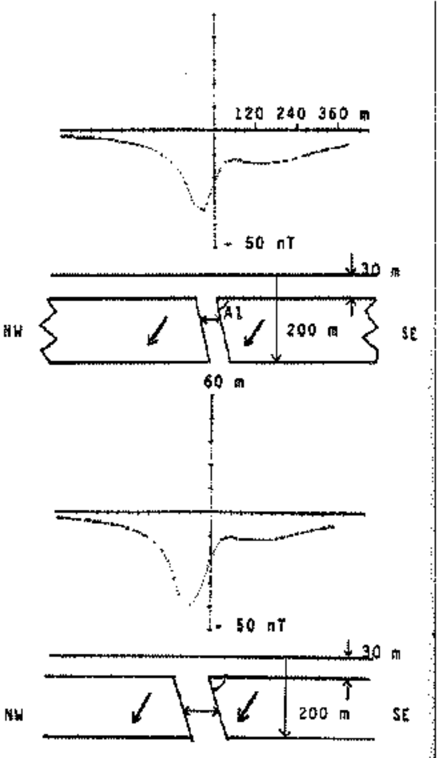
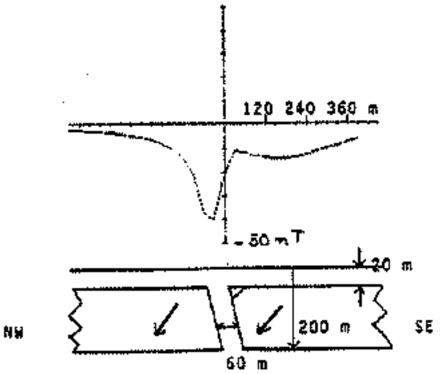


Fig. A-3

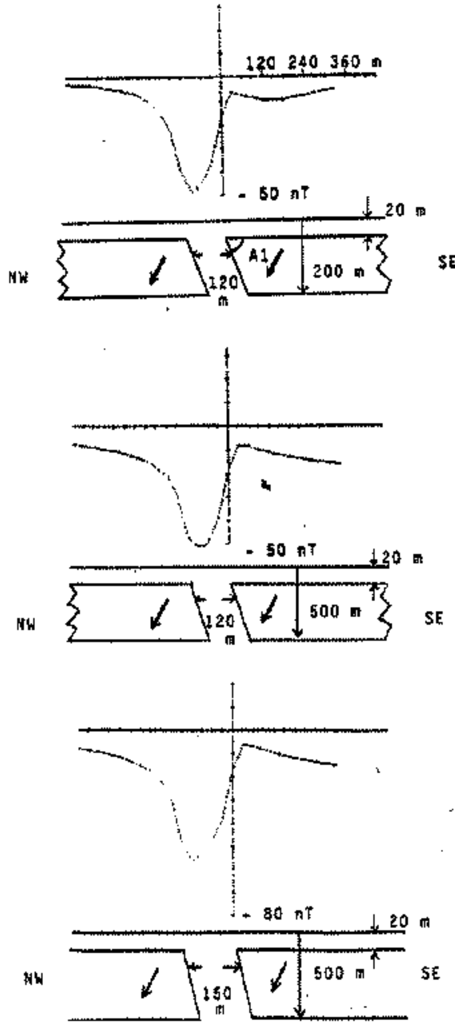
```
J X(J)      T1(J)  T2(J)   T(J)
01-450.00   -4.16  [illegible] [illegible]
02-420.00   -4.75   1.26   -2.49
03-390.00   -4.56  [illegible] -2.72
04-360.00   -4.79   1.63   -3.15
05-330.00   -5.02   1.44   -3.59
06-300.00   -5.27   1.15   -4.12
07-270.00   -5.52    .74   -4.79
08-240.00   -5.77    .14   -5.63
09-210.00   -5.99   -.75   -6.74
10-180.00   -6.13  -2.10   -8.23
11-150.00   -6.12  -4.27  -10.39
12-120.00   -5.80  -8.05  -13.86
13 -90.00   -4.84 -15.93  -20.76
14 -60.00   -2.41 -35.00  -37.41
15 -30.00    3.98 -43.38  -46.80
16   0.00   21.47 -42.41  -20.95
17  30.00   28.91 -40.02  -11.11
18  60.00   25.95 -37.73  -11.78
19  90.00   22.41 -35.55  -13.14
20 120.00   19.33 -33.42  -14.09
21 150.00   16.76 -31.24  -14.48
22 180.00   14.64 -28.97  -14.33
23 210.00   12.91 -26.62  -13.71
24 240.00   11.48 -24.21  -12.73
25 270.00   10.30 -21.83  -11.53
26 300.00    9.31 -19.56  -10.24
27 330.00    8.48 -17.46   -8.98
28 360.00    7.77 -15.59   -7.82
29 390.00    7.16 -13.95   -6.79
30 420.00    6.63   0.00    6.63
31 450.00    6.17   0.00    6.17
```



Model Parameters

SU : 0.0003 emu
T : 56,000 nT
I1: 72°
A1: 80°
L : 45°

Fig. A-2



Model Parameters

SU : 0.0003 emu
T : 56,000 nT
A1 : 80°
L : 45°

Fig. A-4

B. Model Curves for Geoelectrical Depth Soundings.

The geoelectrical field curves were interpreted first wit layer master curves to obtain starter model. This consists o number of layers, thicknesses and resistivities. Further re were accomplished with an interactive computer program that pl field points and the model curves, as shown in Figs. B-1 to B- First the half electrode spacing L/2 and apparent resistivity of the field curve is printed. The model appears in three co Column 1 indicates the number of the layer (Schicht), colum the layer thickness (Machtigk.), and column 3 shows the layer resistivity (Widerst.) The plot shows on a double logarith the field points and the model curve. The curve at the botto difference between field point and model curve. The standard deviation is calculated for all given field points and printe "Std-Abw." If, on the ground of visual comparison of the fie with the model curve or based on the standard deviation, the seems to be inadequate, a new model can be entered and the pr is repeated.

The best-fitting model is then plotted and the numerical are printed under "modellkurve."

Fig. A-1

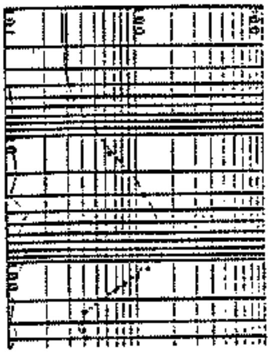
Meßdaten
TUFF FARM RAILROAD

N	L/2	RHOapp
1	4.00	32.4
2	6.00	35.2
3	9.00	50.5
4	14.00	64.1
5	20.00	[illegible]
6	30.00	115.1
7	40.00	114.2
8	60.00	166.0
9	90.00	158.0
10	100.00	147.0
11	115.00	122.9
12	130.00	104.8
13	150.00	[illegible]
14	170.00	[illegible]
15	200.00	51.0
16	250.00	39.6
17	300.00	37.4
18	350.00	39.5
19	400.00	41.5
20	500.00	46.5
21	600.00	50.4

Modell (3)
TUFF FARM RAILROAD

Schicht	Mächtigk.	Widerst.
1	5.00	33
2	15.00	650
3	170.00	17
4	0.00	500

Std-Abw .08379



Modellkurve (3)
TUFF FARM RAILROAD

N	L/2	RHOapp
1	1.00	28.0
2	1.33	[illegible]
3	1.78	[illegible]
4	2.37	[illegible]
5	3.16	[illegible]
6	4.22	31.[illegible]
7	5.62	35.4
8	7.50	42.0
9	10.00	[illegible]
10	13.34	[illegible]
11	17.78	83.[illegible]
12	23.71	103.[illegible]
13	31.62	[illegible]
14	42.17	140.[illegible]
15	56.23	149.9
16	74.99	145.9
17	100.00	126.7
18	133.35	96.0
19	177.83	64.[illegible]
20	237.14	42.[illegible]
21	316.23	35.4
22	421.70	29.7

Fig. A-2

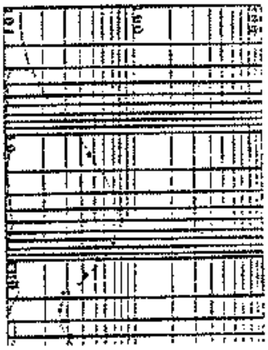
Meßdaten :
TUFF FARM MAG HIGH-3

N	L/2	RHOapp
1	3.00	[illegible]
2	4.00	16.[illegible]
3	5.00	[illegible]
4	7.00	[illegible]
5	10.00	[illegible]
6	15.00	[illegible]
7	20.00	[illegible]
8	30.00	[illegible]
9	40.00	[illegible]
10	50.00	[illegible]
11	75.00	[illegible]
12	100.00	[illegible]
13	130.00	41.0
14	180.00	[illegible]
15	250.00	[illegible]
16	300.00	[illegible]
17	400.00	[illegible]
18	500.00	[illegible]
19	600.00	40.6
20	700.00	47.2
21	800.00	54.1
22	900.00	62.0

Modell (1)
TUFF FARM MAG HIGH-3

Schicht	Mächtigk.	Widerst.
1	3.00	14
2	29.00	175
3	247.00	18
4	0.00	650

Std-Abw .05896



Modellkurve (1)
TUFF FARM MAG HIGH-3

N	L/2	RHOapp
1	1.00	[illegible]
2	1.33	[illegible]
3	1.78	[illegible]
4	2.37	[illegible]
5	3.16	16.4
6	4.22	[illegible]
7	5.62	23.[illegible]
8	7.50	[illegible]
9	10.00	[illegible]
10	13.34	44.[illegible]
11	17.78	[illegible]
12	23.71	[illegible]
13	31.62	70.[illegible]
14	42.17	[illegible]
15	56.23	[illegible]
16	74.99	[illegible]
17	100.00	57.[illegible]
18	133.35	47.[illegible]
19	177.83	[illegible]
20	237.14	26.2
21	316.23	[illegible]
22	421.70	[illegible]
23	562.34	38.1
24	749.89	42.4

Meßdaten :
TUFF FARM MAG LOW-2

N	L/2	RHOapp
1	3.00	16.7
2	4.00	[illegible]
3	5.00	[illegible]
4	7.00	21.1
5	10.00	[illegible]
6	15.00	[illegible]
7	20.00	[illegible]
8	30.00	[illegible]
9	40.00	[illegible]
10	60.00	[illegible]
11	80.00	[illegible]
12	100.00	[illegible]
13	150.00	[illegible]
14	200.00	[illegible]
15	300.00	[illegible]
16	400.00	[illegible]
17	500.00	44.0
18	600.00	[illegible]
19	700.00	[illegible]
20	800.00	[illegible]

Modell (9)
TUFF FARM MAG LOW-1

Schicht	Mächtigk.	Widerst.
1	2.90	10
2	14.50	200
3	173.90	[illegible]
4	0.00	[illegible]

Std-Abw .06678

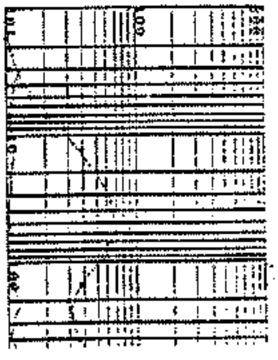


Fig A-3

Modellkurve (1)
TUFF FARM MAG LOW-3

N	L/2	RHOapp
1	1.00	[illegible]
2	1.33	[illegible]
3	1.78	[illegible]
4	2.37	[illegible]
5	3.16	[illegible]
6	4.22	[illegible]
7	5.62	[illegible]
8	7.50	[illegible]
9	10.00	[illegible]
10	13.34	[illegible]
11	17.78	[illegible]
12	23.71	[illegible]
13	31.62	[illegible]
14	42.17	[illegible]
15	56.23	[illegible]
16	74.99	[illegible]
17	100.00	[illegible]
18	133.35	[illegible]
19	177.83	[illegible]
20	237.14	[illegible]
21	316.23	[illegible]
22	421.70	[illegible]
23	562.34	[illegible]

Fig. A-4

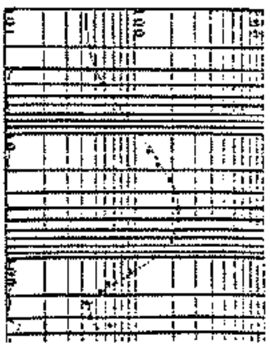
Meßdaten
TUFF FARM APP 18-86

N	L/2	RHOapp
1	3.00	43.6
2	4.00	[illegible]
3	5.00	[illegible]
4	7.00	[illegible]
5	10.00	[illegible]
6	14.00	[illegible]
7	19.00	[illegible]
8	[illegible]	[illegible]
9	[illegible]	[illegible]
10	[illegible]	[illegible]
11	[illegible]	[illegible]
12	[illegible]	[illegible]
13	100.00	[illegible]
14	130.00	[illegible]
15	[illegible]	[illegible]
16	[illegible]	[illegible]
17	[illegible]	[illegible]
18	[illegible]	[illegible]
19	[illegible]	[illegible]
20	[illegible]	[illegible]
21	[illegible]	[illegible]

TUFF FARM APP 18-86

Schicht	Mächtigk.	Widerst.
1	3.00	43
2	29.00	400
3	165.00	[illegible]
4	0.00	9999999

Std-Abw .08452



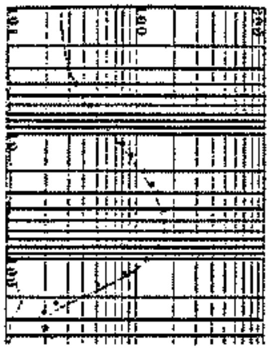
Modellkurve (1)
TUFF FARM APP 18-86

N	L/2	RHOapp
1	1.00	43.3
2	1.33	[illegible]
3	1.78	[illegible]
4	2.37	47.1
5	3.16	51.4
6	4.22	[illegible]
7	5.62	[illegible]
8	7.50	[illegible]
9	10.00	[illegible]
10	13.34	[illegible]
11	17.78	[illegible]
12	23.71	[illegible]
13	31.62	[illegible]
14	42.17	[illegible]
15	56.23	[illegible]
16	74.99	[illegible]
17	100.00	[illegible]
18	133.35	[illegible]
19	177.83	60.1
20	237.14	[illegible]
21	316.23	[illegible]
22	421.70	[illegible]

Modell (8) :
TURF FARM APR 25-86

Schicht	Mächtigk.	Widerst.
1	3.50	26
2	24.00	440
3	165.00	8
4	0.00	999999

Std-Abw .09670



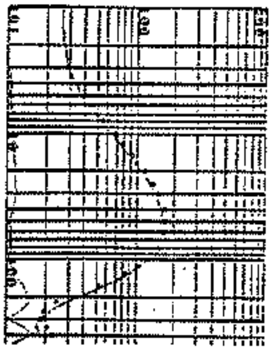
Modellkurve (8)
TURF FARM APR 25-86

N	L/2	RHOapp
1	1.00	26.1
2	1.33	26.3
3	1.78	26.8
4	2.37	27.9
5	3.16	30.0
6	4.22	33.4
7	5.62	40.6
8	7.50	50.7
9	10.00	64.5
10	13.34	81.5
11	17.78	101.5
12	23.71	123.5
13	31.62	145.0
14	42.17	161.7
15	56.23	167.7
16	74.99	157.2
17	100.00	126.0
18	133.35	85.9
19	177.83	51.1
20	237.14	27.1
21	316.23	18.8
22	421.70	20.5

Modell (4) :
TURF FARM APR 25-86

Schicht	Mächtigk.	Widerst.
1	3.50	26
2	24.00	430
3	175.00	8
4	0.00	999999

Std-Abw .09476



Meßdaten :
TURF FARM APR 25-86

N	L/2	RHOapp
1	3.00	29.3
2	4.00	34.9
3	5.00	38.4
4	6.00	44.3
5	8.00	55.9
6	10.00	67.6
7	12.00	79.2
8	15.00	96.6
9	20.00	117.6
10	25.00	136.6
11	30.00	152.9
12	40.00	167.0
13	50.00	167.7
14	60.00	169.6
15	80.00	152.0
16	100.00	122.9
17	130.00	83.0
18	160.00	51.4
19	220.00	24.3
20	260.00	19.7
21	300.00	16.4
22	350.00	20.6
23	400.00	22.5
24	500.00	26.7

Fig. B-5

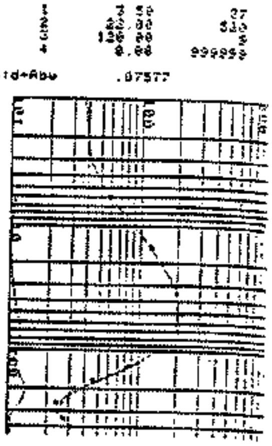
Meßdaten :
TURF FARM MAY 16-86

N	L/2	RHOapp
1	5.00	50.0
2	6.00	[illegible]
3	10.00	50.1
4	15.00	121.0
5	20.00	150.0
6	30.00	151.0
7	50.00	230.0
8	70.00	200.8
9	100.00	140.0
10	130.00	85.0
11	170.00	45.4
12	200.00	[illegible]
13	260.00	[illegible]
14	300.00	[illegible]
15	350.00	[illegible]
16	400.00	[illegible]
17	500.00	[illegible]

Modell (6) :
TURF FARM MAY 16-86

Schicht	Mächtigk.	Widerst.
1	3.50	27
2	22.00	530
3	126.00	5
4	0.00	999999

Std-Abw .07577



Modellkurve (5) :
TURF FARM MAY 16-86

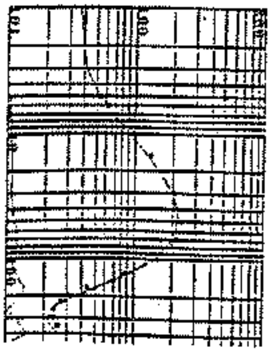
N	L/2	RHOapp
1	1.00	37.2
2	1.33	[illegible]
3	1.78	[illegible]
4	2.37	[illegible]
5	3.16	[illegible]
6	4.22	[illegible]
7	5.62	[illegible]
8	7.50	70.8
9	10.00	89.8
10	13.34	112.0
11	17.78	138.0
12	23.71	165.4
13	31.62	198.5
14	42.17	207.1
15	56.23	207.2
16	74.99	161.2
17	100.00	142.6
18	133.35	91.6
19	177.83	58.2
20	237.14	28.8
21	316.23	25.1
22	421.70	31.0

Fig. B-6

Modell (9) :
TURF FARM JUNE 4-86

Schicht	Mächtigk.	Widerst.
1	3.50	37
2	16.00	695
3	70.00	4
4	0.00	999999

Std-Abw .09496



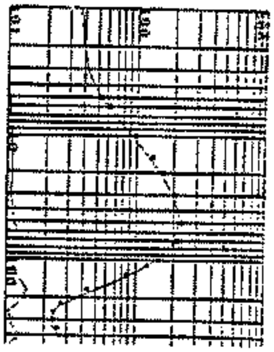
Modellkurve (9) :
TURF FARM JUNE 4-86

N	L/2	RHOapp
1	1.00	37.2
2	1.33	37.5
3	1.78	38.2
4	2.37	39.7
5	3.16	42.7
6	4.22	48.3
7	5.62	57.3
8	7.50	72.5
9	10.00	92.1
10	13.34	116.3
11	17.78	144.2
12	23.71	173.6
13	31.62	200.4
14	42.17	217.4
15	56.23	216.3
16	74.99	191.2
17	100.00	144.5
18	133.35	98.0
19	177.83	46.[illegible]
20	237.14	24.9
21	316.23	21.1
22	421.70	26.0

Modell (11) :
TURF FARM JUNE 4-86

Schicht	Mächtigk.	Widerst.
1	3.50	37
2	16.00	695
3	60.00	4
4	0.00	999999

Std-Abw .08815



Meßdaten :
TURF FARM JUNE 4-86

N	L/2	RHOapp
1	5.00	32.8
2	6.00	[illegible]
3	10.00	[illegible]
4	15.00	[illegible]
5	20.00	163.[illegible]
6	30.00	203.[illegible]
7	50.00	[illegible]
8	70.00	[illegible]
9	100.00	150.[illegible]
10	130.00	86.[illegible]
11	170.00	43.6
12	200.00	31.1
13	220.00	26.6
14	260.00	[illegible]
15	300.00	[illegible]
16	350.00	[illegible]
17	400.00	30.2
18	500.00	37.6

Fig B-7

C. Least Squares Linear Analysis of the Regional Gravity Field.

The regional gravity field was estimated with a least squares method applied to the Bouguer Gravity. It was assumed that the regional field can be represented by a linear function in two dimensions which is a plane of the equation:

$$G = C_0 + C_1 \cdot X + C_2 \cdot Y$$

where G: Observed Bouguer Anomaly

X,Y: horizontal and vertical coordinates of the gravity station

The constants C_0, C_1, and C_2 are determined with the following matrix equation (Davis, J.C., 1973, p. 324):

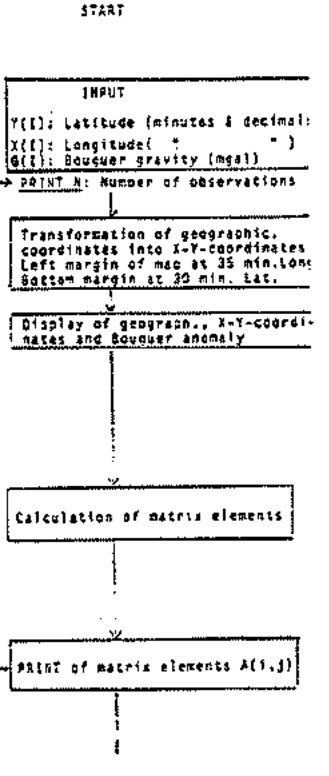
$$\begin{bmatrix} N & \Sigma X & \Sigma Y \\ \Sigma X & \Sigma X^2 & \Sigma X \cdot Y \\ \Sigma Y & \Sigma X \cdot Y & \Sigma Y^2 \end{bmatrix} \cdot \begin{bmatrix} C_0 \\ C_1 \\ C_2 \end{bmatrix} = \begin{bmatrix} \Sigma G \\ \Sigma X \cdot G \\ \Sigma Y \cdot G \end{bmatrix}$$

N is the numberof observations and the summation sign stands for the summation over all observations from 1 to n.

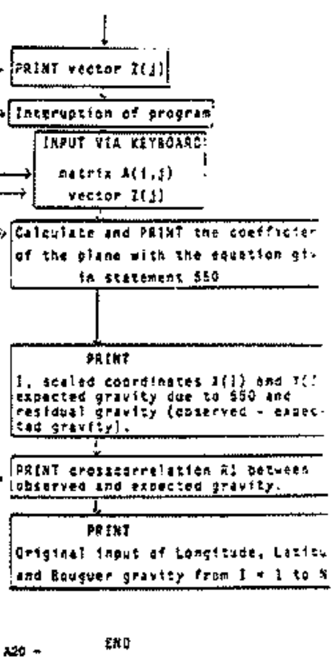
The coefficients C, C, and C are determined from an inversion of the matrix equation which is easily accomplished with the "Matrix ROM" on the HP-85 personal computer. The program "TRD-1" converts latitude and longitude into carthesian coordinates. It prints the matrix and vector elements and the coefficients for the equation of the plane. Finally it gives out a list of the coordinates X(I) and Y(I) for each observation point I and the regional (expected gravity G(I)) and the residual gravity RES (I), which is the local anomaly.

Program "TAD-1"

```
10 REM
20 REM
45 DIM X(300),Y(300),G(300),G1(
   300)
50 DIM A(2,2),Z(2),C(2)
55 DIM X1(300),Y1(300)
60 DISP "INPUT N:NUMBER OF DATA
   SETS"
90 DISP "INPUT: Y(I),X(I),G(I)"
99 FOR I=1 TO 100
110 INPUT Y(I),X(I),G(I)
115 IF Y(I)<0 THEN GOTO 122
120 NEXT I
122 N=I-1
125 PRINT "N=";N
130 ! PRINT "  X(I)   Y(I)   G(I)
   "
140 DISP "  X(I) Y(I) G(I) "
150 FOR I=1 TO N
153 X1(I)=1.44(35-X(I))
155 Y1(I)=1.84*(Y(I)-30)
160 ! PRINT USING 180 ; X(I),Y(I
   160 IF Y(I)<0  THEN GO TO 12
   2
170 DISP USING 180 ; X(I),Y(I),X
   1(I),Y1(I),G(I)
180 IMAGE 5(3D.2D)
190 NEXT I
200 P2=0 @ P3=0 @ P4=0
210 P5=0 @ P6=0 @ P7=0
215 P8=0 @ P9=0
225 Q1=0 @ Q2=0 @ Q3=0
230 REM
240 FOR I=1 TO N
250 P2=P2+X1(I)
255 DISP P2
260 P3=P3+Y1(I)
270 P4=P4+X1(I)*X1(I)
290 P5=P5+X1(I)*Y1(I)
295 P6=P6+Y1(I)*Y1(I)
300 P7=P7+G(I)
310 P8=P8+G(I)*X1(I)
320 P9=P9+G(I)*Y1(I)
325 Q1=Q1+G(I)*G(I)
330 NEXT I
340 A(0,0)=N @ A(0,1)=P2 @ A(0,2
   )=P3
350 A(1,0)=P2 @ A(1,1)=P4 @ A(1,
   2)=P5
360 A(2,0)=P3 @ A(2,1)=P5 @ A(2,
   2)=P6
370 Z(0)=P7 @ Z(1)=P8 @ Z(2)=P9
372 PRINT "MATRIX ELEMENTS"
373 PRINT
375 FOR J=0 TO 2
380 FOR I=0 TO 2
390 ! DISP A(J,I)
395 PRINT "A(";J;",";I;")=";A(J,
   I)
400 NEXT I
```



```
410 NEXT J
415 PRINT
416 ! PRINT "Z(K),K=1 TO 3"
417 ! DISP "Z(I),I=1 TO 3"
420 FOR I=0 TO 2
430 PRINT "Z(";I;")=";Z(I)
431 ! DISP Z(I)
440 NEXT I
455 DISP
460 MAT INPUT A
470 MAT DISP A
480 DISP
490 MAT INPUT Z
500 MAT DISP Z,
510 PRINT
515 PRINT "COEFFICIENTS: C(0),C(
   1),C(2) FOR EQ. OF PLANE"
520 MAT C=SYS(A,Z)
530 MAT PRINT C;
532 PRINT
535 PRINT
536 PRINT "I   X1(I)   Y1(I)   G1(I
   )    RES(I) "
537 PRINT
540 FOR I=1 TO N
550 G1(I)=C(0)+C(1)*X1(I)+C(2)*Y
   1(I)
570 PRINT USING 576 ; I,2*X1(I),
   2*Y1(I),G1(I),G(I)-G1(I)
576 IMAGE 2Z,X,4(3D.2D,X)
577 Q2=Q2+G1(I)
579 Q3=Q3+G1(I)*G1(I)
590 NEXT I
585 R1=SQR((Q3-Q2*Q2/N)/(Q1-P7*P
   7/N))
586 PRINT
588 PRINT "R1=";R1
590 PRINT
595 PRINT " I    X(I)    Y(I)    G(
   I) "
596 PRINT
600 FOR I=1 TO N
610 PRINT USING 620 ; I,X(I),Y(I
   ),G(I)
620 IMAGE 2Z,X,3(3D.2D,2X)
650 NEXT I
660 END
```



```
N= 92
MATRIX ELEMENTS

A( 0 , 0 )= 92
A( 0 , 1 )= 578.984
A( 0 , 2 )= 387.6408
A( 1 , 0 )= 578.984
A( 1 , 1 )= 3706.513736
A( 1 , 2 )= 2327.0371136
A( 2 , 0 )= 387.6408
A( 2 , 1 )= 2327.0371136
A( 2 , 2 )= 1612.6993764

Z( 0 )=-1929.51
Z( 1 )=-12105.03829
Z( 2 )=-7937.344176


COEFFICIENTS: C(0),C(1),C(2) FOR
 EQ. OF PLANE
-21.0787352801
  .255002649105
- .406650621056

I  X1(I)  Y1(I)   G1(I)    RES(I)

01  16.24  15.19  -22.19    4.40
02  12.80   9.20  -21.23    -.20
03  10.86  13.99  -22.36     .17
04  11.14  10.71  -22.38    1.33
05   7.95  13.65  -22.79     .17
06   7.53  17.88  -23.54   -1.35
07  11.48    .37  -19.62    -.36
08  10.92  15.38  -22.46     .23
09   9.24  15.93  -23.28    -.05
10   8.48  10.41  -22.07    -.52
11   8.28   7.43  -21.61   -1.34
12   7.56  17.98  -23.54   -1.71
13   7.56   4.34  -20.95    1.52
14  16.32   4.42  -19.76    -.17
15  15.68   8.83  -20.77    -.74
16  14.20   8.45  -20.89    -.37
17  11.48    .37  -19.62    -.38
18  12.68    .74  -19.54    -.25
19  11.20   5.15  -20.53     .45
20  10.92   6.62  -20.95    1.07
21  13.44   7.36  -20.77    -.33
22  14.98   8.83  -21.98    -.33
23  11.20   9.37  -21.88     .75
24   9.38  11.41  -22.89     .44
25   7.56   9.20  -21.94    -.88
26  13.38   7.29  -20.74    -.34
27  13.82   7.21  -20.80    -.18
```

```
28  12.74   7.18  -20.83  [illegible]
29  12.46   7.07  -20.85  [illegible]
30  12.13   6.39  -20.97  [illegible]
31  11.81   6.92  -20.95  [illegible]
32  11.56   6.81  -20.91  [illegible]
33  11.34   6.77  -20.94  [illegible]
34  13.34   7.36  -20.75  [illegible]
35  13.94   7.43  -20.72  [illegible]
36  14.14   7.51  -20.77  [illegible]
37  14.14   7.80  -20.84  [illegible]
38  14.14   8.13  -20.98  [illegible]
39  14.14   8.50  -20.91  [illegible]
40  11.34   6.59  -20.99  [illegible]
41  11.49   6.43  -20.85  [illegible]
42  11.92   5.73  -20.81  [illegible]
43  11.70   5.19  -20.76  [illegible]
44  11.32   5.11  -20.74  [illegible]
45  12.01   5.35  -20.63  [illegible]
46  12.15   5.79  -20.53  [illegible]
47  12.23   5.67  -20.59  [illegible]
48  10.93   5.91  -20.55  [illegible]
49  11.03   5.92  [illegible]  [illegible]
50  11.12   5.55  -20.61  [illegible]
51  11.29   5.93  -20.61  [illegible]
52  11.25   4.99  -20.53  [illegible]
53  11.31   4.75  -20.58  [illegible]
54  11.34   4.64  -20.49  [illegible]
55  11.40   4.45  -20.49  [illegible]
56  11.51   4.23  -20.40  [illegible]
57  11.56   4.08  -20.36  [illegible]
58  11.62   3.93  -20.30  [illegible]
59  14.28   3.76  -20.07  [illegible]
60  14.25   4.13  -20.53  [illegible]
61  14.23   9.93  -20.84  [illegible]
62  14.09   9.65  -20.95  [illegible]
63  13.86   9.21  -21.07  [illegible]
64  13.32   9.92  -21.10  [illegible]
65  13.24   9.89  -21.15  [illegible]
66  12.89   9.24  -21.34  [illegible]
67  12.46   9.27  -21.39  [illegible]
68  12.65   9.38  -21.21  [illegible]
69  12.54   8.76  -21.18  [illegible]
70  12.38   8.59  -21.13  [illegible]
71  12.26   8.17  -21.10  [illegible]
72  13.12   8.28  -21.06  [illegible]
73  13.07   7.51  -20.98  [illegible]
74  14.14   7.29  -20.94  [illegible]
75  14.42   9.50  -20.91  [illegible]
76  14.79   9.50  -20.87  [illegible]
77  [illegible]
78  [illegible]
79  [illegible]
80  15.80   9.53  -20.83  [illegible]
81  15.29   9.61  -20.81  [illegible]
82  15.31   9.68  -20.79  [illegible]
83  15.11   9.72  -20.77  [illegible]
84  15.06   9.50  -20.75  [illegible]
85  15.03   9.43  -20.74  [illegible]
86  15.04   7.91  -20.67  [illegible]
87  15.01   7.62  -20.59  [illegible]
88  14.93   7.83  [illegible]  [illegible]
89  14.39   6.52  -20.42  [illegible]
90  14.95   6.37  -20.37  [illegible]
91  14.75   6.11  -20.32  [illegible]
92  14.73   5.96  -20.72  [illegible]
```

```
R1= .6355669322696

 I    X(I)    Y(I)    G(I)

01   29.30   34.40   -17.79
02   30.43   33.50   -22.14
03   31.12   33.97   -22.09
04   31.02   34.54   -21.65
05   32.16   33.71   -22.95
06   32.31   34.64   -24.79
07   30.90   30.10   -19.98
08   31.10   33.80   -22.35
09   31.70   34.50   -23.33
10   33.80   33.83   -22.49
11   32.40   32.02   [illegible]
12   31.30   34.64   [illegible]
13   32.30   31.10   -13.43
14   29.10   31.20   -20.49
15   29.40   33.40   -20.07
16   29.90   33.30   -21.26
17   30.90   30.10   -20.09
18   30.50   30.20   [illegible]
19   31.60   31.40   [illegible]
20   31.10   31.30   -19.80
21   30.20   32.90   -21.10
22   30.90   32.40   [illegible]
23   31.80   32.50   -20.76
24   31.50   33.10   -21.53
25   32.30   32.70   -21.94
26   30.22   31.93   -21.01
27   30.35   31.95   -20.98
28   30.45   31.95   -21.30
29   30.55   31.92   -21.12
30   30.66   31.90   -20.37
31   30.76   31.89   -19.85
32   30.87   31.89   -20.71
33   30.95   31.84   -20.47
34   30.13   32.00   -21.21
35   30.02   32.02   -21.25
36   29.95   32.04   [illegible]
37   29.95   32.12   -21.52
38   29.95   32.21   -21.55
39   29.95   32.31   -21.10
40   30.95   31.79   -20.54
41   30.90   31.76   -20.59
42   30.85   31.73   -20.51
43   30.80   31.68   -20.56
44   30.78   31.66   -20.49
45   30.71   31.62   -20.47
46   30.66   31.57   -20.18
47   30.61   31.54   -20.05
48   31.19   31.59   -19.98
49   31.06   31.59   -20.02
50   31.03   31.43   -20.19
51   31.00   31.38   -20.14
52   30.98   31.33   -19.93
53   30.96   31.29   -19.85
54   30.95   31.26   -19.69
55   30.33   31.21   -19.40
56   30.39   31.15   -19.55
57   30.37   31.11   -19.75
58   30.05   31.04   -19.62
59   29.93   32.00   -21.20
60   29.91   31.95   -21.12
61   29.90   31.91   -21.06
62   29.97   32.35   -21.41
63   30.05   32.42   -21.37
64   30.17   32.45   -21.13
```

```
65   30.27   32.47   [illegible]
66   30.43   32.51   -21.66
67   30.55   32.53   -21.45
68   30.48   32.44   -21.65
69   30.52   32.38   -21.63
70   [illegible]   32.22   [illegible]
71   [illegible]   32.14   -21.54
[illegible]
```

FEASIBILITY OF THE DEVELOPMENT OF A WATER DATA SYSTEM IN RHODE ISLAND

by

Todd Chaplin

A thesis submitted in Partial Fullfillment
of the requirements for the Degree of
Master of Science
in
Civil and Environmental Engineering

University of Rhode Island
1985

Master of Science Thesis

of

Todd Chaplin

Approved:

Thesis Committee

Major Professor Calvin P. Poon

Leon T. Thiem

David M. Shaw

A. A. Michel

Dean of the Graduate School

University of Rhode Island

1985

ABSTRACT

Presently there are a number of state and federal agencies collecting water resource data. Often these efforts overlap or the lack of interagency communication produces holes in the database where none should exist. The goals of this feasibility study are to determine what steps by state and federal agencies would be required to establish a data information system that could be shared by researchers, special-interest groups and the public, as well as the agencies involved. The current data needs of the agencies and the advantages of an information system will also be addressed.

Acknowledgement

I wish to thank Dr. Calvin P.C. Poon for his guidance and advice as my major professor these past two years. I would also like to thank my parents and my wife for their support during this time.

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Introduction

Presently there are a number of state and federal agencies collecting water resource data within the state of Rhode Island. Often these efforts overlap or the lack of interagency communication produces holes in the database where none should exist. Access to this data by researchers, special-interest groups, the public, and often the collecting agency itself, is constrained by the prohibitive time and costs required to obtain this data. This research investigates the feasibility of establishing a water data information system for the state of Rhode Island.

Recent increases in public awareness about our water quality and water resources have stirred new activity in the monitoring and protection of our state's water resources. More funds for research and sampling have been promised as a means to safeguard our water resources. However, much of the historical data already collected has not been utilized to its potential and the findings resulting from past studies have not always been adequately disseminated.[1] In fact, many potential users of previously collected data are completely unaware of the vast amounts of data existing in the files of local, State and federal agencies. Because of this lack of communication and exchange between government agencies, industry, and researchers, serious water resource problems may not be given the research attention needed.

Environmental engineers, water resource managers, community planners, state and local governments, and environmental special-interest groups all require accurate and timely data in order to make knowledgeable decisions about projects or actions within their bounds. Various water-user groups all compete for water in different quantities and qualities. In order to ensure that these demands are met in the best possible manner, large volumes of data must be collected, stored, and analyzed, with the results being readily accessible to those who need them.

There is currently no efficient and easily accessible conduit available to obtain this information in Rhode Island. This points out the need for a statewide water data information system which would serve as the central base for Rhode Island's water-using groups. Agencies and researchers could input data, statistically manipulate or reorganize data, and then any authorized user would have easy access to retrieve this data according to their own specific needs. This would allow the sharing of data between agencies as well as facilitating the acquisition of data by researchers and other user groups. This research investigated the feasibility of establishing a water data information system for the state of Rhode Island.

Related Research

Until recently, there has been little interest in establishing a comprehensive data system for disseminating the information collected by state and federal agencies, researchers, and others throughout the state. Large-scale, national data systems have existed for many years, but have not been utilized to their full potential. There presently exists a National Water Use Data System operated by the United States Geological Survey.[2] This inventory style system was established to monitor the quantity of water used in each state and to provide an overview of water use throughout the country. Unfortunately, this system has not been utilized by more than a few states and has since fallen into a state of "non-use." The downfall of the system may have been its specificity to water withdrawal and return records. While this data is important, especially in arid regions of the country, most states are more concerned with specific water quality data in addition to quantity data. Specific forms for data entry also included a large amount of descriptive information which made for cumbersome filing and was of little interest to the local agency.

The United States Geological Survey also maintains the Water Data Storage and Retrieval System, WATSTORE, which utilizes modern data processing techniques to manage the survey's stream and groundwater monitoring program.[3] This system was established in 1971 to provide for more efficient data-releasing activities. This system collects data at 16,000 stream gaging stations, thousands of surface water locations, 30,000 water-level observation wells, and 12,500 groundwater quality wells.[3] This huge database consists of quantity and quality parameters from across the entire country and can be accessed at any district office of the Geological Survey. While this system contains a huge volume of water resource data, it is often difficult, time consuming, and expensive for outside users to acquire this data. All information requests are relayed to a national computer in Virginia where the request is processed and returned to the district office. This can require a minimum turn around time of four hours even for agency personnel.[4] If a wide range of data is required, the information can be requested in writing and takes many days or even weeks to be obtained. This system is not adequate for outside resarchers who need timely data before work can proceed or when information is needed on a regular basis. The U.S. Geological Survey does not consider itself a public information data service and discourages use as such by high cost and long delays. The huge scale of this system also can not meet the specific individual requirements of each state agency, resarcher, or other water-using group.

In response to the generalized nature of large federal information systems, many states are now looking to develop systems to meet their own localized and specific needs. Due to differences in water data requirements, scale of resources and resource development, and differences in available computer hardware, no previously developed system is compatible with the needs of every state.

Planners in the state of Virginia established an information system based on the format of the national system, but more tailored to their own needs.[7] They have realized the importance of a more comprehensive system and are now upgrading their data processing ability. Six other states, Arizona, Illinois, Minnesota, New York, Tennessee, and Washington, have all recently established a geographic information system using commercially obtainable software packages with mapping and overlay capability as well as data management.[6] These systems and others all utilize commercial software packages and minicomputers to handle their own specific environmental resources.

The state of Connecticut began developing an information system along the same lines as the National Water User Data System, but also tailored to their own needs. Initially, their system set out to follow the national guidelines, reporting water withdrawal and return rates for surface water bodies in Connecticut. This system required the filling out of numerous hardcopy forms which were then logged into the system. The Department of Environmental Protection soon realized that a large effort was being made to file these forms, with very little information that was of consequence to the state being retrieved.[13]

At this point in development, it was realized that an original system would better suit the needs of the state of Connecticut. A SAS/Cobol software package was installed on a Honeywell minicomputer to manage the state's public water supply. This system was not user-friendly and it was eventually replaced by the FOCUS software package for database management on a Data General mainframe computer.

The Connecticut system now manages groundwater supplies, public water supplies, and public utilities. Information concerning service connections, population served, and types of users (industrial, residential or commercial) are all maintained on the system. They are attempting to build up more and larger data sets for use with this system, while at the same time investigating the use of the ARC/INFO geographical information system. If this system is obtained it will not be functional for at least two to three years.[13] In the meantime, the FOCUS system will be further developed due to its compatibility with the ARC/INFO software through a changeover using SAS. This development of a working system now, with the potential for merging with other systems in the future, is a desirable feature of the Connecticut system and could be applicable for Rhode Island's information system needs.

The University of Rhode Island was in the process of developing a water-use data system for Rhode Island in 1980.[8] This project was tailored after the national water user system and consisted of an inventory of water withdrawal and discharge to receiving waters. This project had no quality data or other parameters and numerous water users were left out of the system. This project went uncompleted when funding was discontinued and the system is of little use today.

The Rhode Island Department of Environmental Management is currently investigating the possibility of establishing a department-wide geographic information system capable of storing and manipulating all data collected by the department.[6] They have been considering the software package currently in use in the previously mentioned state-wide systems, capable of map digitizing and production, data entry and management, statistical functions, and output displays in a variety of charts and graphs. The agency has realized the need for a system of this type and would like to use the groundwater monitoring program as a pilot study of this system. However, a minimal configuration of this type is expected to cost more than $226,000, which may delay the start of this type of system.[6] Cooperation between agencies, especially the

Department of Environmental Management, could lead to a coordinated statewide information system incorporating all water-data users.

Methodology

In order to determine the feasibility of establishing a water-use data system in Rhode Island, this study involved the following steps:

1) A determination of the water data parameters presently being collected by the major water resource agencies in Rhode Island.

2) A list of all water-use data parameters that would be useful to all those who manage water resources was compiled. This "wish list" includes data parameters currently collected but not readily available to all user groups as well as data which is not presently collected but would be useful to certain water-user groups. This may also include statistical analysis of data or the display of data in forms different from that which it was collected, in order to facilitate monitoring or to readily identify trends and trouble spots.

3) The findings of the above two studies will help in the development of an information system which will best meet the needs of all those who require this information. Interviews and discussion with agency staff and potential users will help coordinate the structuring of the data files within the computer software being designed in conjunction with this study.

4) Recommendations will be made as to the amount of input, cooperation, and coordination of all those involved

which will be necessary to develop an information system which will be useful to everyone. This will be demonstrated by the development of a small pilot information system using data from various agencies, showing the storage, data manipulation, and retrieval capabilities of the proposed system. This study has examples of the various functions and graphic output which the fully developed information system will be capable of, demonstrating the approval ability to manage our water resources.

5) Based on agency cooperation and enthusiasm, the success of a demonstration project, and the potential for the facilitated storage, manipulation, and retrieval of large volumes of data, the feasibility of creating a fully operational on-line water data information system in Rhode Island will be determined.

Data Consideration

Environmental managers are discovering that manual methods of data management are no longer capable of handling the enormous volume of data which is collected, manipulated, stored, and retrieved. Filedrawers, notebooks, and other hardcopy records become inadequate as data sets grow. Federal, state, and local guidelines and regulations require that data be readily available when an environmental resources issue comes to the forefront. State-of-the-art computerized data systems are designed to store and retrieve vast amounts of information in virtualy any form. The major advantage of a well-designed information system is that the data can be entered only once and stored, but may be used within several different environmental functions and by many different interested users.[9]

The development of an information system must include an analysis of the data needs of the users. Judgement must be made as to how much information will be collected, how much accuracy is needed, whether to consider a certain class of information, and the best method to file and retrieve this information. The following rules of thumb were established by Cambell[10] and are applicable here to aid in making these judgements.

1) <u>The system will contain no information for which there is no known or anticipated use</u>. A serious problem of

information systems is data congestion. The input of data to the system just because it can be easily collected or has been historically recorded is not always a wise decision. It must always be asked, "Is this information useful?" Data always collected in the past may not be relevant to today's problems and may be better off left out of the system. The data must be organized and for a specific purpose.

2) <u>Only as much of a particular type of information as needed should be put into the system</u>. A second problem of information is overcollection of a specific type of data. It is more costly and time consuming to collect as much data as possible when a smaller sample may be adequate for a given purpose. This is an arguably complex concept and exactly how much data should be collected is a difficult decision. Since data collection is often the most expensive element of an information system, it makes sense to collect only that data which is necessary.

3) <u>The way information is used will determine the way it is put into the system</u>. This rule simply means that information which is most useful in map form should be input and stored as maps, while data which will be recalled as numbers should be in-put as numbers, and so on. Some data sets may be useful in a variety of forms and therefore should be input as such.

4) The frequency with which data is needed will determine its position in the data file. Data which is used frequently on a regular basis should be stored in a manner so that they can be recalled rapidly.

5) New data should be input as often as necessary. Any information system is only as good as the data which is input to the system. Up-to-date data must be entered as soon as it is available in order that the system provide the best possible output.

6) The system should perform just as effectively in the future as at present. The structuring of data files must allow for the expansion of the system if new data sets are warranted.

7) A new information system should be coordinated as fully as possible with existing systems. If two or more agencies require the same information it is senseless to duplicate the collection and analysis effort. Historically, cooperation between different users has not been common, but with new information systems often requiring expensive computer hardware, the era of cooperation may be upon us. This type of cooperation usually requires adjustments by all those involved, but can also result in the gathering of much more information with less effort and a new perspective on an agency's problem. Coordination seems always to be worth many times the effort.

Hardware

In order for the various users of the Rhode Island Water Data User System to share their own data sets with others and to communicate on a regular basis, a centralized computer system should be available. The system expedites information retrieval and analysis using cross referenced data sets collected from the participating users and will allow for easier dissemination of this information to other agencies, researchers, or special-interest groups. This facilitated means of collecting and disseminating water data will minimize the effort needed when making planning and policy decisions. A computer system capable of performing the many functions required by the various users is essential for the smooth handling of large amounts of environmental data.

There are three major computer systems available at the University of Rhode Island to meet the needs of a water data information system. The Academic Computer Center has a National Advanced System (NAS) 7000N mainframe which uses the IBM System 370 OS/MVS SP1.1 operating system with JES2 to provide batch processing services and a full function timesharing services through the Timesharing Option (TSO). Four Prime 850 minicomputers are used for interactive research and instructional computing through the Primos operating system.[10] A VAX 11/780 minicomputer with the VAX/VMS operating system is located in the same building as the Rhode Island Water Resources Center. There are at present over one hundred fifty terminals which can simultaneously be attached to these computer systems. There are also 5 groups of data transmission telephone numbers totalling thirty-eight lines which are available for dial-up access at 110, 300, and 1200 baud rates. These transmission lines provide direct accessibility to the computer facilities for authorized users located outside the University campus.

In addition to the above hardware, the Academic Computer Center has available other computer peripheral devices which may be required in a state-of-the-art environmental information system. The most recent geographical information systems utilize a wide range of plotters, printers, digitizers, and optical scanners to manage data. The Academic Computer Center has this type of hardware available for any future use in a data management system. A CalComp 1051 Plotter, Science Accessories Corporation digitizer, numerous printers, color graphic terminals, and an optical mark scanner are all presently located at the University.

Implementation of the Rhode Island Water Data User System could be done quite easily utilizing this substantial existing hardware system. Interested users and agencies would need to obtain a computer display terminal, a modem, and have available a data transmission line. This simple setup could be installed and in service very quickly. Many state and federal agencies which would be using the system already have in-house personal computers at their disposal. In this case, communications between the mainframe computer and the microcomputer of the agency would only require a modem hook-up to the University system. By utilizing this existing hardware, costs would be reduced to a minimum for the purchase of hardware. Graphical printouts could be produced at the University and mailed to the user whenever hardcopy data is required. The proximity of the University to most agencies in Rhode Island gives the potential for users to work directly at the University computer center when performing large scale digitizing projects or other routines which require intensive use of peripheral computer devices. Any user which regularly required hardcopies of data could purchase a printer for everyday office use.

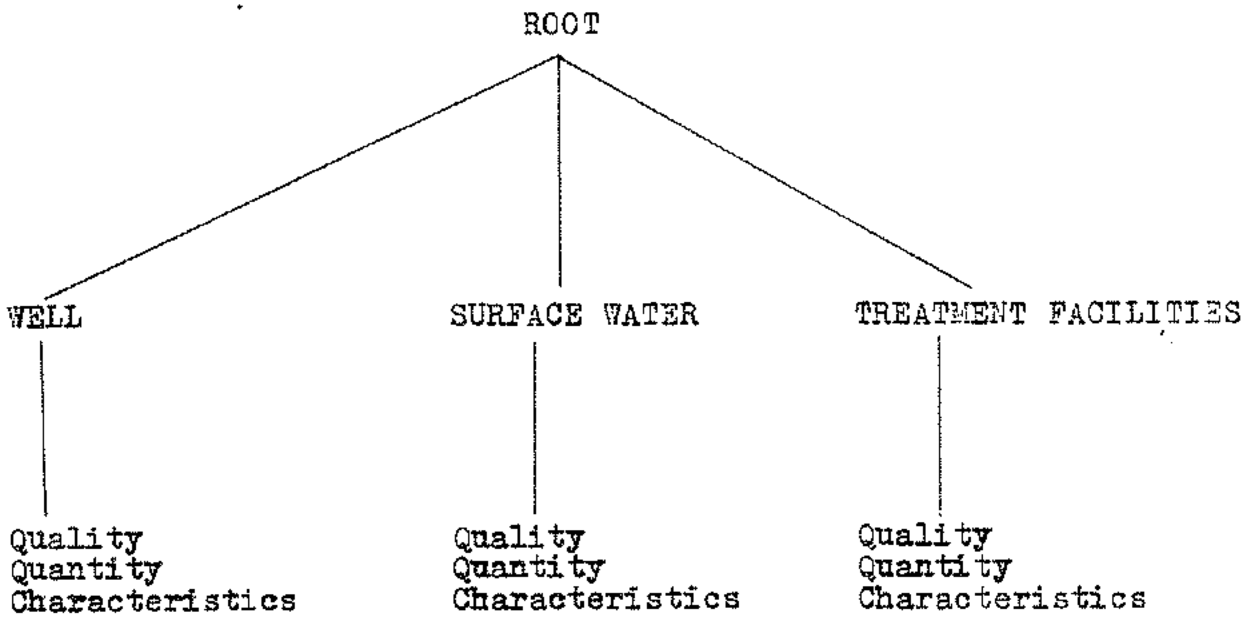
As the RIWDUS expands in the future or new requirements arise, the University can also call upon existing hardware at the Graduate School of Oceanography. A Prime 400 computer and several Prime minicomputers are located at the GSO and could be utilized on a batch job basis or for special applications of the remote sensing equipment available there.

Software

The Academic Computer Center also has very good software resources. A full complement of programming languages are available and supported on all three computer systems. Common programming languages such as Basic, Cobol, Pascal, Fortran, and others are all fully supported. The systems are also equipped with important statistical packages. Database management software is available for the mainframe, VAX, and Prime computers. The NAS/7000N uses FOCUS while the Prime 850's and VAX 11/780 use DATMAN.[10] Other software packages are available which could be immediately utilized, such as SAS for statistical manipulation of data and SAS/Graph and CalComp Graphics for the graphical display and output of data. Future use of ELAS, Earth Resources Laboratory Applications Software, located at the Graduate School of Oceanography, would allow the analysis of land cover, soils, slope, rainfall, elevation, and other useful parameters by remote sensing techniques. Future utilization of this type of software would make the RIWDUS a state-of-the-art geographic information system.

In the development of the RIWDUS, a software system which is flexible, fast, and powerful was desired. Our decision was to use FOCUS as a database management system with SAS/GRAPH to provide statistical functions and graphic interpretation of data. The FOCUS system is a hierarchial structure, locating data elements in essentially a tree-structured scheme. This type of database is characterized by a one-to-many relationship of its files, with higher-order pieces of information linked by branches to lower-order attributes.[11] A system of this type requires more thoughtful design, but once on-line has the advantage over the relational data structure in that the speed of data search and retrieval can be increased and the amount of storage capacity can be decreased. In the long term this will minimize the operational costs of the system for the users.

Hierarchial File Structure



Data parameters and individual attributes for each file are contained in Appendix A.

Figure 1

Costs

The costs of developing an on-line water data system could range from a few thousand dollars for a minimal system with limited use to hundreds of thousands of dollars for a state-of-the-art informational system. The costs of our proposed RIWDUS are small compared to commercially available options. Over one year has been spent in the development of this system, at no cost to the future users. The development of the software for this system goes on line and should not require substantial alteration in the future. Therefore, costs for software will be nonexistent for potential users in our system.

Hardware costs can be kept to a minimum in the RIWDUS by utilizing existing hardware at the University of Rhode Island. All the hardware required for the system is presently available at the University, including peripheral requirements such as air conditioning and extra power capability normally associated with a computer facility. Each user would be required to have their own terminal and modem connection in order to tie in with the system. Most large-scale, regular users, such as the Department of Environmental Management, U.S. Geological Survey, or the Board of Health, are already equipped with their own personal computer. Therefore, simply tying into the system via phone lines and a modem would give the user access to the RIWDUS. Occassional users or researchers could access the system via regular University computer operations.

In order to prepare a cost estimate for comparative purposes, the largest full-time potential user was chosen. The Department of Environmental Management is seen as a state agency which could put to use the tools and techniques of an environmental information system on a routine daily basis. The Division of Water Resources would be the main user of water data in Rhode Island and would benefit most from the system. It has been estimated that the Division of Water Resources has approximately 29,319 data points with 3,416,849 attributes in time and space.[6] The use of the RIWUDS would cost approximately $556,707 over the next 10 years at present worth cost, while the alternative system of purchasing an in-house computer and the subsequent geographic information system software and other peripheral hardware could cost $1,407,940 over the same period. Additionally, the RIWUDS would have the advantage of potential start-up in the summer of 1986 while any alternate system would take up to three years for initial implementation, exclusive of additional time necessary for user agencies to reach an agreement on system capability, cost sharing, etc.[13] Full computer support, and a wide variey of potential computer options are also already at hand. Both alternatives would require a staff member to enter data on a regular basis and be proficient at manipulating and retrieving data in a variety of forms, RIWUDS

COST TABLE[10]

NAS 7000N Mainframe

CPU Time	
5 hrs/month x 12 x \$175.00	= \$10,500/yr
Storage	
3,500,000 records x \$0.45/1000 records	= \$1575/yr
Leased phone line	= \$ 750/yr
Sub total	\$17,205/yr

Fixed Costs[6]

1. Graphics CRT	\$ 6,695
2. Short Haul Modem	\$ 500
Sub total	\$ 7,195

Over 10 years at 12% interest

Annual costs x 10 years + fixed costs = \$179,245

$\$179,245\ (1+.12)^{10} = \$556,707$ present worth[12]

Table 1

Similar Alternative

Cost Table[6]

Yearly Costs

Computer maintenance	$	1,964
Plotter/Graphics maintenance	$	1,920
Software maintenance	$	8,200
Total	$	22,084

Fixed Costs

Hardware

Prime 2250 Computer	$	106,687
Plotter	$	11,995
Graphics Unit	$	5,995
Digitizing Table	$	6,302
Furniture, Air Cond., etc.	$	4,000
Total	$	134,979

Software

ARC/INFO	$	75,000
FOCUS 77	$	7,500
GRAPHICS	$	15,000
Total	$	97,500

Over 10 yrs at 12%

Annual costs x 10 years + fixed costs = \$453,319

$\$453,319\ (1 + .12)^{10} = \$1,407,940$

Table 2

but the RIWUDS would have at its disposal the computer expertise of the Academic Computer Center. Other miscellaneous costs could arise for either system, but it is not anticipated that any single or group of factors could swing the economic advantage of the RIWUDS to any foreseen alternative.

Potential Uses - Three Examples

In an attempt to demonstrate the potential uses of the proposed information system, numerous examples were conceived for three of the largest potential users in Rhode Island; the Department of Environmental Management, Division of Water Resources, the Department of Health - Division of Water Supply, and the Water Resources Board. The examples are meant to show the types of uses for the system and are in no way the only possible uses. These examples show the variety of uses for an information system, from routine data sampling and retrieval to sophisticated trend analysis and relationships between many parameters. It is anticipated that the system could be used to help analyze environmental problems, plan for development with water resources in mind, and to facilitate the publication of reports for scientific data or public information.

The following examples for the three users are arranged by data files, similar to the way they may be arranged in the working system. Each file contains certain related data parameters, with examples of how these parameters could be used following the description of the file. Many of the graphs and plots were produced using the existing SAS/GRAPH software package at the University. Future development of the digitizing capability will eventually replace SAS when generating maps.

DEM: Division of Water Resources

I. Discharge Points

a) Point Source Discharges File:

Location/Identific.

The RI Water User Data System (RIWUDS) will contain the location of all point sources discharges permitted in Rhode Island. This location will be designated by latitude/longitude as well as address, town, and county. Owner of the discharge will also be listed. This will allow all point sources to be quickly identified within a designated area.

ex. List all point source discharges to Narragansett Bay?

Output:

Lat./Long./Source/Address/Town/County

Bristol WWTF, 18 High St., Bristol, RI
E. Greenwich WWTF, 10 First St., E G, RI
Narragansett Condo, 88 Water St., Warwick

etc.

b) Point Source Discharge File: Physical, Chemical and Biological Characteristics

The quantity and quality parameters of the effluent for each discharge will be on file. Average daily flow as well as seasonal or daily maximums and minimums will be listed. All quality parameters that are tested will be listed as well as the frequency of sampling. History of permit compliance and violations will be kept. Where data exists, volume and quality of the receiving body shall also be recorded, with tidal fluccuations, low or high stream flow periods, important biological periods (spawning, stocking, etc,) and any other data which may influence water quality all being kept on file.

c) Data Outputs: Lists, graphs, maps and statistics

1) The above data can be manipulated by the RIWUDS in order to monitor pollution more effectively. The data may be displayed simply in lists, recalling all effluents with similar characteristics.

ex. List all discharges with flow greater than 1000 gpd and copper concentration greater than 1.10 ppm.

Output:

```
Lat./Long./Source/Address/Town/Flow
            Prov. WWTF  Allens Ave, Providence  60MGD
            Shiny Jewelry Smith St Cranston  1500 gpd
```

Lists of this type could be produced by geographic location, flow rate, specific pollutant concentration or other factors.

2) Data may also be displayed in line or bar graph form to show trends in effluent quality. Data could be graphed verses time to show treatment plant performance or displayed verses distance in receiving water to monitor quality trends along a riverway.

ex. Line graph of copper concentration in effluent of wastewater treatment facility, week of August 7 thru August 13, 1984 (see Figure 2).

ex. Line graph of D. O. concentration with distance along Pawtuxet River, July 4, 1982 (see Figure 3).

ex. Bar graph of monthy mean discharge of Providence Wastewater Treatment Facility, 1984 (see Figure 4.)

3) Data may also be displayed in map form. The RIWUDS will have map generating capability equivalent to that of other Geographic Information Systems (GIS) currently being used elsewhere. This mapping capability will allow the production of maps displaying discharge points along a specific receiving body of water, discharge points within a designated area, or the location of sampling stations within a designated area. The location of permit violators could also be displayed to aid in pollution studies.

ex. Generate a map of surface water sampling stations and combined sewage overflows with the study area (see Figure 5).

ex. Plot the location of all known metal finishers in Rhode Island with known permit violations in 1981 (see Figure 6).

4) The RIWUDS will also perform statistical functions such as correlation coefficients, covariance, and regression analysis between two or more variables. This feature could be used in conjunction with the data base to determine relationships between water quantity and quality parameters.

ex. Plot regression analysis of residual cl_2 on effluent coliform concentration (see Figure 7).

II. Surface Water Quality

a) Surface Water: File of Physical Characteristics

The location of surface water throughout Rhode Island can be input by town and country. This geographical data will be used to map surface water, including ponds, reservoirs, lakes, streams, and coastal zones. The characteristics of each water body will be input as well, such as volume or streamflow, area, depth, soil type, water classification and other attribute data, which can be included on the map to illustrate the characteristics of that water body.

ex. Plot a surface water map of Pawcatuck River Basin and include location of Point Source Discharges (see Figure 8).

ex. Plot a map of Quidnick Reservoir and include depth contour intervals of 3 feet (see Figure 9).

b) Surface Water: Chemical, Biological Characteristics

Water quality data for each water body will be input where such data exists. The presence of point source discharges will be noted. Land use surrounding the water body will be recorded, paying special attention to agricultural land, industrial zones, highly developed regions, or other areas which may influence water quality. Biological information should be included where possible, noting the species types, abundance, diversity, sensitive breeding or hatching periods, fish stocking periods, and other biologically important information. Special emphasis could be taken with regards to the shellfish monitoring program. Shellfishing grounds could be mapped along with pollution sources, sampling locations, bacterial sample results, etc. The location and quality of bathing areas could be mapped in a similar fashion.

c) Output of Surface Water Files: Lists, Graphs, Maps, and Stats.

1) As mentioned earlier, simple lists can be rapidly generated.

ex. List all surface water reservoirs in Newport County, with withdrawal greater than 1 MGD.

Name	Town	Withdrawal
Green End Pond	Newport	3.8 MGD
Stafford Pond	Tiverton	2.1 MGD
Watson Reservoir	Tiverton	1.7 MGD

2) Graphical data can also be quickly generated to show changes in surface water quality. These graphs can plot a parameter vs. time, distance, or depth to provide easier monitoring of water quality.

ex. Line graph of D.O. concentration in Pawtuxet River, monthly average, October 1981 to September 1982 (see Figure 10).

ex. Line graph of water quality data vs. depth in Quidnick Reservoir (see Figure 11).

3) Mapping capability will be very helpful in displaying surface water throughout the state. Maps could be generated showing the location of all A-classified water, ponds used in fish stocking programs, or river segments with pollution levels of a particular parameter in excess of a recognized limit. These maps could be quickly generated for public information, publications, or to help solve specific pollution problems.

ex. Map Pawcatuck River Basin and include water quality classification of all surface water within the Basin (see Figure 12).

ex. Map the Pawtuxet river showing the location of Dams, and time of travel dye test sites (see Figure 13).

4) Statistical analysis will also be available to determine the relationship between parameters. The relation between rainfall amount and shellfishing area contamination could be studied to more accurately predict shellfish contamination. Other possibilities include the correlation between effluent discharge quality and receiving stream quality, water quality and biological production, land use and surface water quality, and numerous other relationships between data sets.

III. Combined Sewer Overflows (CSO's)

a) File of CSO's: Physical Location

The RIWUDS will contain the location of all combined sewer overflows in the Providence System. The location of each CSO will be given by latitude/longitude as well as street location and town. When CSO's are located on private land, the owner of the land will be listed as well as any special procedure for inspection of that particular CSO.

b) File of CSO's: Discharge Parameters

The quality and quantity of discharge will be recorded for each CSO along with the size of the sewer line and any other physical characteristics. Any sampling data will be listed and the amount of rainfall and corresponding CSO flow will be recorded.

c) Data Output: Maps and Analysis

1) Map generating capability will be especially useful for monitoring combined sewer overflows. The location of CSO's could be quickly printed with the location of sampling stations in the near coastal zone. Overlay maps could be used to show those CSO's which flow nearly continuously, those which only flow at high rainfall intensity, or those which rarely flow at all.

ex. Map all CSO's and their corresponding surface water sampling stations within the sampling area (see Figure 14).

2) Statistical analysis could be used to show the correlation between the amount of rainfall and the flow in each CSO. CSO discharge could also be related to receiving water body quality or shellfishing ground closures. CSO discharge quality data will be input into this program and analyzed in the near future when the Narragansett Bay Commission starts operating their CSO treatment facilities.

IV. Groundwater

a) Groundwater Location File

The location of all public water supply wells will be kept on file with location given by latitude/longitude, local well number or USGS locater codes, town, and county. Private water supply wells would also be listed using latitude/longitude, street address, town, county, and owner. The locations of groundwater monitoring wells or other wells would be listed in a similar manner.

b) Groundwater File: Well characteristics

The well characteristics of each well would be included in the file. The type of well (dug, driven, etc.), depth to water, depth to bedrock, soil type and characteristics, data drilled, driller, pumpage, and safe yield should all be included.

c) Groundwater File: Quality Parameters

Water quality data of public supply wells and groundwater monitoring wells would be listed. The water quality of private wells could be included if desired, making the file accessible only to authorized persons.

d) Output of Groundwater Data: Lists, Graphs, Maps, Stats

1) Lists of groundwater wells with similar characteristics can be quickly recalled by this information system.

ex. List all wells used to monitor groundwater near West Kingston Landfill, with sodium concentration greater than 3.0 mg/l. Include all other parameters for these wells (see Figure 15).

2) Graphs of well data can also be quickly produced, showing the changes of a particular water quality parameter or pumpage through time.

3) The most useful feature of the RIWUDS is the map generating capability which will be very useful for groundwater monitoring. Maps showing wells with similar drilling depths and water quality could be used as overlays to help identify valuable aquifers and their boundries.

Maps could also show wells which exceed certain drinking water standards within a given location or all wells with pumpage rates above a specified value. Having immediate access to this data will be helpful in avoiding contamination episodes. Knowing the location of potential pollution sources, such as landfills and hazardous waste sites, and the characteristics of the soil will forewarn monitoring agencies as to which wells may pose future contamination problems.

ex. Plot a map of wells located within 1,000 ft. of the West Kingston Landfill (see Figure 16).

ex. Map all water supply sources within the given quadrant (see Figure 17).

4) Statistical analysis will be another useful tool in the monitoring of Rhode Island groundwater. The relationship of water quality to well pumpage could show when wells are being over used. The relation of pumpage rates to water levels can also be very helpful to determine future development goals. Analysis of this type could also be used to examine the relationship of groundwater quality in aquifers along a river to the quality within the river itself. Similarly, well water levels along a river could be compared to river stage. This is useful information to

public health officials and planners.

Dept. of Health: Water Supply Division

I. Surface Water Supply

a) Surface Water Sources: Location File

The Rhode Island Water User Data System (RIWUDS) will contain the location of all surface water systems which are used for public water supply. The owner of the system will also be listed, along with the area served, population served, and the number of connections associated with this surface water supply.

b) Surface Water Sources: Physical, Chemical, Biological File

All quantity and quality parameters will be input for each surface water source. Total capacity of the reservoir, total annual withdrawal, daily average discharge, daily maximum and daily minimum flows will be included in quantity data. Comprehensive quality data and frequency of sampling will be listed for each source.

1) Lists of surface water sources can be rapidly produced with a few key characteristics listed for each. Planners could rapidly generate a list of all surface waters within a county or other specified region. This could be used for public information purposes or when generating reports.

ex. List all surface water sources in Providence County with withdrawal rate greater than 1 MGD

Source	Location	Withdrawal
Scituate Reservoir	Scituate	63 MGD
Waterman Reservoir	Greenville	2 MGD

2) Graphical displays in the form of line, bar and pie graphs will all be available and can quickly generate information in a visual display. Parameters, such as withdrawal or coliforms, can be plotted over time to analyze trends or find maximum and minimum values easily. Pie charts can be used to show the relative amounts of water used for various purposes, such as residential, commercial, industrial or agricultural.

ex. Graph monthly total withdrawal from the Scituate Reservoir in 1982 (see Figure 18).

ex. Generate a pie chart showing 1983 annual sales and the breakdown by town in Newport County (see Figure 19).

3) Mapping capability would allow the display of all surface water supply sources in a particular county or water district. It could also be used to selectively display sources with particular characteristics, such as withdrawal rates greater than 1 MGD or mercury

concentration greater than 0.002 mg/l. Land use data can be mapped in conjunction with surface water sources. This information can be used to monitor long term water quality and the effects of land use factors such as agriculture, industry, road salting and other man-made changes to the landscape surrounding surface water supply sources.

ex. Map surface water and corresponding water quality in the Pawcatuck River Basin (see Figure 20).

ex. Map land use within the Pawcatuck River Basin (see Figure 21).

4) Statistical analysis will be available to study the relationships between two or more parameters. Correlation coefficients, regressions, covariance and other statistical functions can all be performed. This feature will allow for better analysis of surface water quality. The effects of pH could be related to heavy metal concentrations or rainfall related to withdrawal. Runoff could be analyzed and related to water quality, especially where roadsalt or agriculture is concerned. This type of analysis will increase our ability to monitor water quality.

II. Groundwater Supply

a) Groundwater Sources: Location File

The location of all public water supply wells will be input by latitude/longitude, local well number, town, and county. All monitoring wells, injection wells, and any other wells will be included.

b) Groundwater Sources: Well Characteristics

The characteristics of each well will be included in the system. The type of well, depth to water, depth to bedrock, soil type and characteristics, date drilled, driller, pumpage, and safe yield should all be listed for each well.

c) Groundwater Sources: Chemical, Biological, Physical Quality

Sampling results and historical data will be input for each well. All quality parameters and frequency of sampling records should be included. Private well quality data can be included in a confidential file to give a comprehensive record of groundwater quality. Monitoring wells and other wells will also be listed.

d) Groundwater Sources: Outputs

1) Lists can be quickly generated showing a variety of common characteristics between wells. All wells

serving public communities within a county could be quickly listed or all wells within a specified distance of a known contaminated well could be listed for future monitoring. This will facilitate groundwater monitoring by quickly identifying which wells should be sampled.

2) Graphs can be rapidly produced to show changes in a parameter over time for any well. Decreases in water quality can quickly be spotted when graphed in this fashion and the time frame when contamination began can be identified. Trends in pumpage rates are readily observed when plotted in graphical form: this can aid in the monitoring of groundwater and help insure high quality.

ex. Plot monthly total pumpage of Mishnock well #1, 1980 (see Figure 22).

3) Mapping capability can be used to locate any set of groundwater wells within a designated area. This can be useful in showing the locations of important supply wells, contaminated wells, or those wells close to a waste site. Wells of similar depths can be used to help identify boundaries of groundwater aquifers by mapping methods.

ex. Map the quadrangle and show all groundwater supply wells and any surface supply sources (see Figure 23).

ex. Map all wells used for water supply in West Kingston that are within 1000 feet of the landfill and contain greater than 1 ppb of insecticide xxx (see Figure 24).

4) Statistical analysis can be useful in relating data between the data sets. Water quality of monitoring wells for a landfill can be related to water quality of nearby supply wells. Distances from waste sites can be related to water quality and to help monitor the transmissivity of a pollutant through the aquifer. Pumpage rates and quality, or the quantity of surface water and adjacent groundwater, can be examined to determine the extent of a contaminant or trace the source of a contaminant. This type of analysis can quickly and reliably point out areas in need of study and help monitor groundwater quality.

III. Technical File

a) Technical File: Water Supply Systems

This file will contain information on all public water supply systems within the state. The location by latitude/longitude, street address, town, and county will be given as well as the owner of the system. Where raw water is treated, the processes used at each system, the capacity of the treatment facility, system withdrawal, number of connections, location of distribution lines, and other characteristics of the system will all be listed.

b) Technical File: Output of Supply Systems

The data for a water supply as a whole can be used to study water consumption patterns. Ratios of surface water withdrawal to groundwater withdrawal can quickly be seen in pie charts and bar graphs. Total water consumption for a town or county can be compared to the available supply. The percentage of total supply being used within a region can be determined and will show if a water system is operating at its maximum capacity or if future development within the region can be accomodated by the present supply system. This type of data will help to point out areas with facilities not meeting demands or areas with excess capacity. This can be useful when planning a community and help prevent areas of water shortage and utilize areas of surplus.

Water Resources Board

I. Public Water Supply

a) Water System File: Ownership Information

The Rhode Island Water User Data System (RIWUDS) will contain a vast amount of information on the controlling group of the 26 major water supply systems. Ownership information will include the town or private company operating the water supply system, their address, and contact person. The area served by the system as well as the population served will be listed. The per capita water use will be included in the system, and if data becomes available in the future, a breakdown of water use by industrial, commercial, and residential sectors will be included. Finally, the water rates, wholesale and retail charges, and financial data such as debts, loans, or other pertinent information will be input to the system.

b) Water System File: Water Resource Data

Water resource data for each of the water supply systems will include all the physical data pertaining to the water supply itself. The sources of the water system will be listed along with each source's watershed characteristics and safe yield. In addition, the hydraulic characteristics of the water source will be listed, including the water demands for minimum, average, and maximum daily flow through the system. When groundwater wells serve as the water supply source, the location, depth, yield and well history of past problems will be input to the system.

c) Water System File: Facility Data

Information about the facilities of each water supply system will include all data concerning the physical characteristics of the water supply facility and distribution network. Where water treatment is practiced, the purification methods and capacity of the plant will be listed. The distribution system specifications will be input to the information system, including storage size and location, and the piping size and location. The location and type of connection will also be included, as well as all emergency connections. Finally, future expansion or improvement plans for the system will be included.

d) Outputs of Water System Files

1) The RIWUDS will manipulate the above data to better understand the state's water resources. A quick and useful output of the system will be lists of water systems and their characteristics in a variety of forms. This will be very useful when generating reports or to maintain communications with the many water systems.

ex. List mailing address and contact person for all community water supplies, alphabetically by suppliers (see Figure 25).

ex. Alphabetically list water suppliers, with a description including population served, water source, number of metered customers, and annual water sales (see Figure 26).

ex. List the water suppliers with a general description, ranked by population served (see Figure 27).

ex. List the water suppliers, town served, and population served (see Figure 28).

ex. Alphabetically list all towns and the water companies which serve each town. Include the percentage of the town served by each supplier, the self-supplied population and percent of total, and the town population (see Figure 29).

The rapid retrieval of this data in an organized form could quickly answer a variety of questions about a town or county water supply. It will also be useful in determining the amount of future development which can be handled by existing suppliers and point to alternate suppliers in nearby communities.

2) Graphical display of data will also be available in many forms. Line graphs of water withdrawal rates over time will quickly show periods of greatest consumption. Line or bar graphs can be plotted for both surface and groundwater withdrawal and then totalled to show total consumption rates. Pie charts can also be displayed showing the percentages used by residential, commercial, industrial, and other segments of the water using population. These outputs can be generated on a town, county, or regional basis to yield important information about water use, its source, and supply.

ex. Display line graphs showing monthly water production of Mishnock well #1, Kent County Water Authority, 1980 (see Figure 30).

3) Mapping capability equivalent to that of other larger geographic information systems will be available to show the location of water supply systems, their sources, and facilities. Land use maps can be incorporated to show the activities adjacent to water supplies and to better protect these supplies.

ex. Map the quadrant showing the locations of all public water supply systems (see Figure 31).

ex. Map the county and show the percent of town population served by public water supply systems (see Figure 32).

The use of maps and map overlays would quickly show any discrepancies which exist between areas of consumption and withdrawal. Overlays would also be used with land use and water supply sources to monitor potential pollution from land uses which may adversely effect the quality of the water source.

4) Statistical analysis will allow relationships between different parameters to be seen more clearly. The relationship between population and consumption can be studied to insure adequate water supply. Comparisons of rainfall and withdrawal rate can be used as an indicator of recharge to a water source. Using this data, town and state planners could estimate if future water supplies will meet future demands.

II. Private Water Supply Wells

a) Private Well File: Owner and Physical Characteristics

If available, the numerous private water supply wells throughout Rhode Island could be input to the system to establish a confidential and comprehensive record of private water users. Each well would be recorded with information concerning the depth, diameter, type of well, material penetrated, safe yield, proposed use, driller, and completion date. The owner of the well and its location by latitude/longitude, street address, town, and county would also be included.

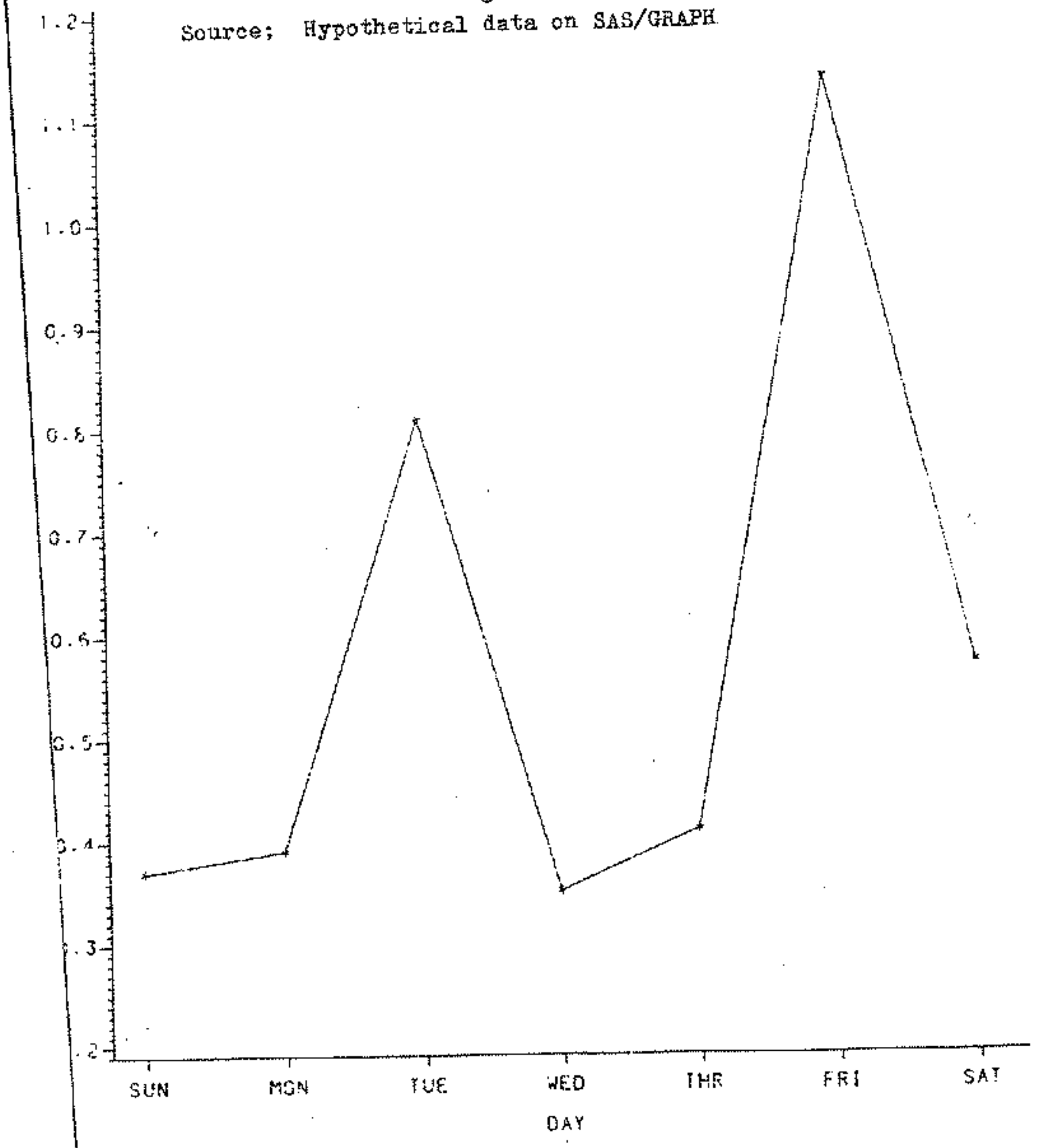
b) Private Well Output

The above information can be output using the same tools and methods as that for public supply systems. Having private well data available will allow for better estimations of total water use from all sources within a specific region. Combining private and public water supply data would give a comprehensive picture of the water demands and needs of a community and the extent of possible future development.

Access to the data of numerous private wells will also facilitate the monitoring of groundwater aquifers. Any contaminated well could be quickly located and the extent of pollution identified. Other wells in the area and similar depth could be quickly identified and monitored. In this manner, the spread of the pollutant can be measured and hopefully traced back to the source.

Statistical analysis can also be used to study the relationships between water quality and well type, quality and depth, rainfall and supply, population and consumption, and various other factors. Trend analysis can be used to help predict regions of high water consumption in the future or to indicate if water quality is declining in a specified area. Graphical displays of water use or lists of water suppliers can be quickly generated when publishing information for reports or to the public. Ready access to this type of comprehensive water data will allow for improved management of water resources and help insure high quality drinking water in quantities sufficient to meet present and future demands.

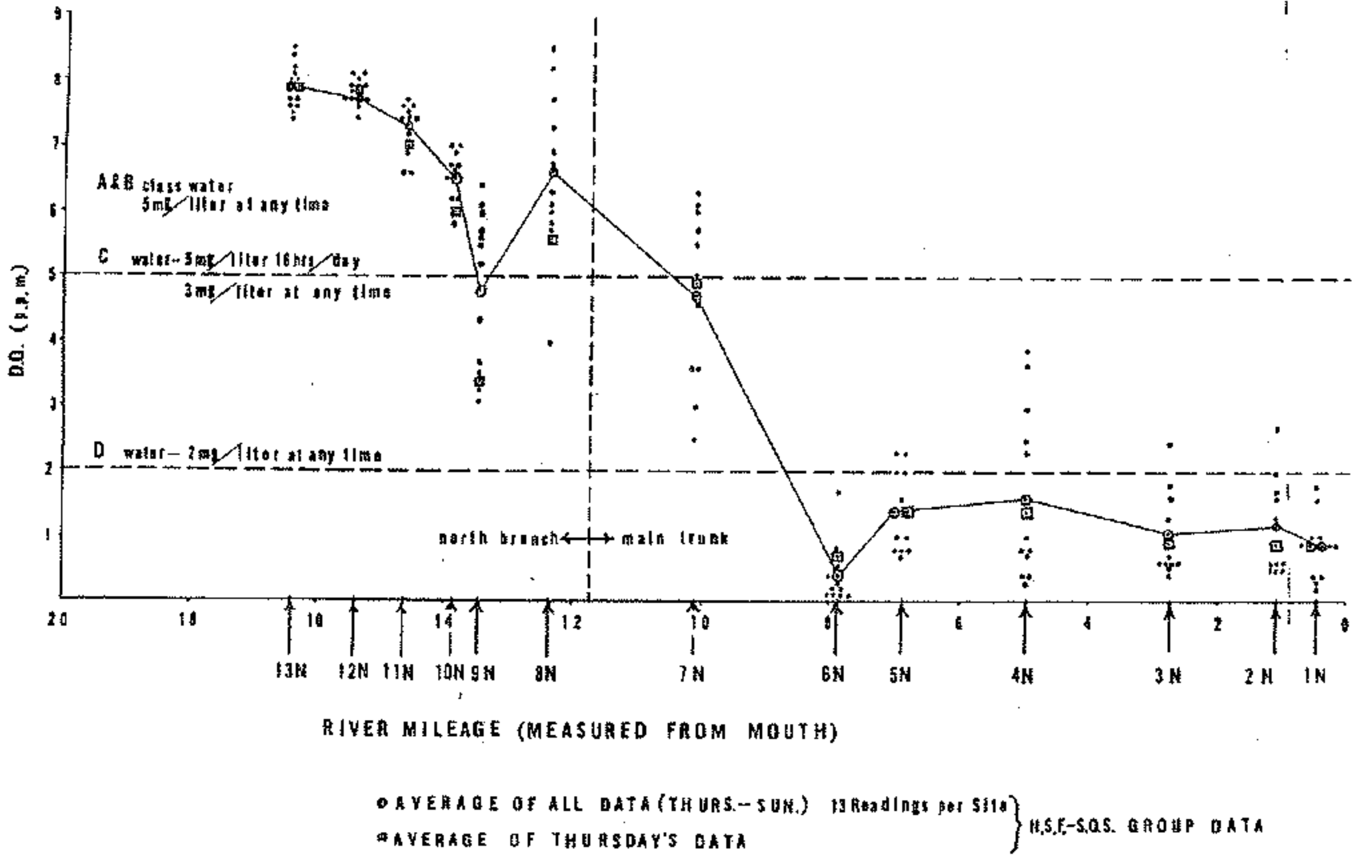
COPPER CONCENTRATION
IN WASTEWATER TREATMENT FACILITY EFFLUENT
WEEK OF AUGUST 7-13
1984
Figure 2
Source; Hypothetical data on SAS/GRAPH



DISSOLVED OXYGEN DATA

FIGURE 3

Source; DEM-Water Resources



MONTHLY AVERAGE OF DAILY DISCHARGE FROM PROVIDENCE WWTF FOR 1984

Figure 4

Source; Hypothetical data on SAS/GRAPH

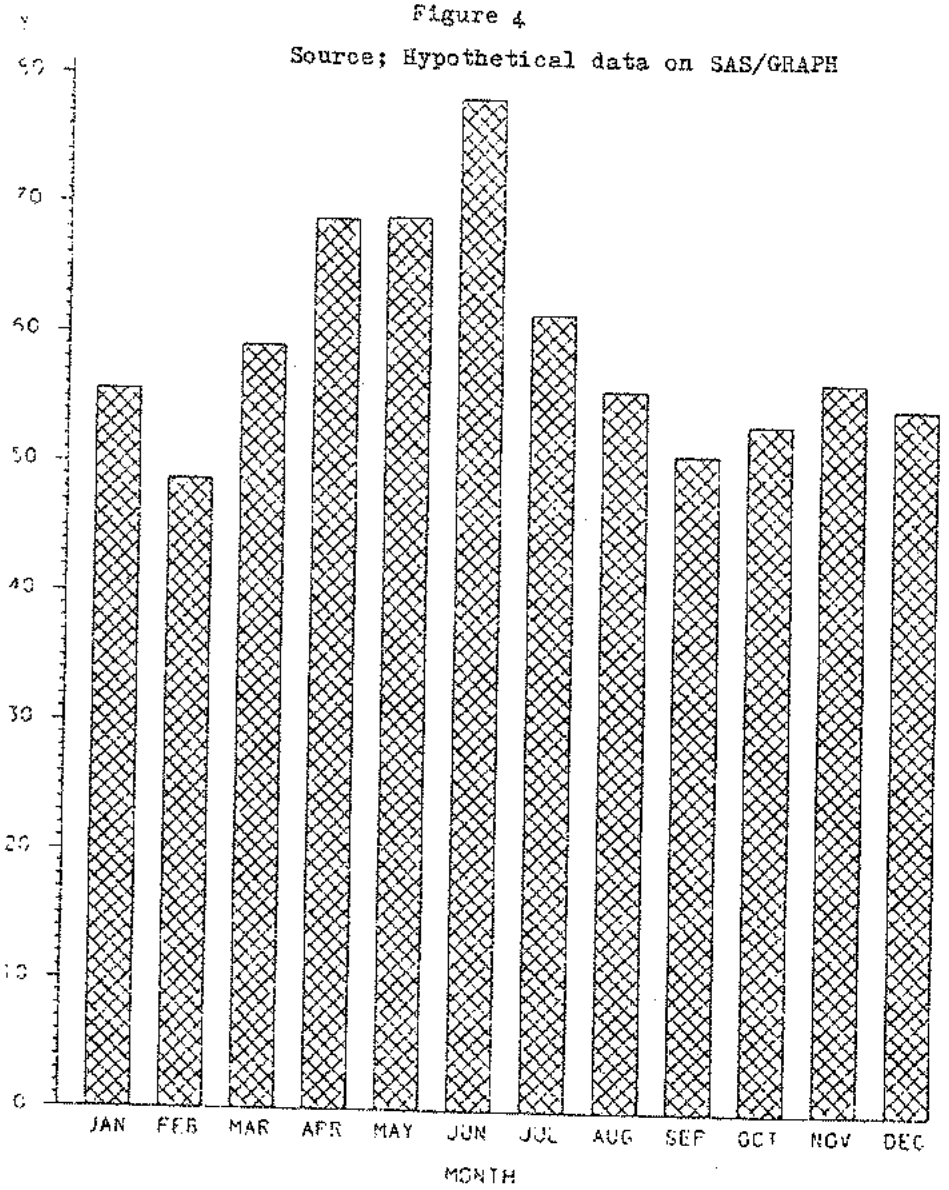
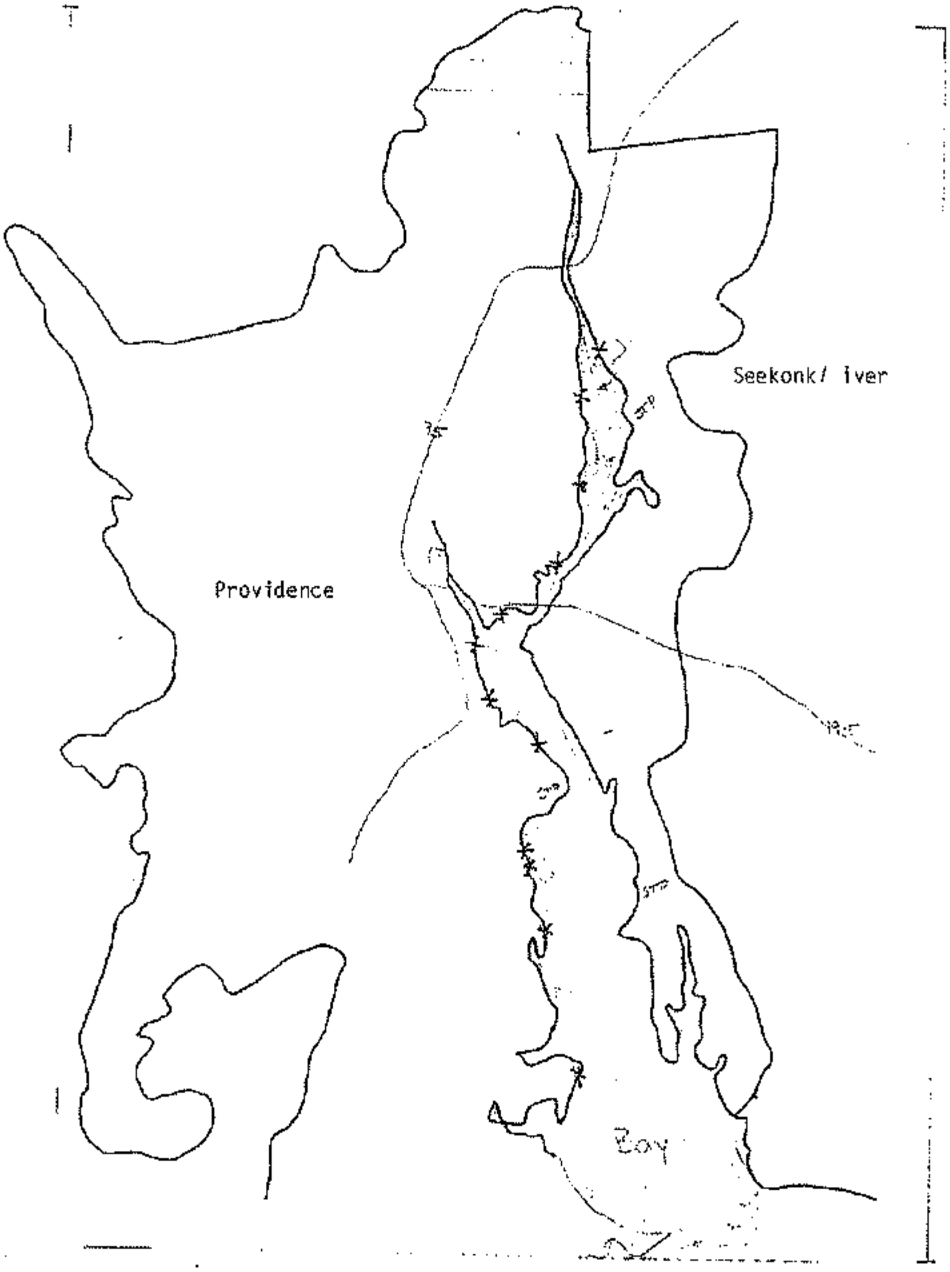


Figure 5

CSO Locations in Upper Narragansett Bay



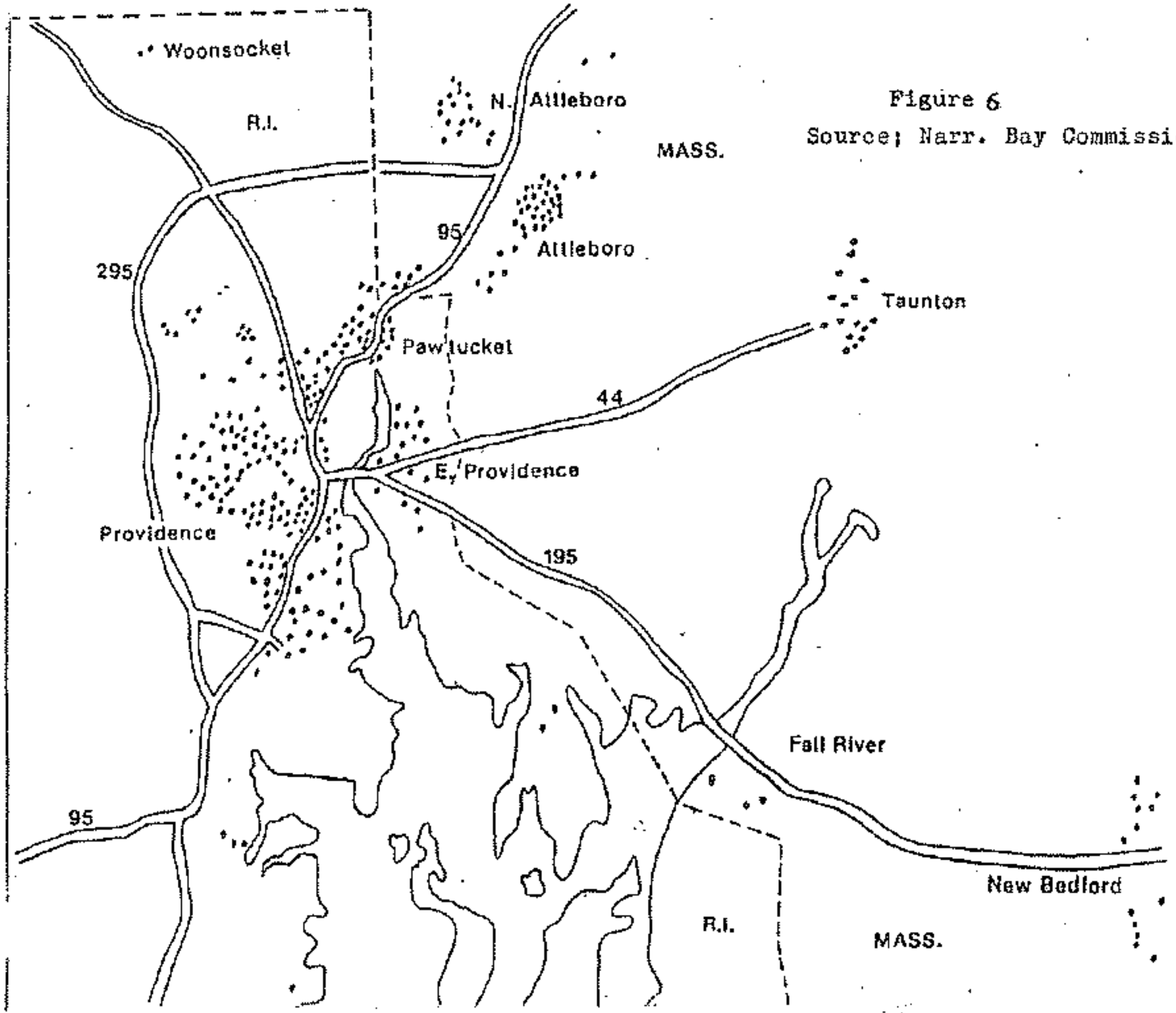


Figure 6
Source; Narr. Bay Commission

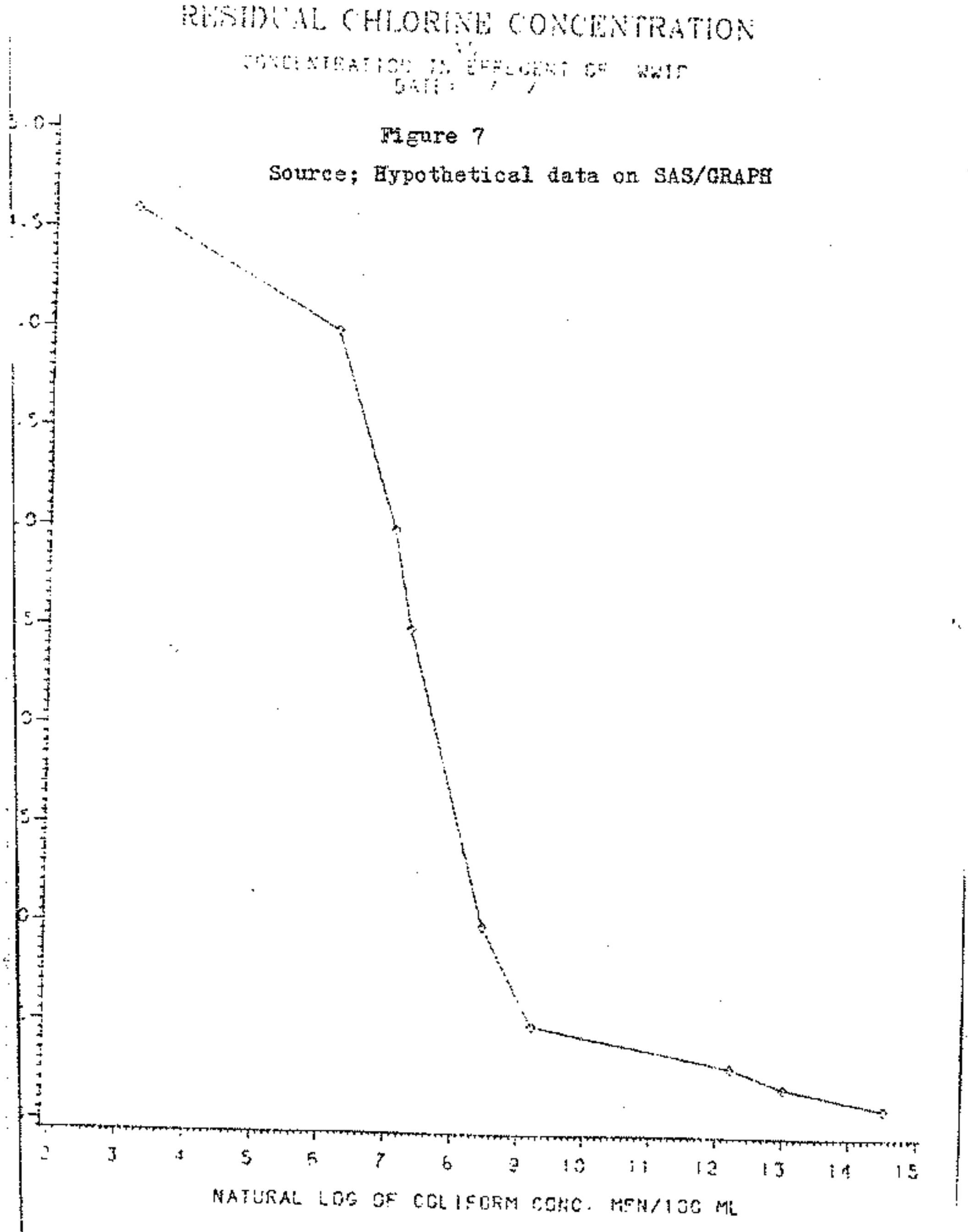


Figure 7

Source; Hypothetical data on SAS/GRAPH

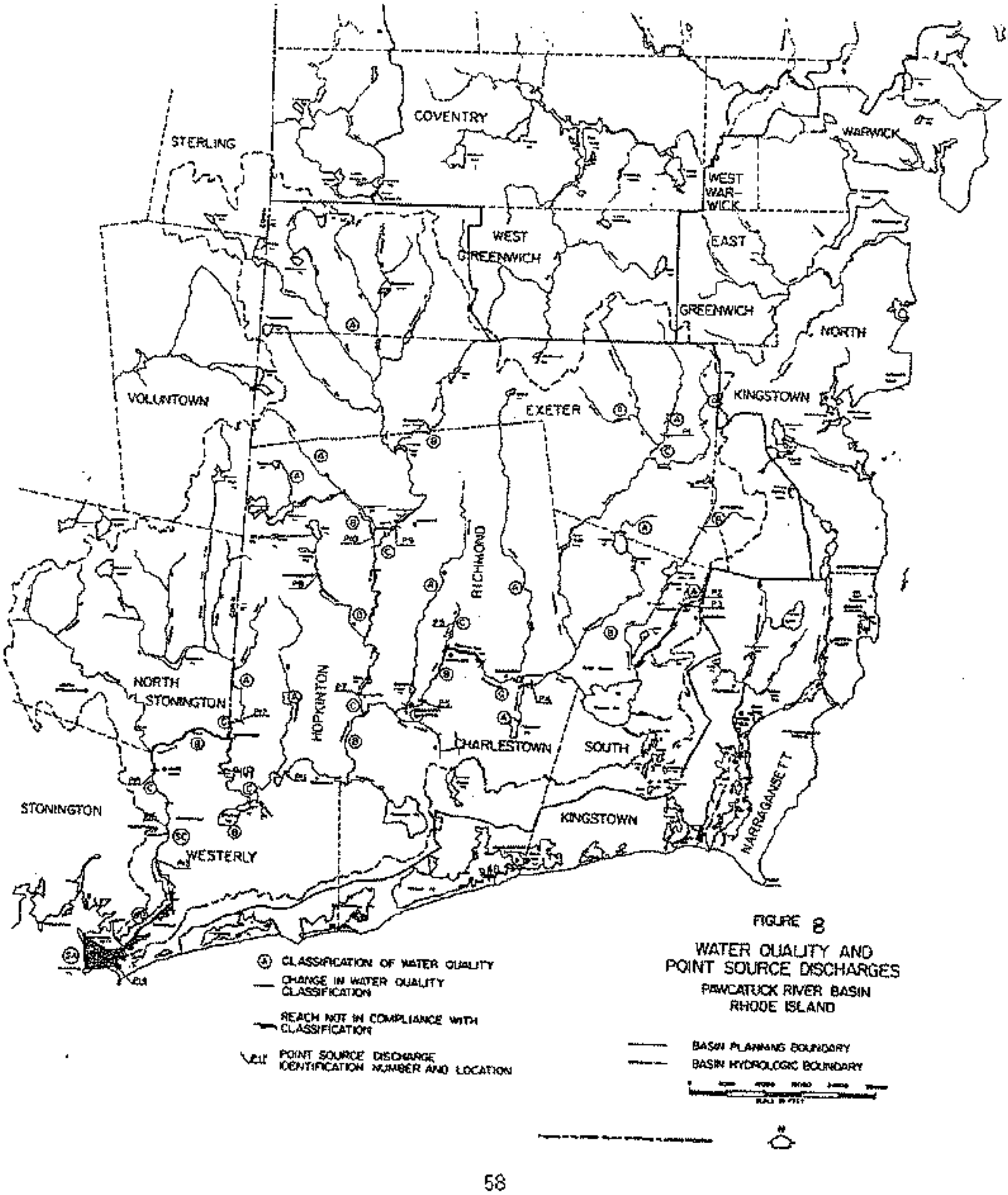


FIGURE 8

WATER QUALITY AND
POINT SOURCE DISCHARGES
PAWCATUCK RIVER BASIN
RHODE ISLAND

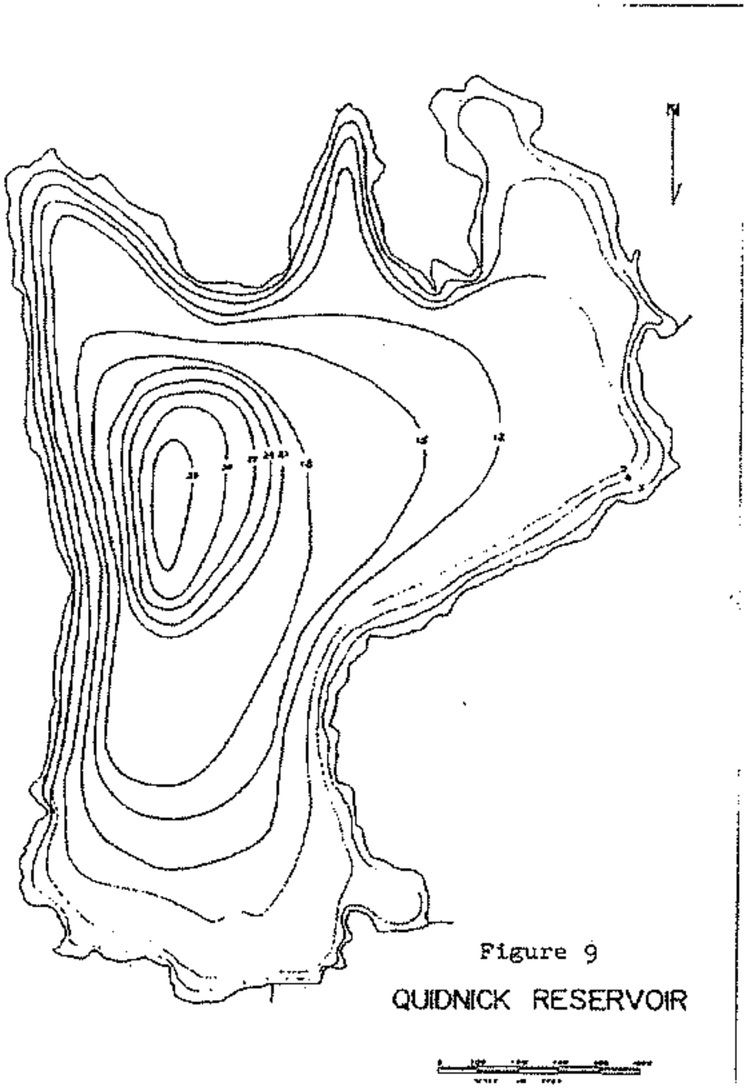


Figure 9

QUIDNICK RESERVOIR

Source; DEM-Fish & Wildlife

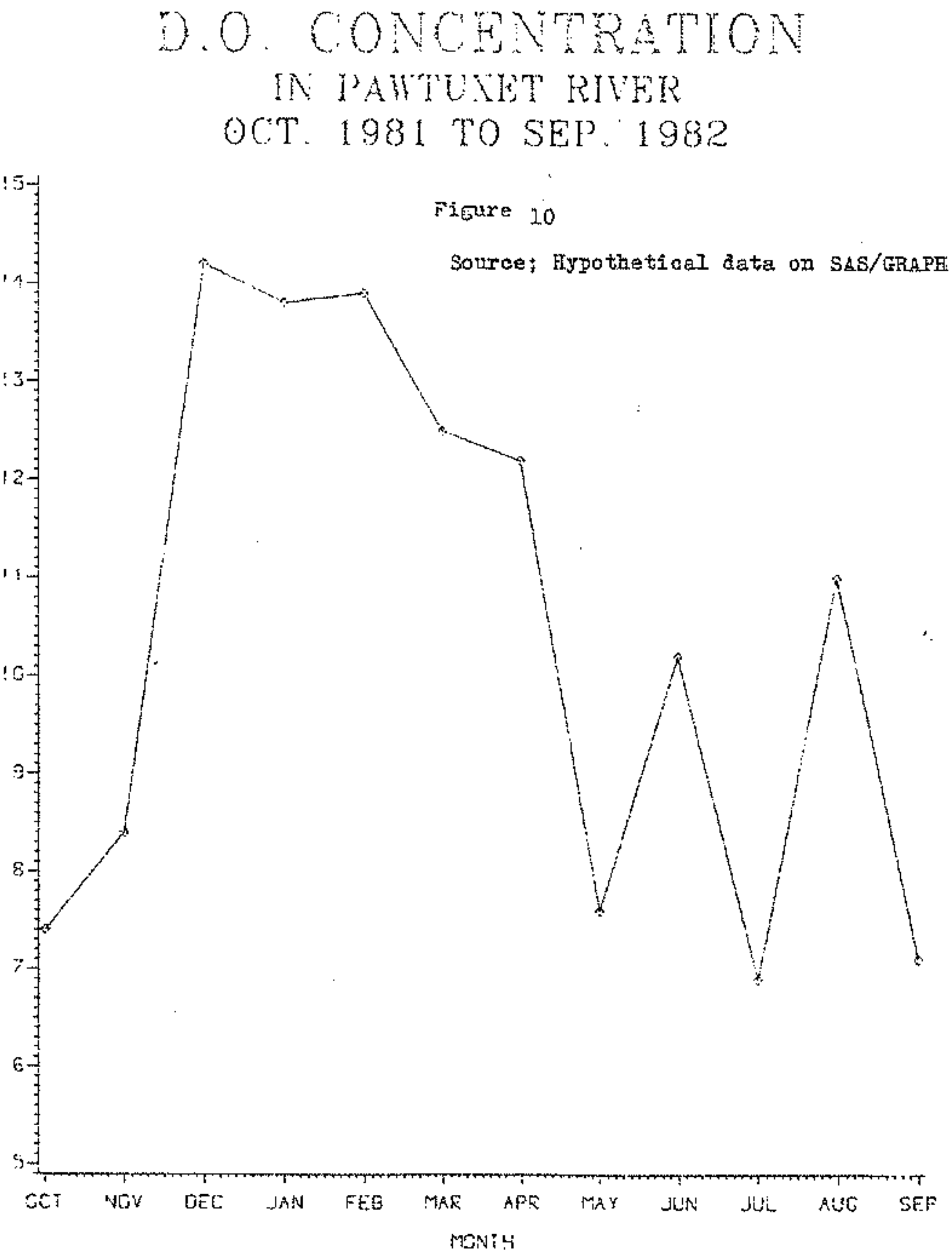
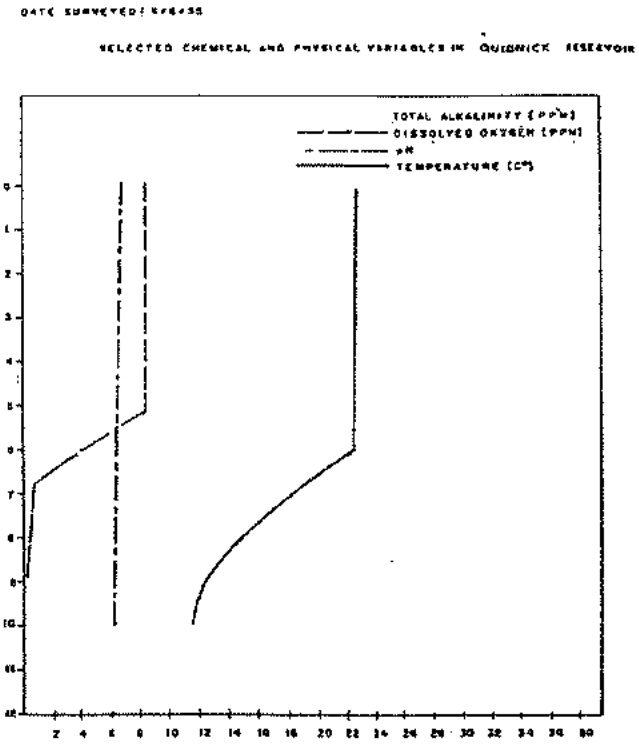


Figure 10

Source; Hypothetical data on SAS/GRAPH

Figure 11



Source; DEM-Fish & Wildlife

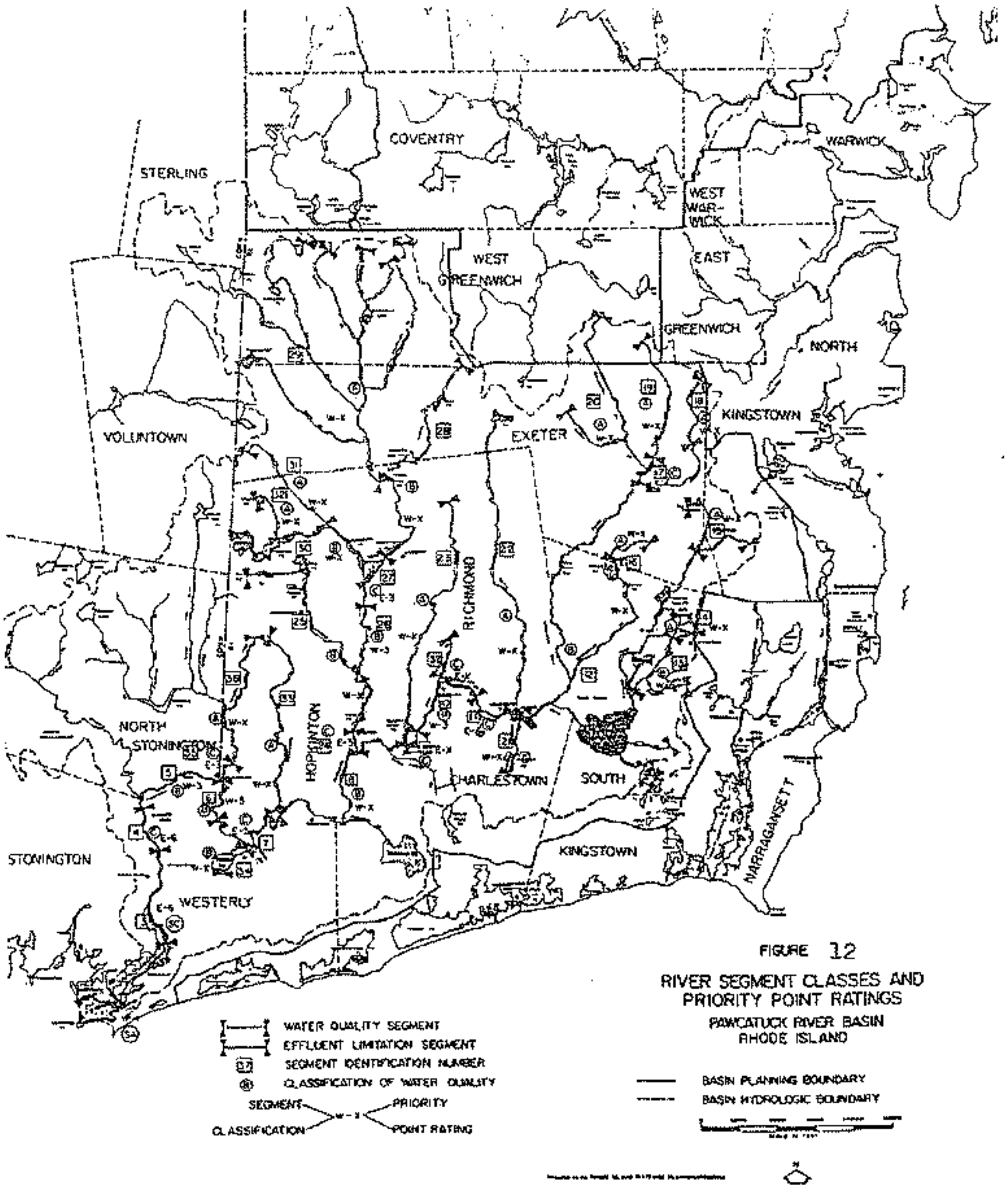
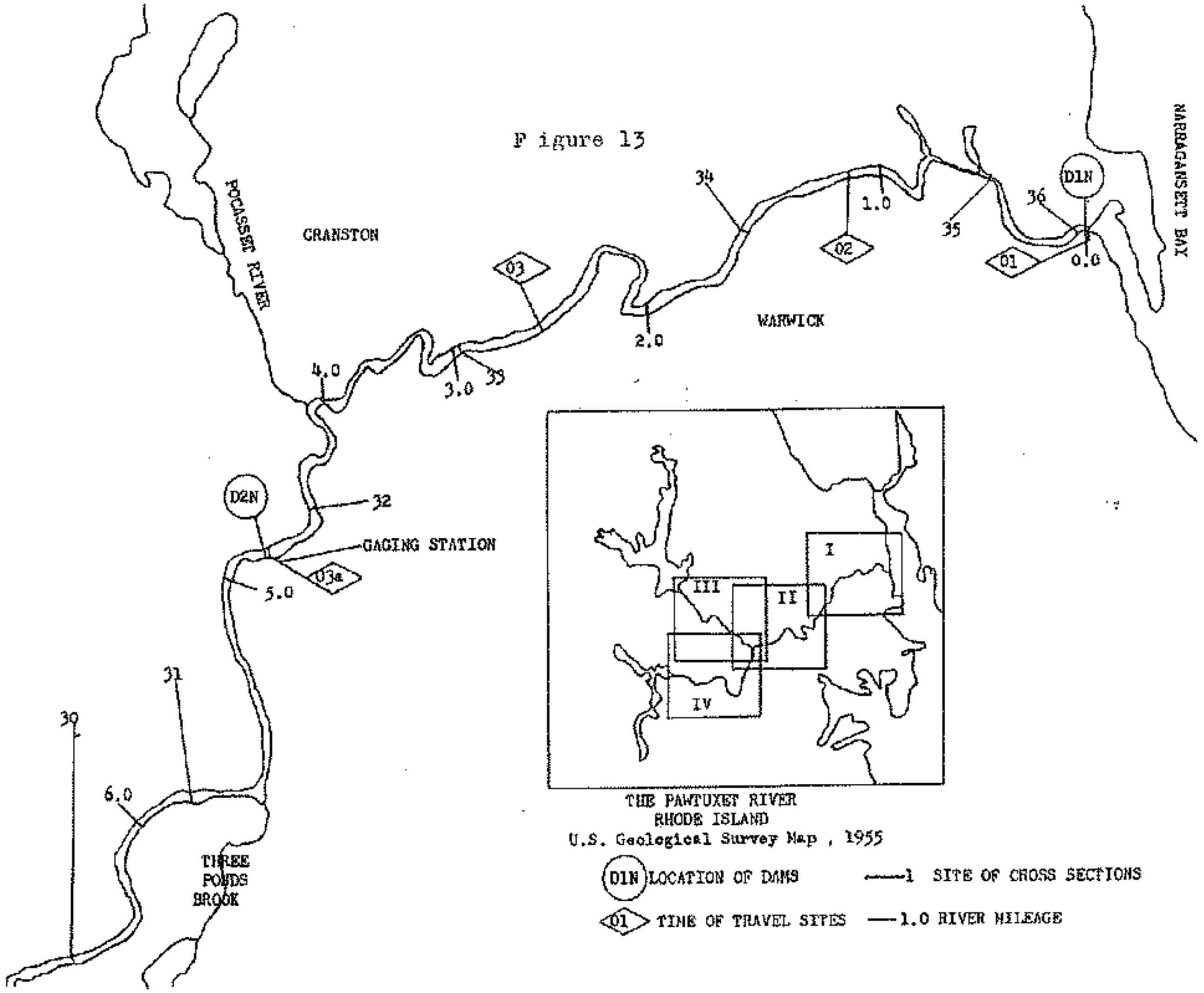


FIGURE 12

RIVER SEGMENT CLASSES AND PRIORITY POINT RATINGS

PAWCATUCK RIVER BASIN
RHODE ISLAND

Figure 13



THE PAWTUXET RIVER
RHODE ISLAND
U.S. Geological Survey Map, 1955

CSO Locations in Upper Narragansett Bay

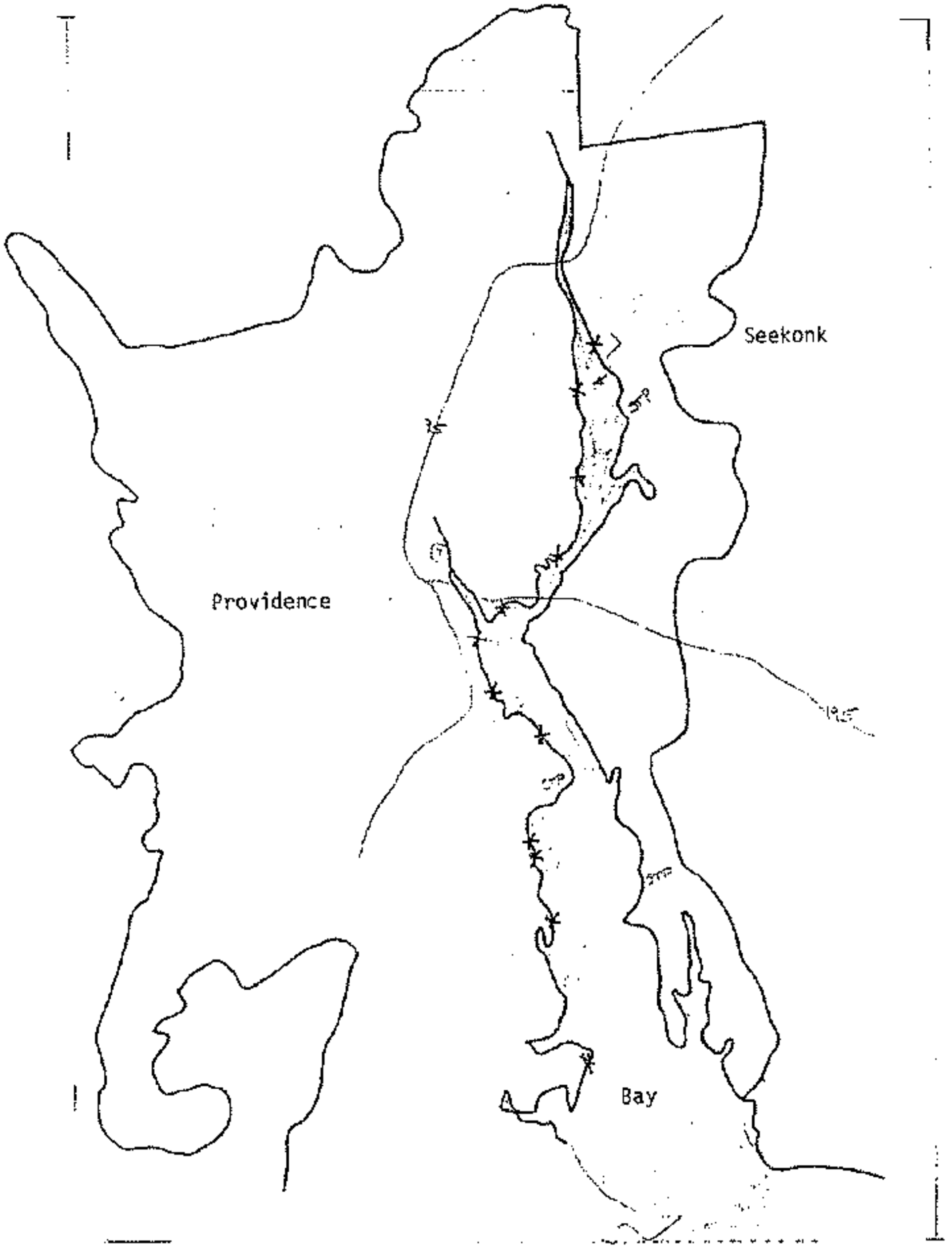


Figure 14

--CHEMICAL ANALYSES OF GROUND WATER MADE DURING A STUDY OF THE EFFECTS OF LEACHATE ON GROUND WATER QUALITY IN THE VICINITY OF THE WEST KINGSTON LANDFILL

SOURCE OF DATA: 1. U.S. GEOLOGICAL SURVEY; 2. U.S. PUBLIC HEALTH SERVICE; 3. STATE HEALTH DEPARTMENT;
4. STATE (OTHER THAN HEALTH DEPARTMENT); 5. INDUSTRIAL; 6. PRIVATE; 7. EDUCATIONAL; AND 8. OTHER.

LOCAL WELL NUMBER	DATE OF SAMPLE	DEPTH TO TOP OF SAMPLE INTERVAL (FEET)	SILICA (SIO2) (MG/L)	IRON (FE) (MG/L)	MANGANESE (MN) (MG/L)	CALCIUM (CA) (MG/L)	MAGNESIUM (MG) (MG/L)	SODIUM (NA) (MG/L)	POTASSIUM (K) (MG/L)	BICARBONATE (HCO3) (MG/L)	ALKALINITY AS (CACO3) (MG/L)	SULFATE (SO4) (MG/L)	CHLORIDE (CL) (MG/L)	FLUORIDE (F) (MG/L)	NITRATE (NO3) (MG/L)	DISSOLVED SOLIDS (RESIDUE AT 180 C)	TOTAL SOLIDS (RESIDUE AT 105 C)	HARDNESS AS (CACO3) (MG/L)	SPECIFIC CONDUCTANCE[a] (MICROMHOS)	PH	TEMPERATURE (C)	COLOR	TURBIDITY AS SILICON DIOXIDE (MG/L)	MBAS (MG/L)	SOURCE OF DATA
											SOUTH KINGSTOWN														
1104	10-24-73	37.7	--	.20	.37	38	12	19	10	--	67	110	46	0.1	.00	--	280	144	400	--	--	35	0.3	.05	3
1104	11-26-73	37.7	--	--	.41	36	11	20	10	--	86	78	35	0.1	.00	--	283	134	450	--	--	30	6.0	.06	3
1104	12-28-73	37.7	--	.06	.60	48	4.9	20	10	--	80	78	36	0.2	.00	--	266	140	425	--	--	15	0.6	.03	3
1104	4-27-74	37.7	--	.35	.46	48	1.0	19	17	--	86	80	25	0.1	.00	--	272	124	375	--	--	25	1.4	.04	3
1104	9-25-74	37.7	--	1.2	.61	30	12	20	16	--	71	80	28	0.1	.06	--	259	124	300	--	--	15	.5	.05	3
1105	10-24-73	45.8	--	4.5	3.4	86	48	49	26	--	49	330	107	0.3	22	--	785	399	--	--	--	35	3.1	.16	3
1105	11-26-73	45.8	--	--	3.6	108	48	52	23	--	100	236	108	0.2	6.6	--	905	442	1400	--	--	50	10	.16	3
1105	12-28-73	45.8	--	6.6	3.6	72	68	48	21	--	102	248	104	0.1	16	--	891	464	1300	--	--	10	15	--	3
1105	1-31-74	45.8	--	100	3.2	112	62	58	21	--	92	372	112	0.0	16	--	886	458	--	--	--	70	9.0	.12	3
1105	2-28-74	45.8	--	35	3.0	112	62	60	18	--	84	360	112	0.3	27	--	926	540	--	--	--	10	7.4	.06	3
1105	3-28-74	45.8	--	18	.00	104	38	57	21	--	72	110	206	0.3	11	--	833	420	--	--	--	30	26	.11	3
1105	4-30-74	45.8	--	15	.00	88	43	58	26	--	87	365	101	0.2	2.2	--	773	400	--	--	--	5	--	.13	3
1105	5-28-74	45.8	--	3.0	14	80	38	23	3.0	--	48	250	49	0.1	1.3	--	606	380	--	--	--	15	1.1	.06	3
1105	7-01-74	45.8	--	8.8	.94	64	24	49	20	--	35	290	95	0.2	1.3	--	667	260	--	--	--	5	0.9	.06	3
1105	8-01-74	45.8	--	4.3	.65	86	34	51	22	--	63	316	102	0.2	3.1	--	562	340	--	--	--	0	15	.05	3
1105	8-27-74	45.8	--	.40	.60	72	15	50	24	--	64	190	99	0.2	2.2	--	556	244	760	--	--	20	3.3	.04	3
1105	9-25-74	45.8	--	0.8	.00	56	29	45	21	--	50	194	102	0.2	1.3	--	552	240	530	--	--	10	0.0	.05	3
1106	10-24-73	38.7	--	.31	.32	36	3.9	12	2.2	--	7	120	24	0.3	1.3	--	204	100	320	--	--	5	0.6	.03	3
1106	11-26-73	38.7	--	--	.44	39	5.6	12	2.8	--	25	93	28	0.1	.89	--	218	122	350	--	--	5	0.1	.04	3
1106	12-28-73	38.7	--	.35	.32	36	8.1	12	2.2	--	23	89	25	0.0	.89	--	230	120	385	--	--	10	0.6	.01	3
1106	1-31-74	38.7	--	3.5	.99	40	7.8	14	2.3	--	23	93	34	0.0	.08	--	271	132	--	--	--	20	2.3	.05	3
1106	2-28-74	38.7	--	26	73	166	56	33	3.2	--	32	500	143	0.2	--	--	966	640	--	--	--	30	4.4	.08	3
1106	3-28-74	38.7	--	20	27	128	42	54	3.9	--	47	275	68	0.2	--	--	938	494	--	--	--	15	10	.07	3
1106	4-30-74	38.7	--	5.0	31	80	14	27	2.0	--	40	300	39	0.1	1.3	--	445	260	--	--	--	5	--	.11	3
1106	5-28-74	38.7	--	4.5	.75	84	24	40	19	--	67	160	95	0.2	3.3	--	943	280	--	--	--	50	9.0	.04	3
1106	7-01-74	38.7	--	.60	13	64	24	20	5.0	--	42	220	31	0.1	3.3	--	376	268	--	--	--	0	6.5	.04	3
1106	8-01-74	38.7	--	4.5	13	64	29	26	2.3	--	34	442	41	0.2	.06	--	404	289	--	--	--	10	6.5	.03	3
1106	8-27-74	38.7	--	.25	13	68	6.3	32	4.0	--	41	190	61	0.1	3.1	--	499	254	700	--	--	5	0.9	.01	3
1106	9-25-74	38.7	--	4.9	5.3	108	29	51	5.0	--	39	300	103	0.2	.06	--	725	370	585	--	--	10	7.0	.06	3
1107	10-23-73	39.6	--	.30	.02	8.0	2.4	3.4	2.2	--	10	22	10	0.0	4.4	--	69	30	110	--	--	5	0.4	.01	3
1107	11-26-73	39.6	--	--	.50	12	2.9	3.0	2.0	--	27	10	9	0.0	.44	--	71	42	118	--	--	5	0.3	.02	3
1107	12-28-73	39.6	--	.09	.44	12	4.4	3.7	1.8	--	27	22	6	0.0	2.2	--	76	48	140	--	--	5	6.4	.01	3
1108	10-19-73	35.4	--	.09	.03	9.8	1.9	6.3	2.0	--	6	28	12	0.1	6.6	--	83	36	128	--	--	5	0.2	.03	3
1108	11-26-73	35.4	--	--	.35	16	2.9	5.5	2.4	--	25	28	14	0.0	1.3	--	90	52	146	--	--	5	6.3	.06	3
1108	12-28-73	35.4	--	.21	.30	13	4.9	5.7	1.9	--	22	30	13	0.6	1.3	--	105	52	155	--	--	5	0.5	.03	3
1108	3-01-74	35.4	--	.08	.30	11	2.9	6.2	2.6	--	21	25	7	0.0	1.3	--	65	40	--	--	--	0	0.5	.01	3
1110	10-23-73	11.4	--	.05	.40	5.4	1.9	4.8	2.1	--	14	15	9	0.1	.00	--	53	22	--	--	--	5	.40	.04	3
1110	11-26-73	11.4	--	--	.38	4.0	1.0	6.0	8.2	--	14	3	9	0.1	.00	--	149	14	69	--	--	30	26	.01	3
1110	12-28-73	11.4	--	.12	.24	4.0	1.4	3.7	1.6	--	10	4	9	0.0	.00	--	32	18	48	--	--	5	1.0	.06	3
1110	1-31-74	11.4	--	1.5	.16	3.2	1.0	3.2	1.3	--	8	5	8	0.1	.00	--	67	12	--	--	--	5	2.4	.01	3
1110	2-28-74	11.4	--	1.0	.22	4.8	1.0	4.3	1.0	--	11	6	11	0.0	.00	--	41	36	--	--	--	10	6.4	.00	3
1110	3-28-74	11.4	--	.70	.30	4.6	1.6	3.3	2.5	--	10	3	11	0.1	.00	--	39	16	--	--	--	10	4.0	.01	3
1110	4-30-74	11.4	--	.38	.36	4.0	1.4	3.8	1.8	--	14	5	6	0.1	.00	--	53	14	--	--	--	0	0	.03	3
1110	5-28-74	11.4	--	.20	.39	4.8	1.5	4.6	2.0	--	14	4	5	0.1	.06	--	55	14	--	--	--	0	0.4	.03	3
1110	8-01-74	11.4	--	.06	.20	3.2	1.5	4.0	1.6	--	14	4	8	0.1	.06	--	44	15	--	--	--	0	1.9	.01	3
1146[b]	6-20-74	42.9	--	.08	.30	71	33	43	29	--	34	280	58	0.3	6.6	--	652	316	280	--	--	--	6.9	.13	3
1146[b]	6-20-74	42.9	--	.05	.16	73	36	43	36	--	38	320	66	0.3	6.6	--	664	334	320	--	--	--	0.9	.21	3
1147[b]	6-20-74	46.4	--	.03	3.3	31	14	22	31	--	15	130	68	0.3	6.6	--	314	134	224	--	--	5	6.4	.32	3
1147[b]	6-29-74	46.4	--	.16	.91	44	19	32	16	--	13	170	66	0.3	6.6	--	426	188	298	--	--	5	0.8	.29	3

[a] Field measurements taken by the Civil and Environmental Engineering Dept., University of Rhode Island or the Rhode Island Water Resources Board.

[b] Sample taken with air compressor--oil may have affected analyses.

Table 3

Figure 15

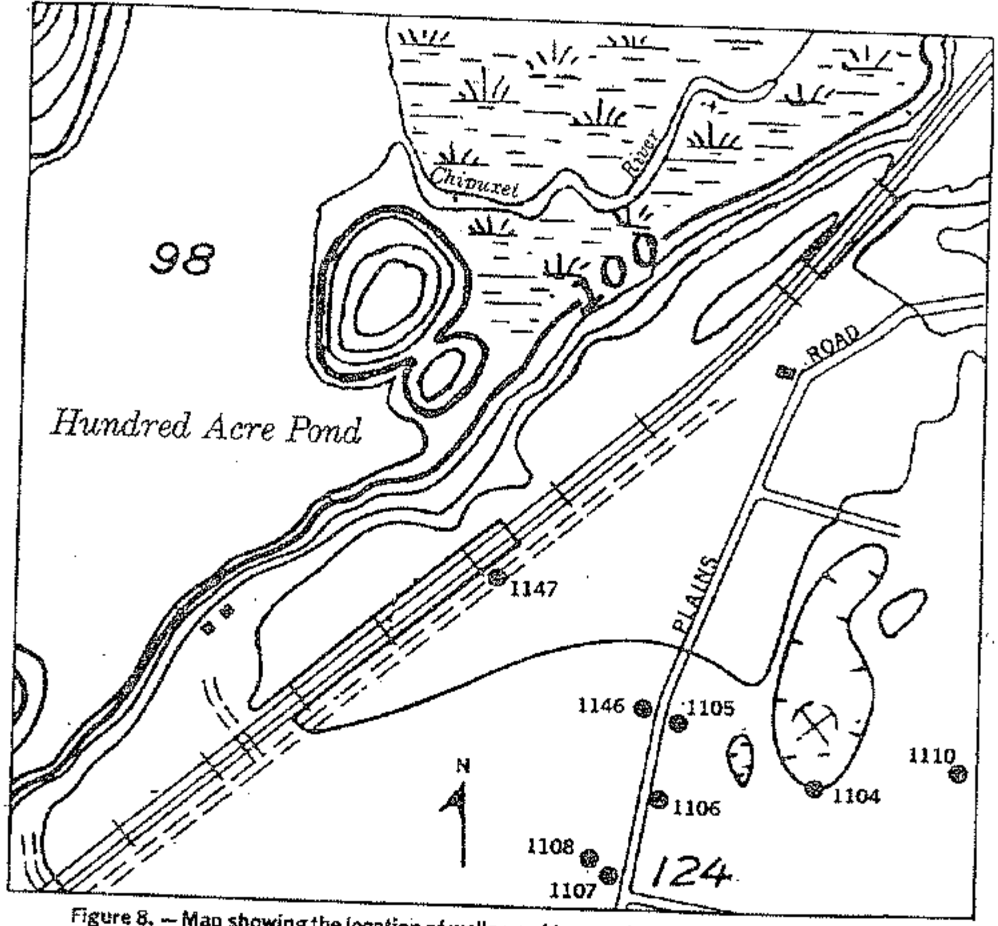
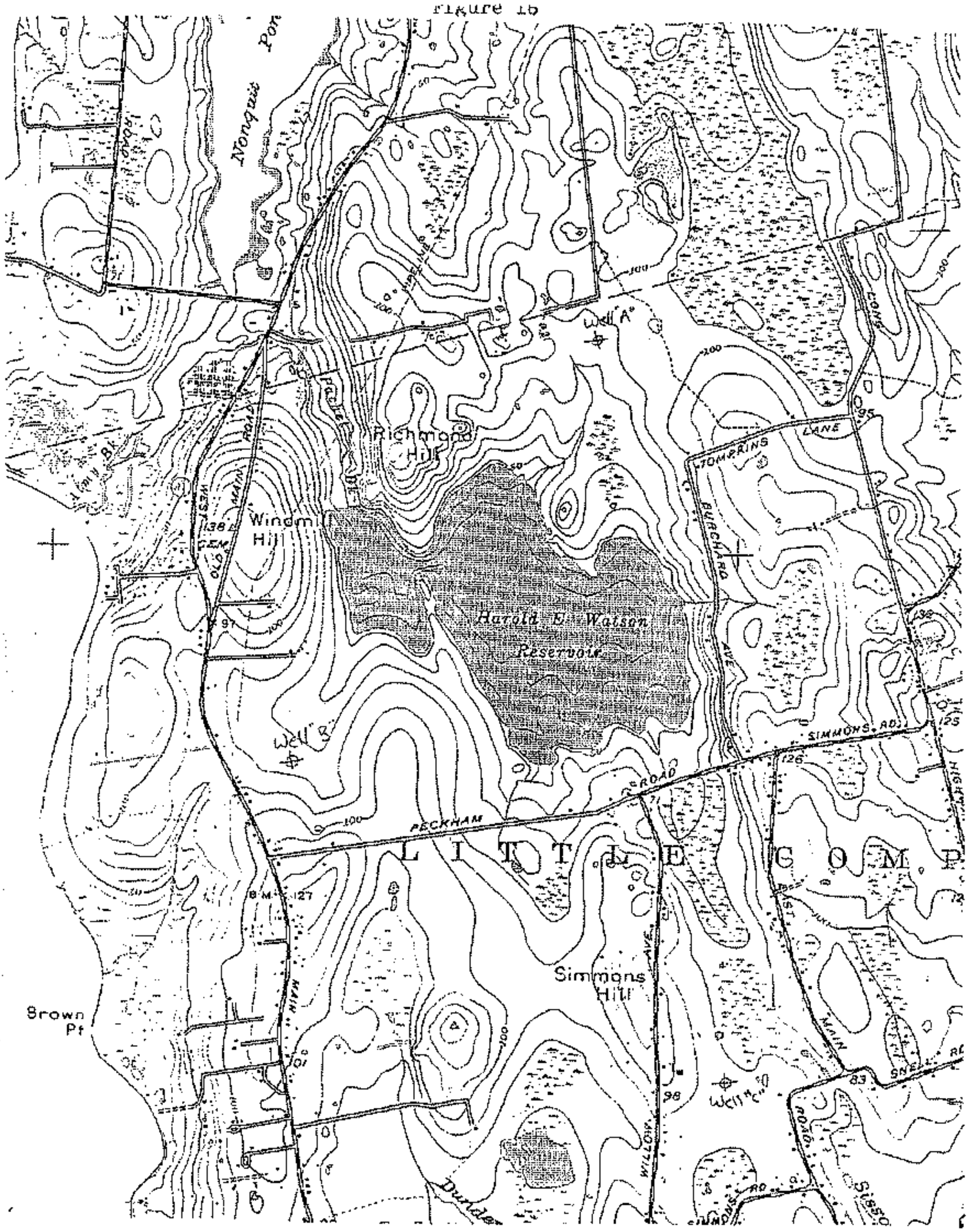


Figure 8. — Map showing the location of wells used to sample ground-water quality in the vicinity of the West Kingston landfill.

CONTOUR INTERVAL 10 FEET

Figure 16



Nonquit Pond
Almy Bk
Richmond Hill
Windmill Hill
Harold E. Watson Reservoir
Well "A"
Well "B"
Well "C"
OLD MAIN ROAD
MAIN RD
TOMPKINS LANE
BURCHARD AVE
SIMMONS RD
PECKHAM ROAD
LITTLE COMP
Simmons Hill
WILLOW AVE
MAIN ROAD
SISSON ROAD
Brown Pt
Dundery
100
138
97
95
126
125
B M 127
101
98
83

MONTHLY TOTAL WITHDRAWAL
SCITUATE RESERVOIR
1982

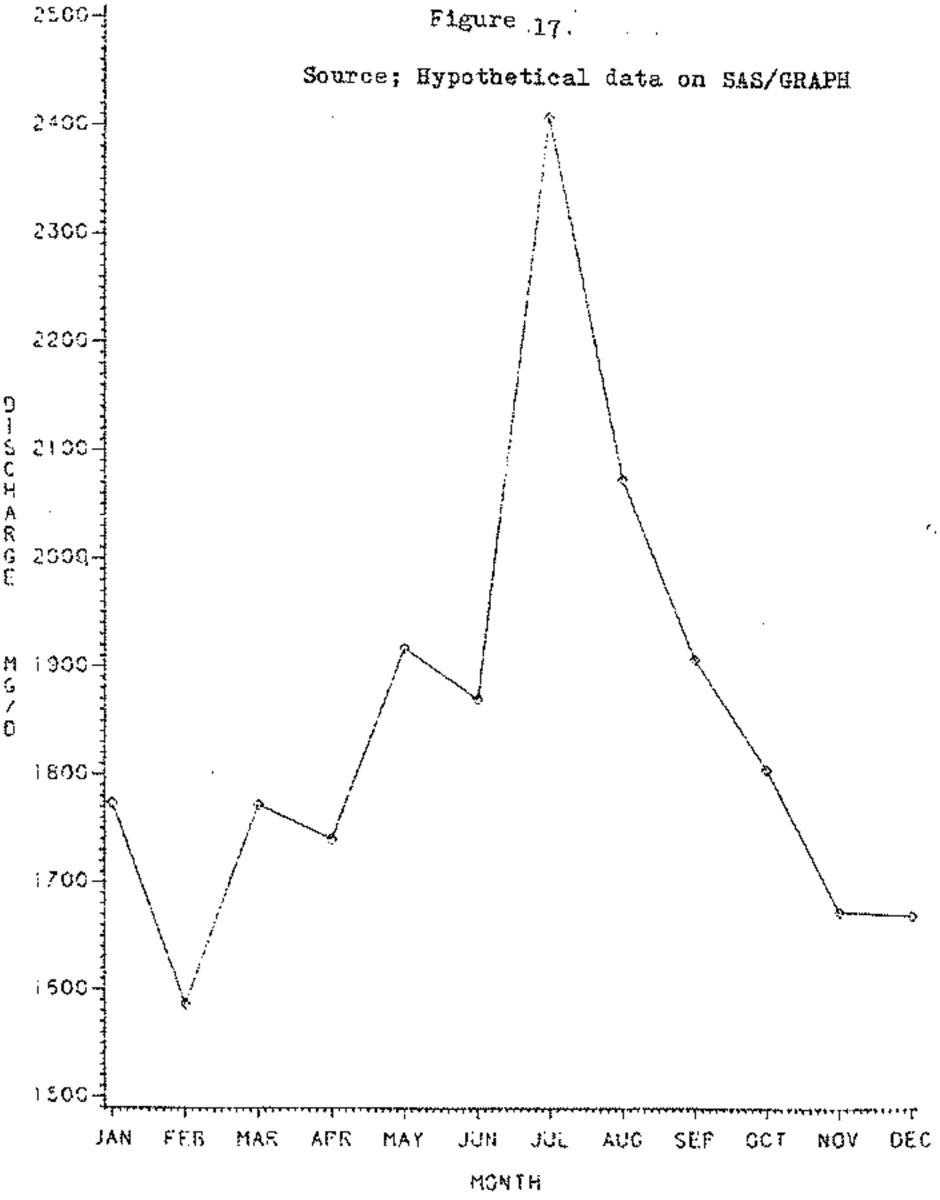


Figure 17.

Source; Hypothetical data on SAS/GRAPH

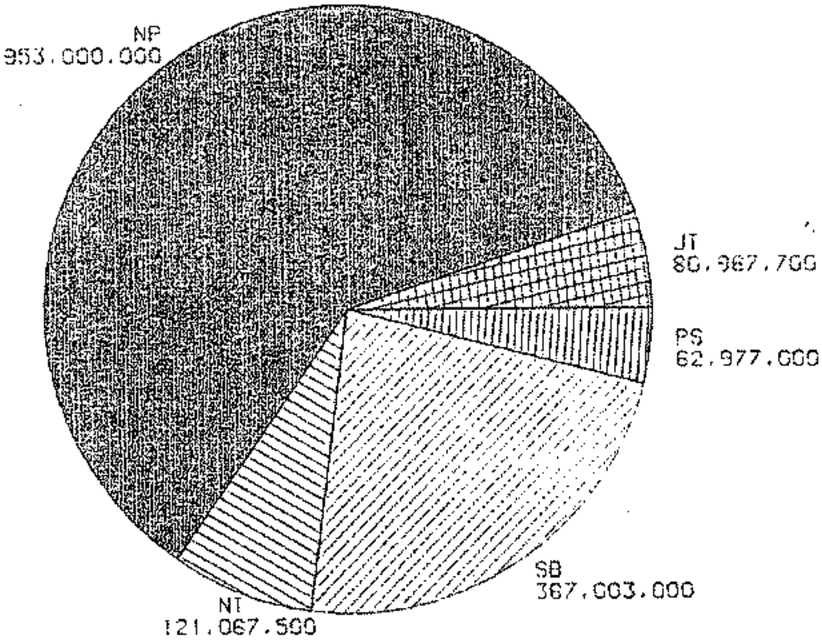
WATER USE BY TOWNS IN NEWPORT COUNTY

1983

SUM OF QUANTITY BY COUNTY

Figure 18

Source; Hypothetical data on SAS/GRAPH



PS=PORTSMOUTH NP=NEWPORT
SB=SOUTH BRIDGE NT=NORTH TIVERTON
JT=JAMESTOWN

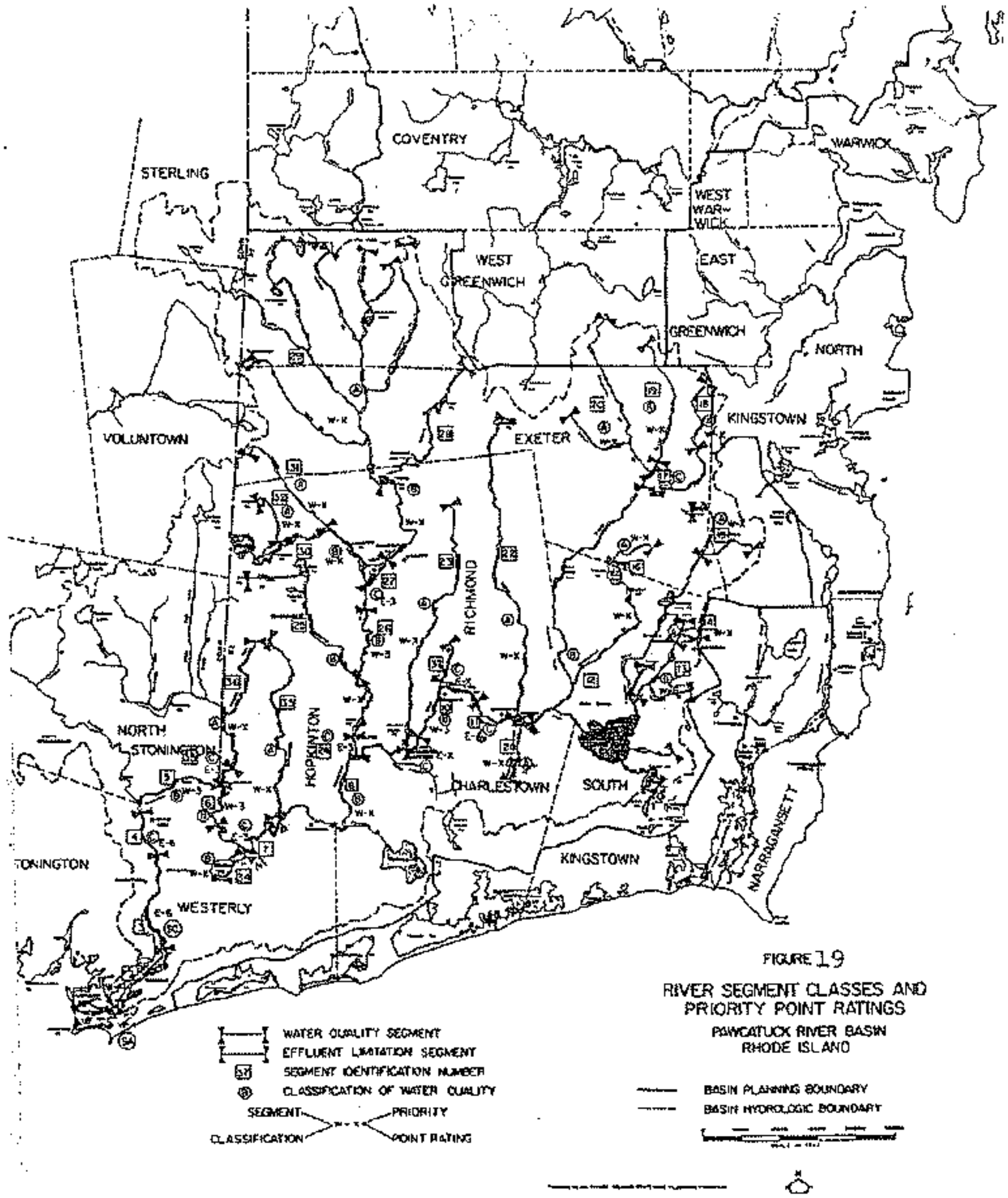


FIGURE 19

RIVER SEGMENT CLASSES AND PRIORITY POINT RATINGS

PAWCATUCK RIVER BASIN
RHODE ISLAND

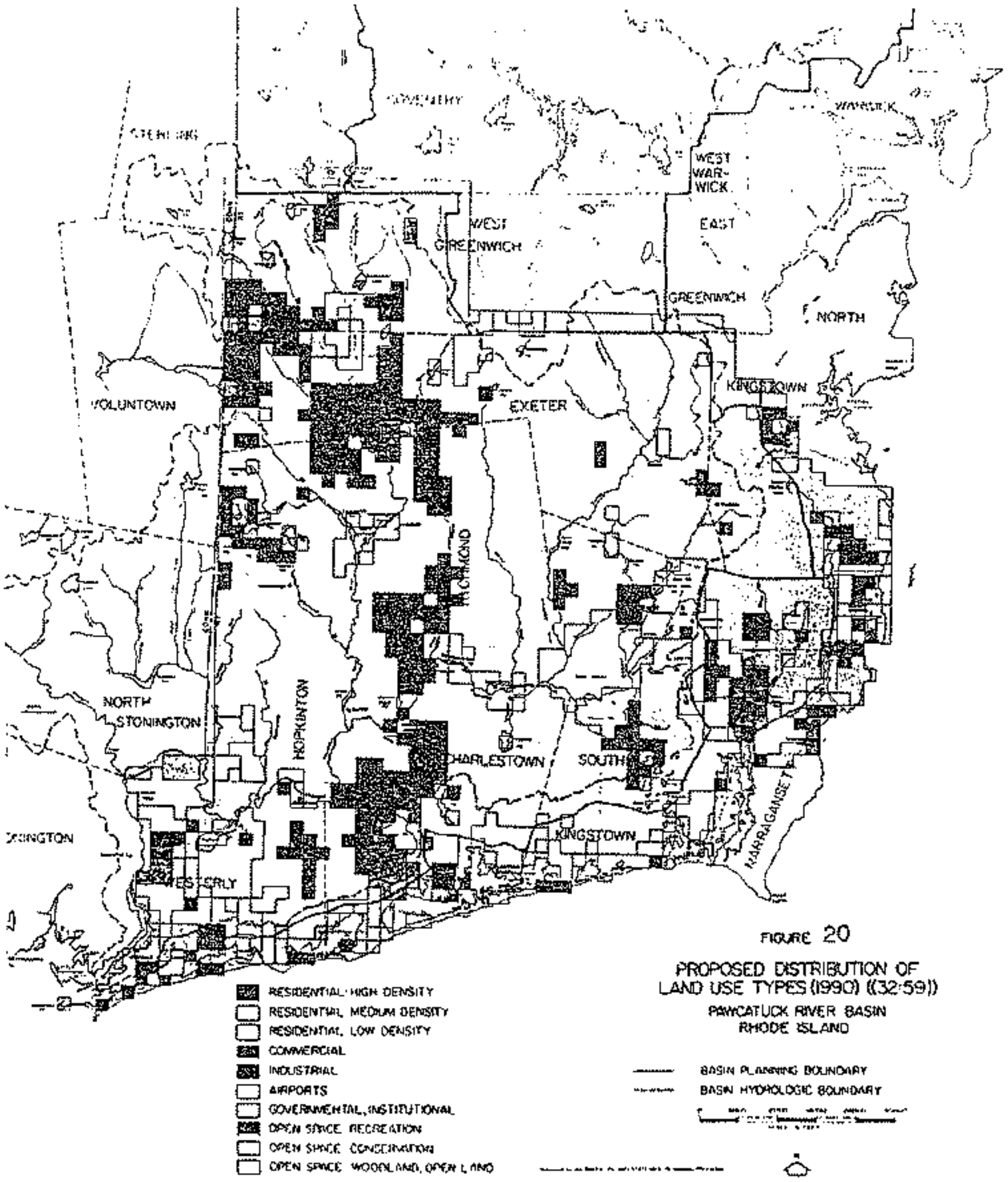


FIGURE 20

PROPOSED DISTRIBUTION OF LAND USE TYPES (1990) ((32:59))

PAWCATUCK RIVER BASIN
RHODE ISLAND

MONTHLY TOTAL PUMPAGE OF MISHNOCK
WELL NO.1
KENT COUNTY WATER AUTHORITY
1980

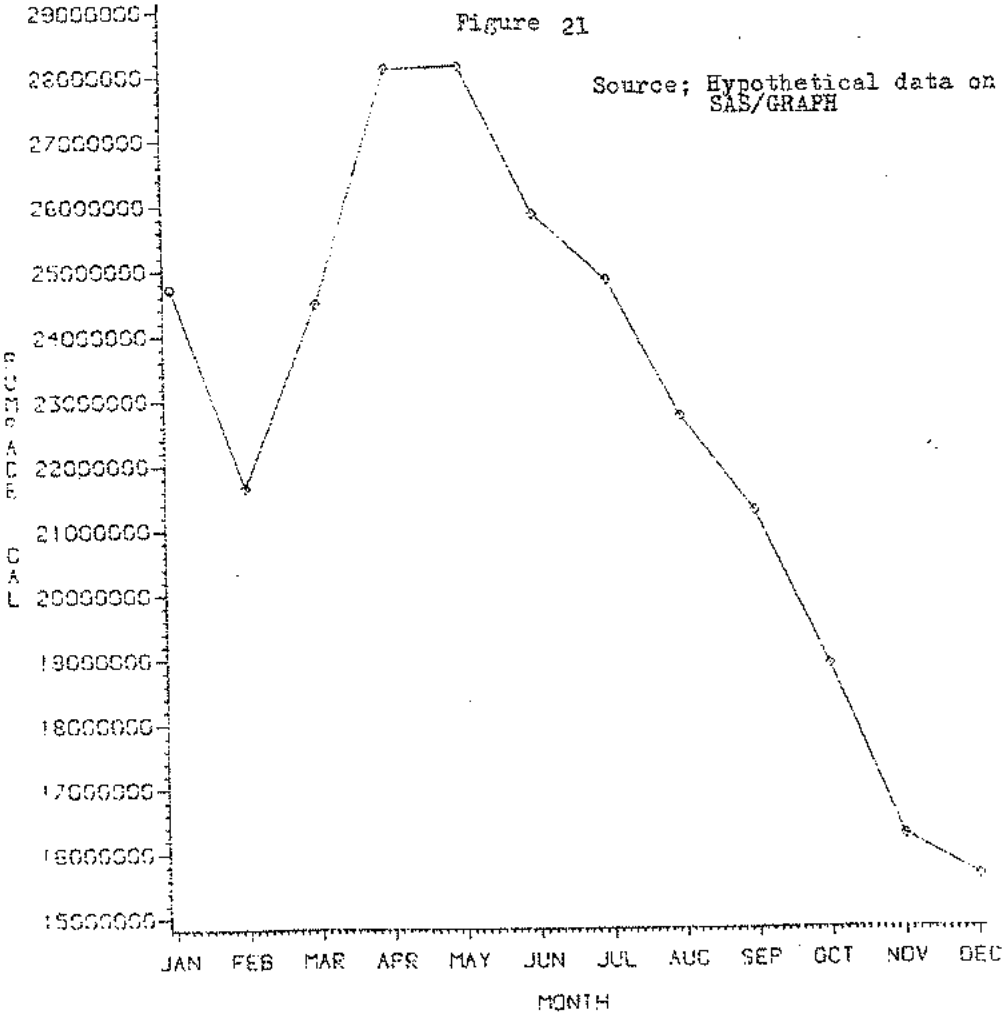


Figure 21

Source; Hypothetical data on SAS/GRAPH

Figure 22

Figure 22

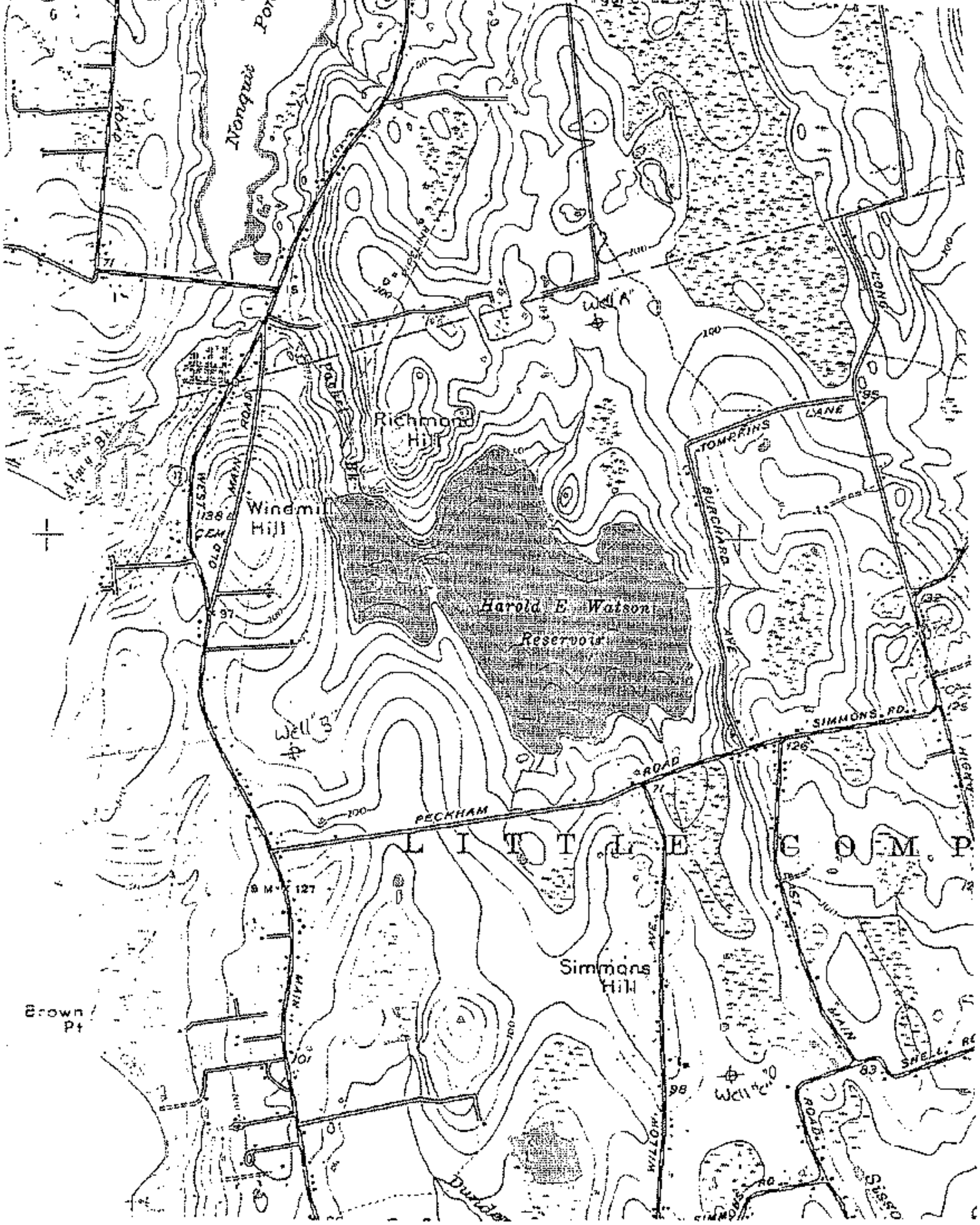
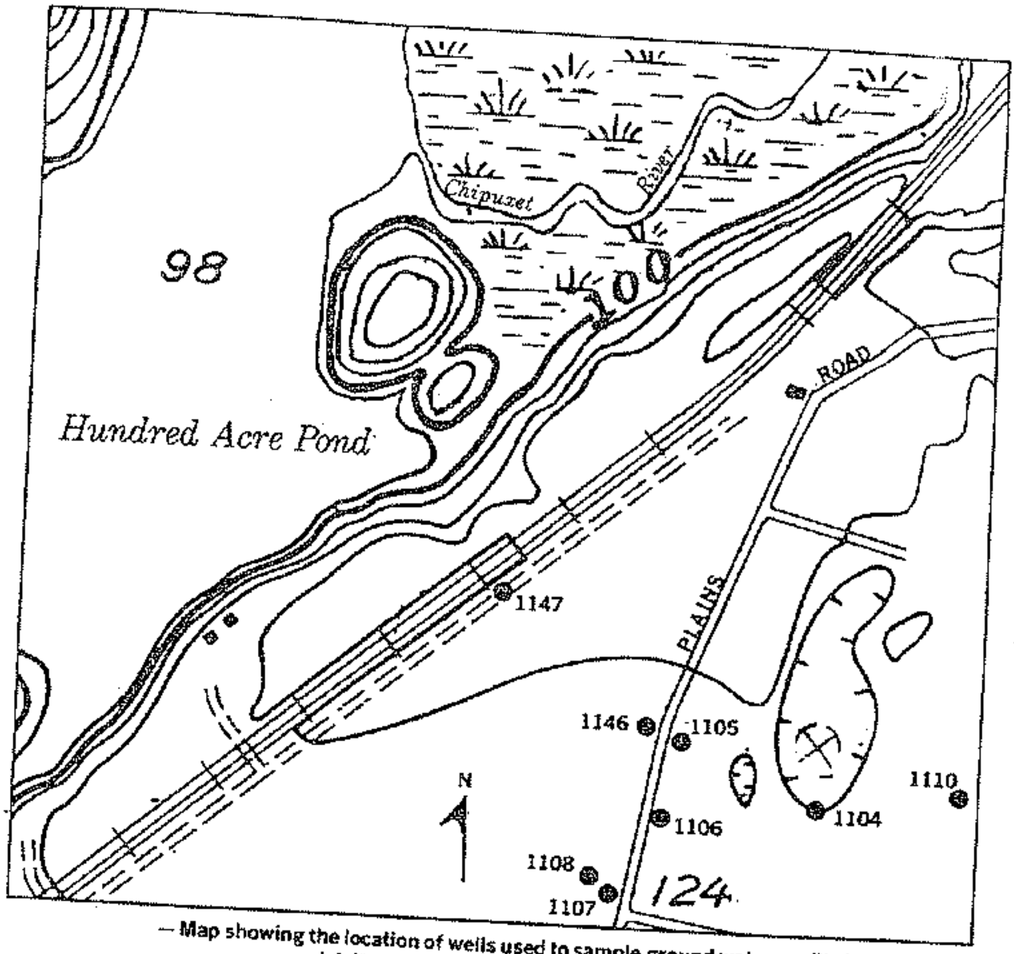


Figure 23



— Map showing the location of wells used to sample ground-water quality in the vicinity of the West Kingston landfill.

CONTOUR INTERVAL 10 FEET

	CONTACT PERSON	MAILING ADDRESS				TELEPHONE NUMBER
ABBEY ESTATES	PAUL NIELSEN	15 ABBY DRIVE	HEBRON	CT	06248	633-1164
ABBY MANNER CONVALESCENT HOME	GREIG YUSHA	ROUTE 14	WINDHAM	CT	06280	423-4636
ACRE LANE INC	ANTHONY PAPPAS	59 ACRE LANE	RIDGEFIELD	CT	06877	438-3342
ALDRICH HEIGHTS WATER CO	AL GRENIER	26 POND STREET	MOOSUP	CT	06354	564-3080
ALMA PROPERTIES	MR. BYINGTON	13 FIRST AVENUE	WATERBURY	CT	06710	757-9549
ANDOVER GARDEN APARTMENTS	BURR CARLSON	65 VALLEY VIEW DRIVE	SOUTH WINDSOR	CT	06074	646-1980
ANSONIA DERBY WATER CO	JOHN B. DEARBORN	230 BEAVER STREET	ANSONIA	CT	06401	735-1808
AQUA VISTA ASSOCIATION INC	MS. JULIE MAGEE	THADDEUS AVENUE	DANBURY	CT	06810	792-0297
ARLINGTON ACRES TRAILER PARK	JOHN N. MORAN	RFD #2 ROUTE 201	STONINGTON	CT	06378	536-1245
ARPIN CT. TRASK ART WELL CO	CHARLES TRASK	26 APT. 2, SHERATON LANE	NORWICH	CT	06360	889-3052
ARROW POINT WATER CO	R. J. BLACK & SONS	740 THOMASTON ROAD, BOX 1	WATERTOWN	CT	06795	354-3654
ARROWHEAD APARTMENTS	JIM KINSLEY	48 LANESVILLE ROAD	NEW MILFORD	CT	06676	354-3654
ARROWHEAD PT HOMEOWNERS ASSOC	WILLIAM SIDE	4 MORTON ROAD	BROOKFIELD	CT	06084	775-3294
ASHLAR OF NEWTOWN	ART SCHERER	TODDY HILL ROAD	NEWTOWN	CT	06470	426-5847
AUGUST HILL APARTMENTS	DAVID SCRANTON	303 MERLINE ROAD	VERNON	CT	06066	643-7244
AVERY HEIGHTS WATER ASSOCIATION INC	ED MILLER	52 SPRUCE LANE	SOUTH WINDSOR	CT	06074	644-2796
AVERY HILL WATER ASSOCIATION	JOANNE WAYLAND	129 AVERY HILL ROAD	LEDYARD	CT	06339	464-0684
AVON OLD FARMS SCHOOL	WALTER J. ULLRAN	500 OLD FARMS ROAD	AVON	CT	06001	673-3201
AVON WATER CO	JOHN A. O'NEIL	P.O. BOX 424	AVON	CT	06001	678-0001
BALL POND WATER DIST	LEROY BURKE	CANDLEWOOD SHORES	BROOKFIELD	CT	06804	775-9775
BANTAM PROPERTIES INC	RAY ZUKOWSKI	50 CIRCLE DRIVE	BANTAM	CT	06750	567-8117
BANTAM VILLAGE	ROBERT DADDARIO	110 MOUNTAIN ROAD, P.O. BOX 98	SUFFIELD	CT	06078	668-5342
BARBARA MANOR APARTMENTS	MR. SHAPIRO	150 NEWINGTON ROAD	WEST HARTFORD	CT	06110	236-5440
BARRETT DIV, SCWA	D. R. CRANDALL	P.O. BOX 415	GALES FERRY	CT	06335	464-0232
BAXTER FARMS COMMUNITY WATER ASSOC	WALTER JAMES	24 MEADOWWOOD ROAD	TOLLAND	CT	06084	875-1595
BAY MOUNTAIN SUBDIVISION	CHARLES J. RAJEWSKI	140 CANTERBURY TURNPIKE	NORWICH	CT	06360	887-8635
BEE BROOK CROSSING	BEE BROOK CONDO #1	P.O. BOX 242	WASH DEPOT	CT	06794	
BEECHWOOD MOBILE HOME PARK, JENSENS	KARL EIRIKSSON	P.O. BOX 600, 246 RED STONE ST	SOUTHINGTON	CT	06489	793-0281
BERKSHIRE CP, BETHEL CONSOL CO	RICHARD STEINER	BENEDICT ROAD	BETHEL	CT	06801	743-6465
BERLIN WATER CONTROL COMM	MARJORIE MARTINCHEK	240 KENSINGTON ROAD	BERLIN	CT	06037	828-7017
BETHEL WATER DEPT	LAWRENCE STRAITON	TOWN HALL LIBRARY PLACE	BETHEL	CT	06801	748-4413
BIG HORN LANE WATER ASSOC	ROBERT MCCORMACK	BIG HORN LANE	WOODSTOCK	CT	06282	974-1436
BIRCH GROVES ASSOCIATION INC	BRIAN J. FORD	21 MAPLE LANE	NEW MILFORD	CT	06776	354-9966
BIRCHWOOD ESTATES WATER ASSOC INC	BRUCE TOLHURST	21 ROBERTS ROAD	MARLBOROUGH	CT	06424	547-5125
BIRCHWOOD HEIGHTS ROAD SUPPLY	MILTON BEEBE	RR #3 BOX 12	STORRS	CT	06268	429-4740
BITGOOD ESTATE A D	RICHARD BOURQUE	P.O. BOX 572	MOOSUP	CT	06354	454-5419
BLACK POINT WATER CO	JOHN HOLLSCHLAGER	95 MAPLE AVENUE	MERIDEN	CT	06450	237-0785
BLUE TRAILS ASSOC	ROBERT REILLY	BARBARA LANE	DURHAM	CT	06422	484-0510
BOLTON ASSOCIATION APARTMENTS	CHARLES MINICUCCI	271 HOP RIVER ROAD	BOLTON	CT	06040	649-2871
BOULDER RIDGE ASSOCIATION	FRANCIS B. CARLO	BOULDER RIDGE ROAD	DANBURY	CT	06810	743-7651
BOXWOOD APARTMENTS	JOHNATHON BARRES	P.O. BOX 495	STONINGTON	CT	06378	535-4140
BRADLEY INTERNATIONAL AIRPORT	CLARENCE HANDY	BUILDING # 85	WINDSOR LOCKS	CT	06096	623-3940
BRIAR RIDGE, DANCON CORP	SAM SHOWAH	44 NORTH STREET	DANBURY	CT	06810	743-2050
BRIARWOOD COLLEGE FOR WOMEN	F. J. BUNDSCHUH	2279 MOUNT VERNON ROAD	SOUTHINGTON	CT	06489	628-4751
BRICK TOP APARTMENTS	JENNY DILLMAN	P.O. BOX 207	MANSFIELD	CT	06250	429-0991
BRIDGEPORT HYDRAULIC CO	ROBERT H. REINERT	P.O. BOX 702	BRIDGEPORT	CT	06609	367-6621
BRIDGEWATER COMMONS CONDOMINIUMS	KARL LANDT	11 BRIDGEWATER COMMON	BRIDGEWATER	CT	06752	966-3507
BRIERE COMMUNITY SUPPLY	THEODORE BRIERE	10 SMITH STREET BOX 310	PUTNAM	CT	06260	928-2667
BRISTOL WATER DEPT	JOHN H. KNIBBS	119 RIVERSIDE AVENUE	BRISTOL	CT	06010	582-7431
BROAD BROOK SEC, NO DIV, CTWC	ALEXANDER TARNOWICZ	25 NORTH ROAD	WAREHOUSE PT	CT	06088	623-3354
BROOK ACRES, RURAL WTR CO	ROBERT ALLEN	RD. 4 - DITTMAR ROAD	WEST REDDING	CT	06896	744-5459
BROOKFIELD DIV, RURAL WTR CO	ROBERT ALLEN	RD. 4 - DITTMAR ROAD	WEST REDDING	CT	06896	744-5459
BROOKFIELD HILLS CONDOMINIUMS	ANDREW BUZZI	64 LAKE AVENUE	DANBURY	CT	06810	792-5052
BROOKLYN CONVALESCENT HOME	EDWARD REESE	WOLF DEN ROAD, P.O. BOX 215	BROOKLYN	CT	06234	774-2260

Mailing Address of Water Suppliers; Table 4

ABBEY ESTATES	IN		G	100	25	0	
ABBY MANNER CONVALESCENT HOME	IN		G	105	0	0	
ACRE LANE INC	IN		G	56	14	0	
ALDRICH HEIGHTS WATER CO	IN		G	138	48	0	
ALMA PROPERTIES	IN		G	28	6	0	
ANDOVER GARDEN APARTMENTS	IN		G	64	32	0	
ANSONIA DERBY WATER CO	IN	A	SGP	32000	6626	6626	1,803.24
AQUA VISTA ASSOCIATION INC	IN		G	280	80	0	
ARLINGTON ACRES TRAILER PARK	IN		G	450	150	0	
ARPIN CT, TRASK ART WELL CO	UI	C	G	60	20	0	
ARROW POINT WATER CO	IN		G	200	49	0	
ARROWHEAD APARTMENTS	IN		G	136	34	0	
ARROWHEAD PT HOMEOWNERS ASSOC	HO	C	G	225	71	0	5.60
ASHLAR OF NEWTOWN	IN		G	156	0	0	
AUGUST HILL APARTMENTS	IN		G	120	0	0	
AVERY HEIGHTS WATER ASSOCIATION INC	IN		G	865	215	0	
AVERY HILL WATER ASSOCIATION	IN		G	150	46	0	
AVON OLD FARMS SCHOOL	IN		G	480	24	0	
AVON WATER CO	IN	A	G	6800	1667	1667	217.38
BALL POND WATER DIST	IN	C	G	640	213	0	18.04
BANTAM PROPERTIES INC	IN		G	240	49	0	
BANTAM VILLAGE	IN		G	40	0	0	
BARBARA MANOR APARTMENTS	IN		G	300	100	0	
BARRETT DIV, SCWA	UR	A	G	270	74	74	
BAXTER FARMS COMMUNITY WATER ASSOC	IN		G	160	42	0	
BAY MOUNTAIN SUBDIVISION	IN		G	60	0	0	
BEE BROOK CROSSING	IN		G	30	0	0	
BEECHWOOD MOBILE HOME PARK, JENSENS	IN		G	460	260	0	
BERKSHIRE CP, BETHEL CONSOL CO	UI	B	G	0	12	12	1.04
BERLIN WATER CONTROL COMM	MU	A	GP	1780	774	774	218.30
BETHEL WATER DEPT	MU	A	SG	8339	2137	2135	324.98
BIG HORN LANE WATER ASSOC	IN		G	40	0	0	
BIRCH GROVES ASSOCIATION INC	IN		G	280	70	0	
BIRCHWOOD ESTATES WATER ASSOC INC	IN		G	184	46	0	
BIRCHWOOD HEIGHTS ROAD SUPPLY	IN		G	72	0	0	
BITGOOD ESTATE A D	IN		G	96	24	0	
BLACK POINT WATER CO	IN	C	G	3200	272	0	8.30
BLUE TRAILS ASSOC	HO		G	216	54	0	
BOLTON ASSOCIATION APARTMENTS	IN		G	72	24	0	
BOULDER RIDGE ASSOCIATION	IN		G	33	0	0	
BOXWOOD APARTMENTS	IN		G	44	0	0	
BRADLEY INTERNATIONAL AIRPORT	ST		G	6500	0	0	140.83
BRIAR RIDGE, DANCON CORP	UI	A	G	276	75	75	
BRIARWOOD COLLEGE FOR WOMEN	IN		G	375	0	0	
BRICK TOP APARTMENTS	IN		G	224	50	0	
BRIDGEPORT HYDRAULIC CO	UI	A	SGP	374329	88331	82347	22,411.73
BRIDGEWATER COMMONS CONDOMINIUMS	IN		G	34	17	0	
BRIERE COMMUNITY SUPPLY	IN		G	78	25	0	
BRISTOL WATER DEPT	MU	A	SG	51495	14231	14231	1,737.61
BROAD BROOK SEC, NO DIV, CTWC	UI	A	G	749	216	214	46.56
BROOK ACRES, RURAL WTR CO	UI	A	G	200	0	0	
BROOKFIELD DIV, RURAL WTR CO	UI	A	G	870	290	0	
BROOKFIELD HILLS CONDOMINIUMS	IN		G	108	36	0	
BROOKLYN CONVALESCENT HOME	IN		G	44	0	0	

Alphabetical general description of water suppliers, Table 5

Towns served by a supplier, ranked alphabetically, Table 6

COMMUNITY WATER SUPPLY	TYPE OF OWNERSHIP	DPUC CLASS	WATER TYPE	TOWN SERVED	1981 RESIDENTIAL POPULATION SERVED
ABBEY ESTATES	IN		G	HEBRON	100
ABBY MANNER CONVALESCENT HOME	IN		G	WINDHAM	105
ACRE LANE INC	IN		G	RIDGEFIELD	56
ALDRICH HEIGHTS WATER CO	IN		G	PLAINFIELD	138
ALMA PROPERTIES	IN		G	WOLCOTT	28
ANDOVER GARDEN APARTMENTS	IN		G	ANDOVER	64
ANSONIA DERBY WATER CO	IN	A	SGP	ANSONIA DERBY SEYMOUR	20500 11500 0 ****** 32000
AQUA VISTA ASSOCIATION INC	IN		G	DANBURY	200
ARLINGTON ACRES TRAILER PARK	IN		G	STONINGTON	450
ARPIN CT, TRASK ART WELL CO	UI	C	G	NORWICH	60
ARROW POINT WATER CO	IN		G	WARREN	200
ARROWHEAD APARTMENTS	IN		G	NEW MILFORD	136
ARROWHEAD PT HOMEOWNERS ASSOC	HO	C	G	BROOKFIELD	225
ASHLAR OF NEWTOWN	IN		G	NEWTOWN	156
AUGUST HILL APARTMENTS	IN		G	ASHFORD	120
AVERY HEIGHTS WATER ASSOCIATION INC	IN		G	SOUTH WINDSOR	865
AVERY HILL WATER ASSOCIATION	IN		G	LEDYARD	150
AVON OLD FARMS SCHOOL	IN		G	AVON	480
AVON WATER CO	IN	A	G	AVON SIMSBURY	5700 1100 ------ 6800
BALL POND WATER DIST	IN	C	G	NEW FAIRFIELD	640
BANTAM PROPERTIES INC	IN		G	LITCHFIELD	240
BANTAM VILLAGE	IN		G	LITCHFIELD	40
BARBARA MANOR APARTMENTS	IN		G	WILLINGTON	300
BARRETT DIV, SCWA	UR	A	G	LEDYARD	270

56254	MERIDEN WATER DEPT	MU	A	SG	15000	14853	2,144.73
56000	GREENWICH DIST, CT-AM WATER CO	UI	A	S	15000	15000	5,074.66
51495	BRISTOL WATER DEPT	MU	A	SG	14231	14231	1,737.61
50409	WESTERN SEC, NO DIV, CTWC	UI	A	GP	14402	14233	1,717.36
48000	NEW LONDON WATER DEPT	MU	A	S	11334	9703	1,973.83
47000	MANCHESTER WATER DEPT	MU	A	SG	12571	12571	1,912.62
45185	NORWICH PUBLIC UTILITIES DEPT	MU	A	S	8538	8408	1,572.70
43604	GUILFORD SYS, G-C DIV, CTWC	UI	A	SG	12542	12458	1,142.63
40000	NORWALK 1ST TAX DIST WATER DEP	MU	A	SGP	10350	10350	1,847.08
38048	NORWALK 2ND TAX DIST WATER DEP	MU	A	S	8544	8544	2,027.94
38000	DANBURY PUBLIC UTILITIES DEPT	MU	A	SG	8147	737	2,821.10
37000	WALLINGFORD WATER DEPT	MU	A	SG	8921	8713	1,843.74
36500	MIDDLETOWN WATER DEPT	MU	A	SG	8084	8075	1,625.34
33200	GROTON UTILITIES DEPT	MU	A	S	4990	4507	3,806.18
32000	ANSONIA DERBY WATER CO	IN	A	SGP	6626	6626	1,803.24
31125	SOUTHINGTON WATER WORKS DEPT	MU	A	SG	8379	8379	1,376.58
23700	UNIVERSITY OF CONNECTICUT	ST		G	0	0	
21160	TORRINGTON WATER CO, MAIN SYS	UI	A	S	0	0	1,706.98
20099	NOROTON DIST, CT-AM WATER CO	UI	A	GP	5812	5778	733.48
19761	NAUGATUCK DIV, CT WATER CO	UI	A	SG	5703	5646	1,072.84
18638	PLAINVILLE WATER CO	IN	A	GP	4581	4575	1,077.65
17500	HAZARDVILLE WATER CO	IN	A	G	5599	5186	566.86
16400	WILLIMANTIC WATER DEPT	MU	A	S	0	0	914.53
15222	ROCKVILLE DIV, CT WATER CO	UI	A	S	4423	4349	1,137.20
13950	RIDGEFIELD WATER SUPPLY CO	IN	A	SG	1747	1747	291.90
12000	WATERTOWN WATER & SEWER AUTH	MU	A	P	0	0	373.44
11500	VILLAGE WATER CO OF SIMSBURY	IN	A	G	3848	3812	577.06
10795	EAST LYME WATER COMM	MU	A	G	3175	3175	281.07
9806	MYSTIC VALLEY DS, CT-AM WTR CO	UI	A	SG	3053	3053	500.86
9000	CRYSTAL WATER CO OF DANIELSON	UI	A	SG	1773	881	398.30
9000	CROMWELL FIRE DIST WATER DIV	MU	A	G	1982	1974	330.70
9000	KENSINGTON FIRE DIST	MU	A	P	2508	2508	
9000	WINSTED WATER WORKS DEPT	MU	A	S	2308	38	898.20
8339	BETHEL WATER DEPT	MU	A	SG	2137	2135	324.98
8211	NEW CANAAN WATER CO	IN	A	SG	3041	3041	375.31
7400	WESTERLY WTR DEP PAWCATUCK SEC	MU		G	0	0	
7071	CHESTER SYS, G-C DIV, CTWC	UI	A	SG	2056	2020	226.66
6918	PUTNAM WATER DEPT	MU	A	SG	1941	170	595.50
6800	AVON WATER CO	IN	A	G	1667	1636	217.38
6676	UNIONVILLE WATER CO	IN	A	GP	1678	1675	233.20
6600	WATERTOWN FIRE DIST	MU	A	GP	0	0	271.70
6600	NAVAL SUB BASE NEW LONDON	FE		P	0	0	
6500	PORTLAND WATER WORKS DEPT	MU	A	SG	1915	1881	224.47
6500	BRADLEY INTERNATIONAL AIRPORT	ST		G	0	0	140.85
6450	PLAINFIELD GREYHOUND	IN		G	0	0	
6300	WORTHINGTON FIRE DIST	MU	A	P	1011	1007	
6110	JEWETT CITY WATER CO	IN	A	SG	1196	696	190.07
5716	TERRYVILLE DIV, CT WATER CO	UI	A	SG	1655	1603	175.42

General description of water suppliers by population served

Table 7

		POPULATION SERVED	PERCENT	SELF SUPPLIED POPULATION	PERCENT	1981 TOWN POPULATION
ANDOVER	ANDOVER GARDEN APARTMENTS	64	2.9 %			
	HOP RIVER HOMES	48	2.2			
		******	*****			
		112	5.1 %	2000	94.9 %	2200
ANSONIA	ANSONIA DERBY WATER CO	20500	107.9 %			
		******	*****			
		20500	107.9 %	-1500	-7.9 %	19000
ASHFORD	CAMP CONNRI	300	9.2 %			
	LEDGEMERE APARTMENTS	130	4.0			
	AUGUST HILL APARTMENTS	120	3.7			
	WOODLAWN APARTMENTS	102	3.1			
	PERRY HILL ESTATES APARTMENTS INC	100	3.1			
	SQUAW HOLLOW ASSOC INC	72	2.2			
	MAR-LEA PARK APARTMENTS	52	1.6			
	SCRANTON ACRES APARTMENTS	45	1.4			
	EVANGELICAL BAPTIST CAMP & HOME	37	1.1			
	RICE APARTMENTS	13	0.4			
		******	*****			
		971	29.9 %	2279	70.1 %	3250
AVON	AVON WATER CO	5700	50.0 %			
	UNIONVILLE WATER CO	1036	9.1			
	FARMINGTON WOODS WATER CO	1030	9.0			
	COLLINSVILLE DIV, CT WATER CO	494	4.3			
	AVON OLD FARMS SCHOOL	480	4.2			
	TOW PATH APARTMENTS	114	1.0			
	REID TREATMENT CENTER	30	0.3			
		******	*****			
		8884	77.9 %	2516	22.1 %	11400
BARKHAMSTED	ROCK TREE APARTMENTS	55	1.9 %			
	WALLENS HILL APARTMENTS	50	1.7			
	PLEASANT VALLEY APARTMENTS	45	1.5			
	RIDGEWOOD APARTMENTS	25	0.8			
		******	*****			
		175	5.9 %	2775	94.1 %	2950
BEACON FALLS	BRIDGEPORT HYDRAULIC CO	1834	45.8 %			
	NAUGATUCK DIV, CT WATER CO	228	5.7			
		******	*****			
		2062	51.5 %	1938	48.5 %	4000
BERLIN	KENSINGTON FIRE DIST	9000	59.1 %			
	WORTHINGTON FIRE DIST	6300	41.4			
	BERLIN WATER CONTROL COMM	1780	11.7			
	NEW BRITAIN WATER DEPT	200	1.3			
	MERIDEN WATER DEPT	4	0.0			
		******	*****			
		17284	113.6 %	-2064	-13.6 %	15220

Table 8

MONTHLY TOTAL PUMPAGE OF MISHNOCK
WELL NO.1
KENT COUNTY WATER AUTHORITY
1980

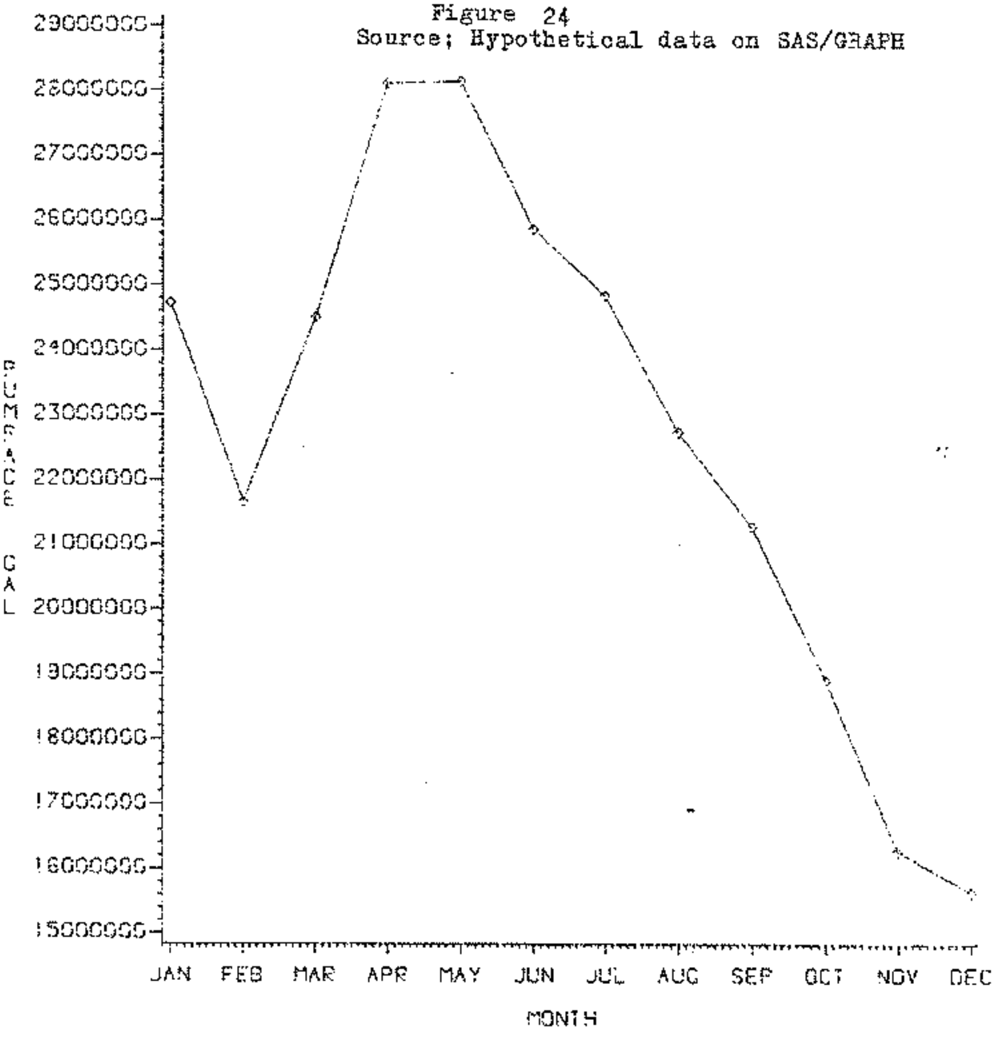
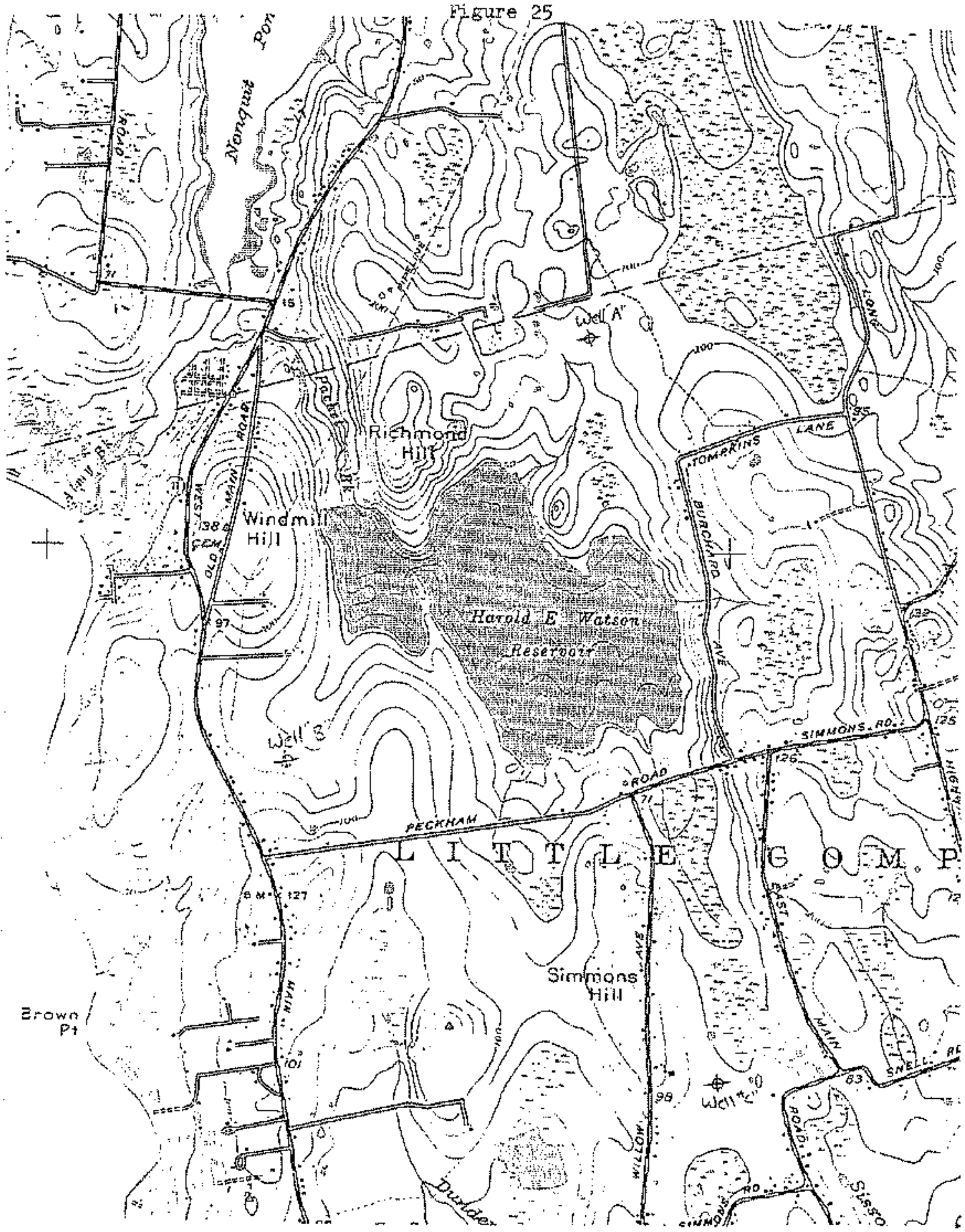


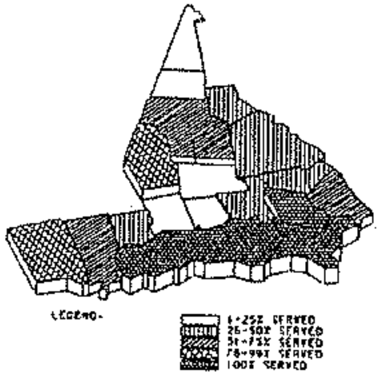
Figure 24
Source; Hypothetical data on SAS/GRAPH

Figure 25



Nonquit Pon
ROAD
Richmond Hill
Windmill Hill
WEST MAIN ROAD
OLD CEM
138
97
15
71
Well "A"
100
Harold E. Watson Reservoir
Well "B"
TOMPKINS LANE
BURCHARD AVE
SIMMONS RD.
125
126
132
PECKHAM ROAD
L I T T L E C O M P
B M 127
MAIN
EAST MAIN
Simmons Hill
WILLOW AVE
98
Well "C"
83
SNELL RD
ROAD
SIMMONS RD
Sisso
Dundee
Brown Pt
101
HIGHW

Anywhere County



Percent of Town Population Served by Community Water Supplies in 1981

Table 9

In 1981, 84 percent of county County was served by community water supplies. The remaining 16 percent was self-supplied and relied on private residential wells.

Community water supplies sold water to all customers at an average annual rate of 105.9 mgd. Sales exclusively to residential customers amounted to 54.1 mgd or about 51 percent of the total water use. 1981 Per capita water use, based on sales of water to residential customers, was estimated to be 80 gallons per person per day.

	1981 POPULATION	SELF SUPPLIED POPULATION	POPULATION ON COMMUNITY WATER SUPPLIES	PERCENT POP. SERVED
BETHEL	16120	5466	10654	66.1
BRIDGEPORT	142060	-12271	154331	108.6
BROOKFIELD	13000	6631	6369	49.0
DANBURY	60720	16566	44154	72.7
DARIEN	18900	-1030	19930	105.4
EASTON	5990	2999	2991	49.9
FAIRFIELD	54960	-6650	61610	112.1
GREENWICH	59600	3485	56115	94.2
MONROE	14200	9889	4311	30.4
NEW CANAAN	18100	10027	8073	44.6
NEW FAIRFIELD	11420	9384	2036	17.8
NEWTOWN	19370	12659	6711	34.6
NORWALK	77770	-407	78177	100.5
REDDING	7320	6960	360	4.9
RIDGEFIELD	20180	4131	16049	79.5
SHELTON	31380	8700	22680	72.3
SHERMAN	2330	1826	504	21.6
STAMFORD	102200	36960	65240	63.8
STRATFORD	50900	-2115	53015	104.2
TRUMBULL	32700	-3135	35835	109.6
WESTON	8400	8008	392	4.7
WESTPORT	25530	-2578	28108	110.1
WILTON	15550	14765	785	5.0
	======	======	======	====
	808700	130270	678430	83.9

Conclusions

The results of this research have led to the conclusion that an up-to-date information system is necessary for the state of Rhode Island and can be provided and maintained at relatively low cost. Environmental information systems are currently being used by many agencies throughout the nation and would be a powerful tool for Rhode Island to utilize for resource management and protection. Pollution of water resources by toxic wastes, pesticides, sewage, urban run-off, and other means have made the job of pollution control much more complex. The use of a computerized data base would facilitate data analysis of Rhode Island's water resources, hopefully preventing pollution, water supply shortages, and other potential problems, through the early recognition of undesirable trends.

The powerful data management tools being developed for the RIWUDS at no cost to the state are an attractive first step in bringing Rhode Island up to a state-of-the-art information system to protect our limited water resources. The wide range of hardware presently available to the system also makes it immediately accessible once the software is complete and data can be input to the system. The variety of peripheral computer devices as well as the large pool of expertise which can be called upon add to the attractiveness of the system. Finally, the flexibility of the system to interconnect or merge with other systems in the future must be considered. Utilizing the remote sensing equipment and the map generating capability at the Graduate School of Oceanography would give the system the power to tackle the most complex of environmental data management problems. Also, the system will be flexible to interaction with other information systems which develop privately within other state agencies. Ideally, the development of the proposed RIWUDS will be the impetus needed to organize a network system throughout Rhode Island, whereby data can be quickly and easily retrieved and exchanged by those agencies, researchers, and individuals who most need them. The establishment of this system will help to insure that Rhode Island water resources are always of the highest possible quality.

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Appendix

DATA ELEMENTS GROUPING

NO.	DATA ELEMENT	SOURCE	FORMAT	REMARK	GROUP TITLE
1	INVENTORY UNIT IDENTIFIER	CT,P112	19-C	CT17	AMOUNT
2	WITHDRAWAL/RETURN CODE	CT,P113	1-C	CT17	AMOUNT
3	WITHDRAWAL/RETURN SIC CODE	CT,P114	4-D	CT17	AMOUNT
4	REPORTING YEAR (date)	CT,P115	4-D	CT17	AMOUNT
5	WATER TYPE	CT,P116	1-C	CT17	AMOUNT
6	ANNUAL AMOUNT	CT,P117	9-D	CT17	AMOUNT
7	ANNUAL COST	CT,P118	9-D	CT17	AMOUNT
8	REQUIRED MINIMAL FLOW	CT,P119		CT17	AMOUNT
9	MINIMUM DEPTH	CT,P120		CT17	AMOUNT
10	HEAD	CT,P121	3-D	CT17	AMOUNT
11	LOW FLOW AUGMENTATION	CT,P122	7-D	CT17	AMOUNT
12	MINIMUM INFLOW	CT,P123		CT17	AMOUNT
13	MAXIMUM INFLOW	CT,P124		CT17	AMOUNT
14	MINIMUM OUTFLOW	CT,P125		CT17	AMOUNT
15	MAXIMUM OUTFLOW	CT,P126		CT17	AMOUNT
16	MINIMUM DAILY USE	CT,P127	7-D	CT17	AMOUNT
17	DAY OF MINIMUM USE	CT,P128	3-D	CT17	AMOUNT
18	MAXIMUM DAILY USE	CT,P129	7-D	CT17	AMOUNT
19	DAY OF MAXIMUM USE	CT,P130	3-D	CT17	AMOUNT
20	MEASURING METHOD	CT,P131	1-C	CT17	AMOUNT
21	MEASURING ENTITY	CT,P132	30-C	CT17	AMOUNT
22	MEASURING ACCURACY	CT,P133	1-C	CT17	AMOUNT
23	WATER QUALITY AVAILABLE	CT,P134	1-C	CT17	AMOUNT
24	NWUDS WASTEWATER TREATMENT TYPE	CT,P135	1-C	CT17	AMOUNT
25	TYPE OF TREATMENT	CT,P136	2-D	CT17	AMOUNT
26	WASTEWATER	CT,P137	1-C	CT17	AMOUNT
27	RESTRICTIONS	CT,P138	1-C	CT17	AMOUNT
28	PERMITS	CT,P139	1-C	CT17	AMOUNT
29	WATER SOURCE IDENTIFIER	CT,P93	19-C	CT13	ASSOC. WATER SOURC

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           31 FACILITY IDENTIFIER                      CT,P209     19-C    CT27        ASSOCIATED LANDFILLS

           32 WATER SOURCE IDENTIFIER                  CT,P210     19-C    CT27        ASSOCIATED LANDFILL

           33 RIVER MILE                               CT,P211     5-D     CT27        ASSOCIATED LANDFI

           34 LOW FLOW (7 DAY/10 YEAR)                 CT,P212             CT27        ASSOCIATED LANDFILLS

           35 TOTAL COLIFORMS                          DOH (WELL)  6.0     ANNUALLY    BACTERIOLOGICAL

           36 FECAL COLIFORMS                          DEM         6.0     WEEKLY      BACTERIOLOGICAL -NARR
 AGANSETT BAY
           37 TOTAL COLIFORMS                          DEM         6.0     WEEKLY      BACTERIOLOGICAL -NARR
 AGANSETT BAY
           38 FECAL COLIFORMS                          DEM         6.0     BIANNUALLY  BACTERIOLOGICAL -SH
 LFISH AREAS
           39 TOTAL COLIFORMS                          DEM         6.0     BIANNUALLY  BACTERIOLOGICAL -SHEL
 LFISH AREAS
           40 FECAL COLIFORMS                          DEM         6.0     ANNUALLY    BATHING AREA SAMPLING

           41 TOTAL COLIFORMS                          DEM         6.0     ANNUALLY    BATHING AREA SAMPLI

           42 COLIFORM (FECAL 0.7 UM-MF)               USGS                            BIOLOGICAL

           43 COLIFORM (TOTAL IMMED)                   USGS                            BIOLOGICAL

           44 STREPTOCOCCI (FECAL,KF AGAR)             USGS                            BIOLOGICAL

           45 ALDRIUM (TOTAL IN BOTTOM MATERIAL)       USGS                            CHEMICAL

           46 ALDRIUM (TOTAL)                          USGS                            CHEMICAL

           47 ALUMINUM                                 USGS                            CHEMICAL

           48 ARSENIC                                  USGS                            CHEMICAL

           49 ARSENIC (SUSPENDED TOTAL)                USGS                            CHEMICAL

           50 ARSENIC (TOTAL)                          USGS                            CHEMICAL

           51 BARIUM                                   USGS                            CHEMICAL
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DATA ELEMENTS GROUPING

NO.	DATA ELEMENT	SOURCE	FORMAT	REMARK	GROUP TITLE
52	BARIUM (SUSPENDED RECOVERABLE)	USGS			CHEMICAL
53	BARIUM (TOTAL RECOVERABLE)	USGS			CHEMICAL
54	BERYLLIUM	USGS			CHEMICAL
55	BORON (TOTAL RECOVERABLE)	USGS			CHEMICAL
56	CADMIUM	USGS			CHEMICAL
57	CADMIUM (TOTAL RECOVERABLE)	USGS			CHEMICAL
58	CALAIUM	USGS			CHEMICAL
59	CHLORDANE (TOTAL IN BOTTOM MATERIAL)	USGS			CHEMICAL
60	CHLORDANE (TOTAL)	USGS			CHEMICAL
61	CHLORIDE	USGS			CHEMICAL
62	CHROMIUM	USGS			CHEMICAL
63	CHROMIUM (TOTAL RECOVERABLE)	USGS			CHEMICAL
64	COBALT	USGS			CHEMICAL
65	COBALT (SUSPENDED RECOVERABLE)	USGS			CHEMICAL
66	COBALT (TOTAL RECOVERABLE)	USGS			CHEMICAL
67	COPPER	USGS			CHEMICAL
68	COPPER (SUSPENDED RECOVERABLE)	USGS			CHEMICAL
69	COPPER (TOTAL RECOVERABLE)	USGS			CHEMICAL
70	DDD (TOTAL IN BOTTOM MATERIAL)	USGS			CHEMICAL
71	DDD (TOTAL)	USGS			CHEMICAL
72	DDDE (TOTAL IN BOTTOM MATERIAL)	USGS			CHEMICAL
73	DDE (TOTAL)	USGS			CHEMICAL
74	DDT (TOTAL IN BOTTOM MATERIAL)	USGS			CHEMICAL
75	DDT (TOTAL)	USGS			CHEMICAL
76	DIELDRIN (TOTAL IN BOTTOM MATERIAL)	USGS			CHEMICAL
77	DIELDRIN (TOTAL)	USGS			CHEMICAL
78	ENDOSULFAN (TOTAL IN BOTTOM MATERIAL)	USGS			CHEMICAL
79	ENDOSULFAN (TOTAL)	USGS			CHEMICAL
80	ENDRIN (TOTAL IN BOTTOM MATERIAL)	USGS			CHEMICAL

82 HEPTAACHLOR (EXPOIDE TOTAL IN BOTH MATL)	USGS	CHEMICAL
83 HEPTACHLOR (EPOXIDE TOTAL)	USGS	CHEMICAL
84 HEPTACHLOR (TOTAL IN BOTTOM MATERIAL)	USGS	CHEMICAL
85 HEPTACHLOR (TOTAL)	USGS	CHEMICAL
86 IRON (TOTAL RECOVERABLE)	USGS	CHEMICAL
87 LEAD (TOTAL RECOVERABLE)	USGS	CHEMICAL
88 LINDANE (TOTAL IN BOTTOM MATERIAL)	USGS	CHEMICAL
89 LINDANE (TOTAL)	USGS	CHEMICAL
90 MAGNESIUM	USGS	CHEMICAL
91 MANGANESE (TOTAL RECOVERABLE)	USGS	CHEMICAL
92 MERCURY (TOTAL RECOVERABLE)	USGS	CHEMICAL
93 METHOVYCHLOR (TOTAL IN BOTTOM MATERIAL)	USGS	CHEMICAL
94 METHOVYCHLOR (TOTAL)	USGS	CHEMICAL
95 MIREX (TOTAL IN BOTTOM MATERIAL)	USGS	CHEMICAL
96 MIREX (TOTAL)	USGS	CHEMICAL
97 NAPHTHALENES,POLYCHLOR (TOTAL)	USGS	CHEMICAL
98 NICKEL (TOTAL SUSPENDED)	USGS	CHEMICAL
99 NITROGEN (AMMONIA + ORGANIC TOTAL)	USGS	CHEMICAL
100 NITROGEN (AMMONIA)	USGS	CHEMICAL
101 NITROGEN (NO2 TOTAL)	USGS	CHEMICAL
102 NITROGEN (NO2+NO3)	USGS	CHEMICAL

DATA ELEMENTS GROUPING

NO.	DATA ELEMENT	SOURCE	FORMAT	REMARK	GROUP TITLE
103	NITROGEN (NO3 TOTAL)	USGS			CHEMICAL
104	NITROGEN (ORGANIC TOTAL)	USGS			CHEMICAL
105	NITROGEN (TOTAL)	USGS			CHEMICAL
106	OIL AND GREASE (TOTAL RECOVERABLE)	USGS			CHEMICAL
107	PCB (TOTAL IN BOTTOM MATERIAL)	USGS			CHEMICAL
108	PCN (TOTAL IN BOTTOM MATERIAL)	USGS			CHEMICAL
109	PERTHANE (TOTAL IN BOTTOM MATERIAL)	USGS			CHEMICAL
110	PERTHANE (TOTAL)	USGS			CHEMICAL
111	PHENOLS	USGS			CHEMICAL
112	PHOSPHORUS	USGS			CHEMICAL
113	PHOSPHORUS (ORTHO)	USGS			CHEMICAL
114	PHOSPHORUS (TOTAL)	USGS			CHEMICAL
115	POTASSIUM	USGS			CHEMICAL
116	SELENIUM (TOTAL)	USGS			CHEMICAL
117	SILICA	USGS			CHEMICAL
118	SILVER (TOTAL RECOVERABLE)	USGS			CHEMICAL
119	SODIUM	USGS			CHEMICAL
120	SODIUM (%)	USGS			CHEMICAL
121	SODIUM (ADSORPTION RATIO)	USGS			CHEMICAL
122	SULFATE	USGS			CHEMICAL
123	TOXAPHENE (TOTAL IN BOTTOM MATERIAL)	USGS			CHEMICAL
124	TOXAPHENE (TOTAL)	USGS			CHEMICAL
125	ZINC (TOTAL ERECOVERABLE)	USGS			CHEMICAL
126	ALKALINITY (AS CACO3)	DOH (WELL)	3.1	ANNUALLY	CHEMICAL ANALYSIS
127	CALCIUM	DOH (WELL)	2.2	ANNUALLY	CHEMICAL ANALYSIS
128	CHLORIDE (AS CL)	DOH (WELL)	3.0	ANNUALLY	CHEMICAL ANALYSIS
129	COLOR (APPARENT)	DOH (WELL)	3.0	ANNUALLY	CHEMICAL ANALYSIS
130	FLOURIDE	DOH (WELL)	2.2	ANNUALLY	CHEMICAL ANALYSIS
131	HARDNESS (AS CACO3)	DOH (WELL)	3.1	ANNUALLY	CHEMICAL ANALYSIS

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          133 MAGNESIUM                          DOH (WELL)   2.2      ANNUALLY     CHEMICAL ANALYSIS

          134 MANGANESE (AS MN)                  DOH (WELL)   2.2      ANNUALLY     CHEMICAL ANALYSIS

          135 NITRATE (AS N)                     DOH (WELL)   2.1      ANNUALLY     CHEMICAL ANALYSIS

          136 PH                                 DOH (WELL)   2.1      ANNUALLY     CHEMICAL ANALYSIS

          137 POTASSIUM                          DOH (WELL)   2.2      ANNUALLY     CHEMICAL ANALYSIS

          138 SODIUM                             DOH (WELL)   4.1      ANNUALLY     CHEMICAL ANALYSIS

          139 SULFATE                            DOH (WELL)   2.2      ANNUALLY     CHEMICAL ANALYSIS

          140 TOTAL SOLIDS                       DOH (WELL)   3.0      ANNUALLY     CHEMICAL ANALYSIS

          141 TURBIDITY                          DOH (WELL)   3.1      ANNUALLY     CHEMICAL ANALYSIS

          142 ALDRIN                             DOH (WELL)   3.2      ANNUALLY     CHLORINATED HYDROCARBO
 N PESTICIDES
          143 CHLORANE                           DOH (WELL)   3.2      ANNUALLY     CHLORINATED HYDROCARBO
 N PESTICIDES
          144 DDT                                DOH (WELL)   3.2      ANNUALLY     CHLORINATED HYDROCARBO
 N PESTICIDES
          145 DIEDRIN                            DOH (WELL)   3.2      ANNUALLY     CHLORINATED HYDROCARBO
 N PESTICIDES
          146 ENDRIN                             DOH (WELL)   3.2      ANNUALLY     CHLORINATED HYDROCARBO
 N PESTICIDES
          147 HEPLACHOR                          DOH (WELL)   3.2      ANNUALLY     CHLORINATED HYDROCARBO
 N PESTICIDES
          148 HEPTACHLOR EPOXIDE                 DOH (WELL)   3.2      ANNUALLY     CHLORINATED HYDROCARBO
 N PESTICIDES
          149 LINDANE                            DOH (WELL)   3.2      ANNUALLY     CHLORINATED HYDROCARBO
 N PESTICIDES
          150 METHOXYCHLOR                       DOH (WELL)   3.2      ANNUALLY     CHLORINATED HYDROCARBO
 N PESTICIDES
          151 TOXAPHENE                          DOH (WELL)   2.3      ANNUALLY     CHLORINATED HYDROCARBO
 N PESTICIDES
          152 CONGRESSIONAL DISTRICT             CT,P43       2-D      CT7          CONGRSSIONAL DISTRICT

          153 DISTRICT NAME                      CT,P44       10-C     CT7          CONGRSSIONAL DISTRICT
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DATA ELEMENTS GROUPING

	NO.	DATA ELEMENT	SOURCE	FORMAT	REMARK	GROUP TI
ILE						
	154	INVENTORY UNIT IDENTIFIER	CT,P100	19-C	CT15	CONNECTION POINT
	155	WITHDRAWAL/RETURN CODE	CT,P101	1-C	CT15	CONNECTION POINT
	156	SOURCE IDENTIFIER	CT,P104	19-C	CT16	CONVEYANCE
	157	SINK IDENTIFIER	CT,P105	19-C	CT16	CONVEYANCE
	158	TYPE OF CONVEYANCE	CT,P106	2-C	CT16	CONVEYANCE
	159	DESIGN CAPACITY	CT,P107	7-D	CT16	CONVEYANCE
	160	INTER-BASIN TRANFER	CT,P108	1-C	CT16	CONVEYANCE
TICS	161	AGGRESSIVE INDEX	DOH (WELL)	2.2	ANNUALLY	CORRESION CHARACTERIS
TICS	162	ALKALINITY (AS CACO3)	DOH (WELL)	3.0	ANNUALLY	CORRESION CHARACTERIS
TICS	163	CALCIUM (AS CACO3)	DOH (WELL)	3.1	ANNUALLY	CORRESION CHARACTERIS
TICS	164	LANGERLIER INDEX	DOH (WELL)	2.2	ANNUALLY	CORRESION CHARACTERIS
TICS	165	PH	DOH (WELL)	2.1	ANNUALLY	CORRESION CHARACTERIS
TICS	166	TOTAL SOLIDS	DOH (WELL)	3.0	ANNUALLY	CORRESION CHARACTERIS
	167	COUNTY CODE	CT,P33	3-D	CT5	COUNTY
	168	COUNTY NAME	CT,P34	16-D	CT5	COUNTY
	169	NATURAL DRAINAGE SYSTEM UNIT	CT,P19	6-D	CT2	DRAINAGE BASIN
	170	FIRST ORDER BASIN NAME	CT,P20	35-C	CT2	DRAINAGE BASIN
	171	SECOND ORDER BASIN NAME	CT,P21	35-C	CT2	DRAINAGE BASIN
	172	THIRD ORDER BASIN NAME	CT,P22	35-C	CT2	DRAINAGE BASIN
	173	NWUDS IDENTIFER	NWU,P3-1	15-D		FACILITY DATA
	174	NON-U.S. COUNTY	NWU,P3-10	3-C		FACILITY DATA
	175	LATITUDE	NWU,P3-11	6-D		FACILITY DATA
	176	LONGITUDE	NWU,P3-12	7-D		FACILITY DATA
	177	HYDROLOGIC UNIT	NWU,P3-13	8-D		FACILITY DATA
	178	CONGRESSIONAL DISTRICT	NWU,P3-14	2-D		FACILITY DATA
	179	TYPE	NWU,P3-15	40-C		FACILITY DATA
	180	SIC CODES	NWU,P3-16	24-D		FACILITY DATA
	181	MAILING STREET ADDRESS	NWU,P3-17	40-C		FACILITY DATA
	182	MAILING CITY	NWU,P3-18	20-C		FACILITY DATA

184 DUNS NUMBER	NWU,P3-2	9-D		FACILITY DATA
185 MAILING ZIP	NWU,P3-20	5-D		FACILITY DATA
186 MAILING COUNTRY	NWU,P3-21	20-C		FACILITY DATA
187 LAST UPDATE	NWU,P3-22			FACILITY DATA
188 SUBCATEGORY	NWU,P3-3	2-C		FACILITY DATA
189 FACILITY NAME	NWU,P3-4	40-C		FACILITY DATA
190 STREET ADDRESS	NWU,P3-5	40-C		FACILITY DATA
191 CITY NAME	NWU,P3-6	20-C		FACILITY DATA
192 CITY CODE	NWU,P3-7	4-D		FACILITY DATA
193 COUNTY	NWU,P3-8	3-D		FACILITY DATA
194 STATE	NWU,P3-9	2-D		FACILITY DATA
195 FACILITY IDENTIFIER	CT,P246	19-C	CT31	FLOOD STRUCTURE
196 FACILITY IDENTIFIER	CT,P53	19-C	CT9	GENERAL FACILITY
197 PRIMARY SIC CODE	CT,P54	4-D	CT9	GENERAL FACILITY
198 FACILITY SIC CODES	CT,P55	4-D	CT9	GENERAL FACILITY
199 DUNS NUMBER	CT,P56	9-D	CT9	GENERAL FACILITY
200 FACILITY NAME	CT,P57	40-C	CT9	GENERAL FACILITY
201 FACILITY STREET ADDRESS	CT,P58	40-C	CT9	GENERAL FACILITY
202 FACILITY MAILING STREET ADDRESS	CT,P59	40-C	CT9	GENERAL FACILITY
203 FACILITY MAILING TOWN	CT,P60	16-C	CT9	GENERAL FACILITY
204 FACILITY MAILING STATE	CT,P61	2-C	CT9	GENERAL FACILITY

DATA ELEMENTS GROUPING

NO.	DATA ELEMENT	SOURCE	FORMAT	REMARK	GROUP TITLE
205	FACILITY MAILING ZIP CODE	CT,P62	5-D	CT9	GENERAL FACILITY
206	FACILITY MAILING COUNTRY	CT,P63	25-C	CT9	GENERAL FACILITY
207	LAST UPDATE	CT,P64	8-D	CT9	GENERAL FACILITY
208	COUNTY CODE	CT,P10	3-D	CT1	GEOGRAPHIC LOCATION
209	STATE CODE	CT,P11	2-D	CT1	GEOGRAPHIC LOCATION
210	PLANE COORDINATE DESIGNATOR	CT,P12	8-D	CT1	GEOGRAPHIC LOCATION
211	HYDROLOGIC UNIT	CT,P13	8-D	CT1	GEOGRAPHIC LOCATION
212	NATURAL DRAINAGE SYSTEM UNIT	CT,P14	6-D	CT1	GEOGRAPHIC LOCATION
213	CONGRESSIONAL DISTRICT	CT,P15	2-D	CT1	GEOGRAPHIC LOCATION
214	RPA NAME	CT,P16	2-D	CT1	GEOGRAPHIC LOCATION
215	LATITUDE	CT,P6	6-D	CT1	GEOGRAPHIC LOCATION
216	LONGITUDE	CT,P7	7-D	CT1	GEOGRAPHIC LOCATION
217	CITY CODE	CT,P8	4-D	CT1	GEOGRAPHIC LOCATION
218	TOWN CODE	CT,P9	3-D	CT1	GEOGRAPHIC LOCATION
219	ARSENIC	DOH (WELL)	2.3	ANNUALLY	HEAVY METALS
220	BARIUM	DOH (WELL)	2.3	ANNUALLY	HEAVY METALS
221	CADMIUM	DOH (WELL)	2.3	ANNUALLY	HEAVY METALS
222	CHROMIUM	DOH (WELL)	2.3	ANNUALLY	HEAVY METALS
223	COPPER	DOH (WELL)	2.3	ANNUALLY	HEAVY METALS
224	LEAD	DOH (WELL)	2.3	ANNUALLY	HEAVY METALS
225	MERCURY	DOH (WELL)	2.3	ANNUALLY	HEAVY METALS
226	NICKEL	DOH (WELL)	2.3	ANNUALLY	HEAVY METALS
227	SELENIUM	DOH (WELL)	2.3	ANNUALLY	HEAVY METALS
228	SILVER	DOH (WELL)	2.3	ANNUALLY	HEAVY METALS
229	ZINC	DOH (WELL)	2.3	ANNUALLY	HEAVY METALS
230	2,4,5 T SILVEX	DOH (WELL)	3.3	ANNUALLY	HERBICIDES
231	2,4,5 TP SILVEX	DOH (WELL)	3.3	ANNUALLY	HERBICIDES
232	2,4,D SILVEX	DOH (WELL)	3.3	ANNUALLY	HERBICIDES
233	BOD5 CONC.	DEM	3.1	MONTHLY	INDUSTRIAL DISCHARGE
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

235 COLOR	DEM	4.	MONTHLY	INDUSTRIAL DISCHARGES
236 FECAL COLIFORMS	DEM	6.1	MONTHLY	INDUSTRIAL DISCHARGES
237 FLOW	DEM	2.4	MONTHLY	INDUSTRIAL DISCHARGES
238 NITROGEN (TOTAL AMMONIA AS N)	DEM	5.	MONTHLY	INDUSTRIAL DISCHARGES
239 NITROGEN (TOTAL AMMONIA) CONC.	DEM	3.1	MONTHLY	INDUSTRIAL DISCHARGES
240 PH	DEM	2.1	MONTHLY	INDUSTRIAL DISCHARGES
241 TEMPERATURE	DEM	3.	MONTHLY	INDUSTRIAL DISCHARGES
242 TOD CONC.	DEM	4.	MONTHLY	INDUSTRIAL DISCHARGES
243 TOD LOAD	DEM	5.	MONTHLY	INDUSTRIAL DISCHARGES
244 TOTAL COPPER LOADING	DEM	3.1	MONTHLY	INDUSTRIAL DISCHARGES
245 TOTAL NICEL CONC.	DEM	2.2	MONTHLY	INDUSTRIAL DISCHARGES
246 TOTAL NICKEL LOADING	DEM	3.1	MONTHLY	INDUSTRIAL DISCHARGES
247 TOTAL PHOSPHOROUS CONC.	DEM	2.2	MONTHLY	INDUSTRIAL DISCHARGES
248 TOTAL PHOSPHOROUS LOADING	DEM	3.1	MONTHLY	INDUSTRIAL DISCHARGES
249 TOTAL ZINC CONC.	DEM	2.2	MONTHLY	INDUSTRIAL DISCHARGES
250 TOTAL ZINC LOADING	DEM	3.1	MONTHLY	INDUSTRIAL DISCHARGES
251 TOTALK COPPER CONC.	DEM	2.2	MONTHLY	INDUSTRIAL DISCHARGES
252 TSS CONC.	DEM	4.1	MONTHLU	INDUSTRIAL DISCHARGES
253 TSS LOADING	DEM	5.	MONTHLY	INDUSTRIAL DISCHARGES
254 SOURCE IDENTIFIER	CT,P188	19-C	CT23	INSTREAM REGULATION
255 SINK IDENTIFIER	CT,P189	19-C	CT23	INSTREAM REGULATION

DATA ELEMENTS GROUPING

NO.	DATA ELEMENT	SOURCE	FORMAT	REMARK	GROUP TITLE
256	REGULATING AGENCY IDENTIFIER	CT,P190	10-C	CT23	INSTREAM REGULATION
257	PURPOSE OF REGULATION	CT,P191	40-C	CT23	INSTREAM REGULATION
258	FACILITY IDENTIFIER	CT,P232	19-C	CT30	IRRIGATION
259	CROP IRRIGATED	CT,P233	4-D	CT30	IRRIGATION
260	METHOD OF IRRIGATION	CT,P234	2-C	CT30	IRRIGATION
261	FREQUENCY OF IRRIGATION	CT,P235	1-C	CT30	IRRIGATION
262	AVERAGE YIELD	CT,P236	7-D	CT30	IRRIGATION
263	UNIT OF MEASUREMENT	CT,P237	2-C	CT30	IRRIGATION
264	ACRES IRRIGATED	CT,P238	7-D	CT30	IRRIGATION
265	TIME PERIOD AND INCHES	CT,P239		CT30	IRRIGATION
266	IRRIGATION POWER SOURCE	CT,P240	2-D	CT30	IRRIGATION
267	IRRIGATION PIPE SIZE	CT,P241	2-D	CT30	IRRIGATION
268	IRRIGATION PIPE LENGTH	CT,P242	5-D	CT30	IRRIGATION
269	NORMAL OPERATING CAPACITY	CT,P243	4-D	CT30	IRRIGATION
270	CROP IRRIGATED	NWU,P3-68	4-D		IRRIGATION DATA
271	METHOD OF IRRIGATION	NWU,P3-69	30-C		IRRIGATION DATA
272	FREQUENCY OF IRRIGATION	NWU,P3-70	1-D		IRRIGATION DATA
273	AVERAGE YIELD	NWU,P3-71	7-D		IRRIGATION DATA
274	UNIT OF MEASUREMENT	NWU,P3-72	2-C		IRRIGATION DATA
275	ACRES IRRIGATED	NWU,P3-73	7-D		IRRIGATION DATA
276	ANNUAL AMOUNT APPLIED	NWU,P3-74	10-D		IRRIGATION DATA
277	MONTHLY AMOUNT APPLIED	NWU,P3-75	10-D		IRRIGATION DATA
278	FECAL COLIFORMS	DEM	6.0	WEEKLY	MONITORING OF BATHING AREAS
279	TOTAL COLIFORMS	DEM	6.0	WEEKLY	MONITORING OF BATHING AREAS
280	INVENTORY UNIT IDENTIFIER	CT,P142	19-C	CT18	MONTHLY USE
281	WITHDRAWAL/RETURN CODE	CT,P143	1-C	CT18	MONTHLY USE
282	WITHDRAWAL/RETURN SIC CODE	CT,P144	4-D	CT18	MONTHLY USE
283	MONTH	CT,P145	2-D	CT18	MONTHLY USE
284	MONTHLY AMOUNT	CT,P146	7-D	CT18	MONTHLY USE

286 MINIMUM DAILY USE	CT,P148	7-0	CT18	MONTHLY USE
287 DAY OF MINIMUM USE	CT,P149	3-0	CT18	MONTHLY USE
288 MAXIMUM DAILY USE	CT,P150	7-0	CT18	MONTHLY USE
289 DAY OF MAXIMUM USE	CT,P151	3-0	CT18	MONTHLY USE
290 CITY CODE	CT,P28	4-0	CT4	MUNICIPALITY
291 CITY NAME	CT,P29	16-0	CT4	MUNICIPALITY
292 TOWN CODE	CT,P30	3-0	CT4	MUNICIPALITY
293 WATER SOURCE IDENTIFIER	CT,P261	19-C	CT34	NAVIGATION
294 RIVER MILE	CT,P262	5-0	CT34	NAVIGATION
295 MAXIMUM SIZE SHIPS	CT,P263		CT34	NAVIGATION
296 SHIPPING YEAR	CT,P264	4-0	CT34	NAVIGATION
297 AVREAGE SIZE SHIPS	CT,P265		CT34	NAVIGATION
298 ANNUAL NUMBER SHIPS	CT,P266		CT34	NAVIGATION
299 ANNUAL TONNAGE	CT,P267		CT34	NAVIGATION
300 PRINCIPAL PRODUCTS	CT,P268		CT34	NAVIGATION
301 PRINCIPAL PRODUCTS	NWU,P3-100	20-C		NAVIGATION DATA
302 ANNUAL NUMBER SHIPS	NWU,P3-101	7-0		NAVIGATION DATA
303 AVERAGE SIZE SHIPS	NWU,P3-102	19-0		NAVIGATION DATA
304 NAVIGATION MINIMUM FLOW	NWU,P3-79	10-0		NAVIGATION DATA
305 NAVIGATION MINIMUM DEPTH	NWU,P3-80	3-0		NAVIGATION DATA
306 MAXIMUM SIZE SHIPS	NWU,P3-81	20-0		NAVIGATION DATA

DATA ELEMENTS GROUPING

ILE	NO.	DATA ELEMENT	SOURCE	FORMAT	REMARK	GROUP II
	307	NAVIGATION MANAGEMENT AGENCY NAME	NWU,P3-82	40-C		NAVIGATION DATA
	308	NAVIGATION MANAGEMENT AGENCY ADDRES	NWU,P3-83	40-C		NAVIGATION DATA
	309	NAVIGATION MANAGEMENT AGENCY CITY	NWU,P3-84	20-C		NAVIGATION DATA
	310	NAVIGATION MANAGEMENT AGENCY COUNTY	NWU,P3-85	3-D		NAVIGATION DATA
	311	NAVIGATION MANAGEMENT AGENCY ATATE	NWU,P3-86	2-D		NAVIGATION DATA
	312	ENTRY LATITUDE	NWU,P3-87	6-D		NAVIGATION DATA
	313	ENTRY LONGITUDE	NWU,P3-88	7-D		NAVIGATION DATA
	314	ENTRY COUNTY	NWU,P3-89	3-D		NAVIGATION DATA
	315	ENTRY STATE	NWU,P3-90	2-D		NAVIGATION DATA
	316	ENTRY NON-U.S. COUNTRY	NWU,P3-91	2-C		NAVIGATION DATA
	317	ENTRY HYDROLOGIC UNIT	NWU,P3-92	8-D		NAVIGATION DATA
	318	DEPARTURE LATITUDE	NWU,P3-93	6-D		NAVIGATION DATA
	319	DEPARTURE LONGITUDE	NWU,P3-94	7-D		NAVIGATION DATA
	320	DEPARTURE COUNTY	NWU,P3-95	3-D		NAVIGATION DATA
	321	DEPARTURE ATATE	NWU,P3-96	2-D		NAVIGATION DATA
	322	DEPARTURE NON-U.S. COUNTRY	NWU,P3-97	2-C		NAVIGATION DATA
	323	DEPARTURE HYDROLOGIC UNIT	NWU,P3-98	8-D		NAVIGATION DATA
	324	ANNUAL TONNAGE	NWU,P3-99	10-D		NAVIGATION DATA
	325	ACENAPHTHENE CONC..	DEM	2.0	ANNUALLY	ORGANICS SCAN
	326	ACENAPHTHENE LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
	327	ACENAPHTYLENE CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
	328	ACENAPHTYLENE LOADING	DEM	2.3	ANNUALLY	ORGANICS SCAN
	329	ACROLEIN CONC.	DEM	2.2	ANNUALLY	ORGANICS SCAN
	330	ACROLEIN LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
	331	ACRYLONITRATE LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
	332	ALDRIN CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
	333	ALDRIN LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
	334	ALPHA RADIOACTIVITY TOTAL	DEM	2.3	ANNUALLY	ORGANICS SCAN
	335	AMMONIA (AS N) CONC.	DEM	2.1	ANNUALLY	ORGANICS SCAN

DATA ELEMENTS GROUPING

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NO.	DATA ELEMENT	SOURCE	FORMAT	REMARK	GROUP
358	BIS ETHER CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
359	BIS ETHER CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
360	BIS ETHER LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
361	BIS ETHER LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
362	BIS METHANE CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
363	BIS METHANE LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
364	BIS PHTHAIATE CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
365	BIS PHTHALATE LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
366	BOD5 CONC.	DEM	3.1	ANNUALLY	ORGANICS SCAN
367	BOD5 LOADING	DEM	2.3	ANNUALLY	ORGANICS SCAN
368	BOTYL BENZYL PHTHALATE CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
369	BOTYL BENZYL PHTHALATE LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
370	BROMIDE	DEM	2.3	ANNUALLY	ORGANICS SCAN
371	BROMIDE CONC.	DEM	2.2	ANNUALLY	ORGANICS SCAN
372	BROMOFORM CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
373	BROMOFORM LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
374	BROMOPHENYL(4,-) CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
375	BROMOPHENYL(4,-) PHENYL LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
376	CARBON TETRACHLORIDE CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
377	CARBON TETRACHLORIDE LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
378	CHLOROBERCENE CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
379	CHLOROBERCENE LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
380	CHLORODANE CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
381	CHLORODANE LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
382	CHLORODIBROMETHANE CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
383	CHLORODIBROMOMETHANE LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
384	CHLOROETHANE CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
385	CHLOROETHANE LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
386	CHLOROETHYLVINYL(2-) ETHER CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN

388 CHLOROFORM CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
389 CHLOROFORM LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
390 CHLORONAPTHALENE(2,-) CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
391 CHLORONAPTHALENE(2,-) LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
392 CHLOROPHENOL(2-) CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
393 CHLOROPHENOL(2-) LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
394 CHLOROPHENYL(4,-) CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
395 CHLOROPHENYL(4,-) PHENYL LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
396 CHROMIUM LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
397 CHRYSENE CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
398 CHRYSENE LOADING	DEM	2.3	ANNUALLY	ORGANICS SCAN
399 COBALT CONC.	DEM	2.2	ANNUALLY	ORGANICS SCAN
400 COBALT LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
401 COD CONC.	DEM	3.1	ANNUALLY	ORGANICS SCAN
402 COD LOADING	DEM	2.3	ANNUALLY	ORGANICS SCAN
403 COLOR	DEM	4.0	ANNUALLY	ORGANICS SCAN
404 DDD (4,4-) LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
405 DDD(4,4-) CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
406 DDE(4,4-) CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
407 DDE(4,4-) LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
408 DDT(4,4-) CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN

DATA ELEMENTS GROUPING

NO.	DATA ELEMENT	SOURCE	FORMAT	REMARK	GROUP TITLE
409	DDT(4,4-) LOAD	DEN	2.3	ANNUALLY	ORGANICS SCAN
410	DI-N-BUTYL PHTHALATE CONC.	DEN	2.0	ANNUALLY	ORGANICS SCAN
411	DI-N-BUTYL PHTHALATE LOAD	DEN	2.3	ANNUALLY	ORGANICS SCAN
412	DI-N-OCTYL PHTHALATE CONC.	DEN	2.0	ANNUALLY	ORGANICS SCAN
413	DI-N-OCTYL PHTHALATE LOAD	DEN	2.3	ANNUALLY	ORGANICS SCAN
414	DIBENZO ANTHRACENE CONC.	DEN	2.3	ANNUALLY	ORGANICS SCAN
415	DIBENZO ANTHRACENE LOAD	DEN	2.3	ANNUALLY	ORGANICS SCAN
416	DICHLORO(1,2-) BENZENE CONC.	DEN	2.0	ANNUALLY	ORGANICS SCAN
417	DICHLORO(1,2-) BENZENE LOAD	DEN	2.3	ANNUALLY	ORGANICS SCAN
418	DICHLORO(1,3-) BENZENE LOAD	DEN	2.3	ANNUALLY	ORGANICS SCAN
419	DICHLORO(1,3-) CONC.	DEN	2.0	ANNUALLY	ORGANICS SCAN
420	DICHLORO(1,4-) BENZENE CONC.	DEN	2.0	ANNUALLY	ORGANICS SCAN
421	DICHLORO(1,4-) BENZENE LOAD	DEN	2.3	ANNUALLY	ORGANICS SCAN
422	DICHLOROBENZIDINE(3,3-) CONC.	DEN	2.0	ANNUALLY	ORGANICS SCAN
423	DICHLOROBENZIDINE(3,3-) LOAD	DEN	2.3	ANNUALLY	ORGANICS SCAN
424	DICHLOROBROMOMETHANE CONC.	DEN	2.0	ANNUALLY	ORGANICS SCAN
425	DICHLOROBROMOMETHANE LOAD	DEN	2.3	ANNUALLY	ORGANICS SCAN
426	DICHLORODIFLOUROMETHANE CONC.	DEN	2.0	ANNUALLY	ORGANICS SCAN
427	DICHLORODIFLOUROMETHANE LOAD	DEN	2.3	ANNUALLY	ORGANICS SCAN
428	DICHLOROETHANE(1,1-) CONC.	DEN	2.0	ANNUALLY	ORGANICS SCAN
429	DICHLOROETHANE(1,1-) LOAD	DEN	2.3	ANNUALLY	ORGANICS SCAN
430	DICHLOROETHANE(1,2-) CONC.	DEN	2.0	ANNUALLY	ORGANICS SCAN
431	DICHLOROETHANE(1,2-) LOAD	DEN	2.3	ANNUALLY	ORGANICS SCAN
432	DICHLOROETHYLENE(1,1-) CONC.	DEN	2.0	ANNUALLY	ORGANICS SCAN
433	DICHLOROETHYLENE(1,1-) LOAD	DEN	2.3	ANNUALLY	ORGANICS SCAN
434	DICHLOROPHENOL(2,4-) CONC.	DEN	2.0	ANNUALLY	ORGANICS SCAN
435	DICHLOROPHENOL(2,4-) LOAD	DEN	2.3	ANNUALLY	ORGANICS SCAN
436	DICHLOROPROPANE(1,2-) CONC.	DEN	2.0	ANNUALLY	ORGANICS SCAN
437	DICHLOROPROPANE(1,2-) LOAD	DEN	2.3	ANNUALLY	ORGANICS SCAN

439 DICHLOROPROPYLENE(1,2-) LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
440 DIELDRIN LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
441 DIELDRINCONC..	DEM	2.0	ANNUALLY	ORGANICS SCAN
442 DIETHYL PHTHALATE CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
443 DIETHYL PHTHALATE LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
444 DIMETHYLPHENOL(2,4-) CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
445 DIMETHYLPHENOL(2,4-) LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
446 DINITO(2,6-) TOLUENE CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
447 DINITO(2,6-) TOLUENE LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
448 DINITRO(2,4-) TOLUENE CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
449 DINITRO(2,4-) TOLUENE LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
450 DINITRO-O-CRESOL(2,4-) CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
451 DINITRO-O-CRESOL(2,6-) LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
452 DINITROPHENOL(2,4-) CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
453 DINITROPHENOL(2,4-) LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
454 DIPHENYL(1,2-) HYDRAZINE CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
455 DIPHENYL(1,2-) HYDRZINE LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
456 ENDOSULFAN SULFATE CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
457 ENDOSULFAN SULFATE LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
458 ENDRIN ALDEHYDE CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
459 ENDRIN ALDEHYDE LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN

DATA ELEMENTS GROUPING

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NO.	DATA ELEMENT	SOURCE	FORMAT	REMARK	GROUP TI
460	ENDRIN CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
461	ENDRIN LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
462	ETHYLBENZENE CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
463	ETHYLBENZENE LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
464	FECAL COLIFORMS	DEM	6.0	ANNUALLY	ORGANICS SCAN
465	FLOURANTHENE CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
466	FLOURANTHENE LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
467	FLOURENE CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
468	FLOURENE LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
469	FLOURIDE CONC.	DEM	2.2	ANNUALLY	ORGANICS SCAN
470	FLOURIDE LOAD.	DEM	2.3	ANNUALLY	ORGANICS SCAN
471	FLOW	DEM	6.0	ANNUALLY	ORGANICS SCAN
472	HEPTACHLOR CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
473	HEPTACHLOR EPOXIDE CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
474	HEPTACHLOR EPOXIDE LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
475	HEPTACHLOR LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
476	HEXA CHLORO ETHANE CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
477	HEXA CHLORO ETHANE LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
478	HEXA CHLOROBENZENE CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
479	HEXA CHLOROBENZENE LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
480	HEXA CHLOROBUTADIENE CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
481	HEXA CHLOROBUTADIENE LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
482	INDENO PYRENE CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
483	INDENO PYRENE LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
484	ISOPHORONE CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
485	ISOPHORONE LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
486	METHYL BROMIDE CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
487	METHYL BROMIDE LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
488	METHYL CHLORIDE CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN

490 METHYLENE CHLORIDE CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
491 METHYLENE CHLORIDE LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
492 N-NITRO SODI-N-PROPYLAMINE CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
493 N-NITRO SODI-N-PROPYLAMINE LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
494 N-NITRO SODIMETHYLAMINE CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
495 N-NITRO SODIMETHYLAMINE LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
496 N-NITRO-SODIPHENYLAMINE CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
497 N-NITRO-SODIPHENYLAMINO LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
498 NAPTHALENE CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
499 NAPTHALENE LOADING	DEM	2.3	ANNUALLY	ORGANICS SCAN
500 NITRATE-NITRITE (AS N) CONC.	DEM	2.2	ANNUALLY	ORGANICS SCAN
501 NITRATE-NITRITE (AS NH) LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
502 NITROBENZENE CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
503 NITROBENZENE LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
504 NITROPHENOL(2-) CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
505 NITROPHENOL(2-) LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
506 NITROPHENOL(4-) CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
507 NUTROPHENOL(4-) LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
508 OIL AND GREASE CONC.	DEM	2.2	ANNUALLY	ORGANICS SCAN
509 OIL AND GREASE LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
510 P-CHLORO-M-CRESOL CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN

DATA ELEMENTS GROUPING

NO.	DATA ELEMENT	SOURCE	FORMAT	REMARK	GROUP TITLE
511	P-CHLORO-M-CRESOL LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
512	PCB-1016 CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
513	PCB-1016 LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
514	PCB-1221 CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
515	PCB-1221 LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
516	PCB-1232 CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
517	PCB-1232 LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
518	PCB-1242 CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
519	PCB-1242 LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
520	PCB-1248 CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
521	PCB-1248 LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
522	PCB-1254 CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
523	PCB-1254 LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
524	PCB-1260 CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
525	PCB-1260 LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
526	PENTACHLOROPHENOL CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
527	PENTACHLOROPHENOL LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
528	PH	DEM	2.1	ANNUALLY	ORGANICS SCAN
529	PHENANTHRACENE CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
530	PHENANTHRACENE LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
531	PHENOL CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
532	PHENOL LOADING	DEM	2.3	ANNUALLY	ORGANICS SCAN
533	PYRENE CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
534	PYRENE LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
535	RADIUM 226 RADIOACTIVITY TOTAL	DEM	2.3	ANNUALLY	ORGANICS SCAN
536	RADIUM RADIOACTIVITY TOTAL	DEM	2.3	ANNUALLY	ORGANICS SCAN
537	SULFATE CONC. (AS SO4)	DEM	2.2	ANNUALLY	ORGANICS SCAN
538	SULFATE LOAD (AS SO4)	DEM	2.3	ANNUALLY	ORGANICS SCAN
539	SULFIDE CONC. (AS S)	DEM	2.2	ANNUALLY	ORGANICS SCAN

541	SULFIDE LOAD (AS S)	DEM	2.3	ANNUALLY	ORGANICS SCAN
542	SULFIDE LOAD (AS SO3)	DEM	2.3	ANNUALLY	ORGANICS SCAN
543	SURFACTANTS CONC.	DEM	2.2	ANNUALLY	ORGANICS SCAN
544	SURFACTANTS LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
545	TEMPERATURE	DEM	3.0	ANNUALLY	ORGANICS SCAN
546	TETRACHLOROETHANE LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
547	TETRACHLOROETHANE(1,1,2,2-) CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
548	TETRACHLOROETHANE(1,1,2,2-) LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
549	TETRACHLOROETHYLENE CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
550	TOC CONC.	DEM	3.1	ANNUALLY	ORGANICS SCAN
551	TOC LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
552	TOLUENE CONC.	DEM	2.3	ANNUALLY	ORGANICS SCAN
553	TOTAL AARSENIC CONC.	DEM	2.2	ANNUALLY	ORGANICS SCAN
554	TOTAL ALUMINUM CONC.	DEM	2.2	ANNUALLY	ORGANICS SCAN
555	TOTAL ALUMINUM LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
556	TOTAL ANTIMONY CONC.	DEM	2.2	ANNUALLY	ORGANICS SCAN
557	TOTAL ANTIMONY LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
558	TOTAL ARSENIC LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
559	TOTAL BERIUM CONC.	DEM	2.2	ANNUALLY	ORGANICS SCAN
560	TOTAL BERIUM LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
561	TOTAL BORON CONC.	DEM	2.2	ANNUALLY	ORGANICS SCAN

DATA ELEMENTS GROUPING

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NO.	DATA ELEMENT	SOURCE	FORMAT	REMARK	GROUP
562	TOTAL BORON LOAD	DEN	2.3	ANNUALLY	ORGANICS SCAN
563	TOTAL BUYLLIUM CONC.	DEN	2.2	ANNUALLY	ORGANICS SCAN
564	TOTAL BUYLLIUM LOAD	DEN	2.3	ANNUALLY	ORGANICS SCAN
565	TOTAL CADMIUM CONC.	DEN	2.2	ANNUALLY	ORGANICS SCAN
566	TOTAL CADMIUM LOAD	DEN	2.3	ANNUALLY	ORGANICS SCAN
567	TOTAL CHLORINE RESIDUAL CONC.	DEN	2.2	ANNUALLY	ORGANICS SCAN
568	TOTAL CHLORINE RESIDUAL LOAD	DEN	2.3	ANNUALLY	ORGANICS SCAN
569	TOTAL CHROMIUM CONC.	DEN	2.2	ANNUALLY	ORGANICS SCAN
570	TOTAL COPPER CONC.	DEN	2.2	ANNUALLY	ORGANICS SCAN
571	TOTAL COPPER LOAD	DEN	2.3	ANNUALLY	ORGANICS SCAN
572	TOTAL CYANIDE CONC.	DEN	2.2	ANNUALLY	ORGANICS SCAN
573	TOTAL CYANIDE LOAD	DEN	2.3	ANNUALLY	ORGANICS SCAN
574	TOTAL IRON CONC.	DEN	2.2	ANNUALLY	ORGANICS SCAN
575	TOTAL IRON LOAD	DEN	2.3	ANNUALLY	ORGANICS SCAN
576	TOTAL LEAD CONC.	DEN	2.2	ANNUALLY	ORGANICS SCAN
577	TOTAL LEAD LOAD	DEN	2.3	ANNUALLY	ORGANICS SCAN
578	TOTAL MAGNESIUM CONC.	DEN	2.2	ANNUALLY	ORGANICS SCAN
579	TOTAL MAGNESIUM LOAD	DEN	2.3	ANNUALLY	ORGANICS SCAN
580	TOTAL MANGANESE CONC.	DEN	2.2	ANNUALLY	ORGANICS SCAN
581	TOTAL MANGENESE LOAD	DEN	2.3	ANNUALLY	ORGANICS SCAN
582	TOTAL MERCURY CONC.	DEN	2.2	ANNUALLY	ORGANICS SCAN
583	TOTAL MERCURY LOAD	DEN	2.3	ANNUALLY	ORGANICS SCAN
584	TOTAL MOLYBDENUM CONC.	DEN	2.2	ANNUALLY	ORGANICS SCAN
585	TOTAL MOLYBDENUM LOADD	DEN	2.3	ANNUALLY	ORGANICS SCAN
586	TOTAL NICKEL CONC.	DEN	2.2	ANNUALLY	ORGANICS SCAN
587	TOTAL NICKEL LOAD	DEN	2.3	ANNUALLY	ORGANICS SCAN
588	TOTAL ORGANIC NITROGEN (AS N) LOAD	DEN	2.3	ANNUALLY	ORGANICS SCAN
589	TOTAL ORGANIC NITROGEN CONC.	DEN	2.2	ANNUALLY	ORGANICS SCAN
590	TOTAL PHENOLS CONC.	DEN	2.2	ANNUALLY	ORGANICS SCAN
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

592 TOTAL PHOSPHOROUS (AS P) LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
593 TOTAL PHOSPHOROUS CONC.	DEM	2.2	ANNUALLY	ORGANICS SCAN
594 TOTAL SELENIUM LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
595 TOTAL SELENIUM CONC.	DEM	2.2	ANNUALLY	ORGANICS SCAN
596 TOTAL SILVER CONC.	DEM	2.2	ANNUALLY	ORGANICS SCAN
597 TOTAL SILVER LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
598 TOTAL THALLIUM CONC.	DEM	2.2	ANNUALLY	ORGANICS SCAN
599 TOTAL THALLIUM LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
600 TOTAL TIN CONC.	DEM	2.2	ANNUALLY	ORGANICS SCAN
601 TOTAL TIN LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
602 TOTAL TITANIUM CONC.	DEM	2.2	ANNUALLY	ORGANICS SCAN
603 TOTAL TITANIUM LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
604 TOTAL ZINC CONC.	DEM	2.2	ANNUALLY	ORGANICS SCAN
605 TOTAL ZINC LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
606 TOLUENE LOADING	DEM	2.3	ANNUALLY	ORGANICS SCAN
607 TOXAPHENE CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
608 TOXAPHENE LOADING	DEM	2.3	ANNUALLY	ORGANICS SCAN
609 TRANS(1,2-)-DICHLOROETHANE CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
610 TRANS(1,2-)-DICHLOROETHYLENE LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
611 TRICHLOROBENZENE(1,2,4-) CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
612 TRICHLOROBENZENE(1,2,4-) LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN

DATA ELEMENTS GROUPING

NO.	DATA ELEMENT	SOURCE	FORMAT	REMARK	GROUP TITLE
613	TRICHLOROETHANE(1,1,2-) CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
614	TRICHLOROETHANE(1,1,2-) LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
615	TRICHLOROETHANE(2,1,1-) CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
616	TRICHLOROETHANE(2,1,1-) LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
617	TRICHLOROETHYLENE CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
618	TRICHLOROETHYLENE LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
619	TRICHLOROFLOUROMETHANE CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
620	TRICHLOROFLOUROMETHANE LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
621	TRICHLOROPHENOL(2,4,6-) CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
622	TRICHLOROPHENOL(2,4,6-) LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
623	TSS CONC.	DEM	3.1	ANNUALLY	ORGANICS SCAN
624	TSS LOAD	DEM	3.3	ANNUALLY	ORGANICS SCAN
625	VINYL CHLORIDE CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
626	VINYL CHLORIDE LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
627	a ENDOSULFAN CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
628	a ENDROSULFAN LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
629	a-BHC CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
630	a-BHC LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
631	d-BHC CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
632	d-BHC LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
633	r-BHC CONC.	DEM	2.0	ANNUALLY	ORGANICS SCAN
634	r-BHC LOAD	DEM	2.3	ANNUALLY	ORGANICS SCAN
635	OWNER IDENTIFIER	CT,P47	19-C	CT8	OWNER/OPERATOR
636	OWNED IDENTIFIER	CT,P48	19-C	CT8	OWNER/OPERATOR
637	PROPORTION OWNER	CT,P49	5-0	CT8	OWNER/OPERATOR
638	TYPE OF OWNERSHIP	CT,P50	2-C	CT8	OWNER/OPERATOR
639	INVENTORY UNIT IDENTIFIER	CT,P165	19-C	CT20	PERMITS
640	WITHDRAWAL/RETURN CODE	CT,P166	1-C	CT20	PERMITS
641	PERMIT NUMBER	CT,P167		CT20	PERMITS

643 PERMITTER AMOUNT	CT,P169	9-D	CT20	PERMITS
644 REGULATING AGENCY IDENTIFIER	CT,P170	10-C	CT20	PERMITS
645 B-BHC LOAD	DEM	2.3	ANNUALLY	PESTICIDES
646 ALKALINITY (LAB)	USGS			PHYSICAL
647 BOD5	USGS			PHYSICAL
648 COD	USGS			PHYSICAL
649 COLOR	USGS			PHYSICAL
650 DO	USGS			PHYSICAL
651 FLOW	USGS			PHYSICAL
652 HARDNESS	USGS			PHYSICAL
653 HARDNESS (NONCARBONATE)	USGS			PHYSICAL
654 PH	USGS			PHYSICAL
655 SEDIMENT (DISCHARGE SUSPENDED)	USGS			PHYSICAL
656 SEDIMENT (SUSPENDED)	USGS			PHYSICAL
657 SEDIMENT SUSPEND SIEVE (DIAM. X<0.62MM)	USGS			PHYSICAL
658 SETTLE WATER (RESIDUE)	USGS			PHYSICAL
659 SOLIDS (RESIDUE--TOTAL, SUSPENDED @105C)	USGS			PHYSICAL
660 SOLIDS (SUM OF CONTENTS)	USGS			PHYSICAL
661 SPECIFIC CONDUCTANCE	USGS			PHYSICAL
662 T.S.S.	USGS			PHYSICAL
663 TEMPURATURE	USGS			PHYSICAL

DATA ELEMENTS GROUPING

NO.	DATA ELEMENT	SOURCE	FORMAT	REMARK	GROUP TITLE
664	TURBIDITY	USGS			PHYSICAL
665	FACILITY IDENTIFIER	CT,P215	19-C	CT28	POWER
666	RIVER MILE	CT,P216	5-D	CT28	POWER
667	GENERATING CAPACITY	CT,P217	8-D	CT28	POWER
668	ANNUAL POWER	CT,P218	10-D	CT28	POWER
669	MONTHLY POWER PRODUCED	CT,P219	10-D	CT28	POWER
670	TYPE OF POWER	CT,P220	2-C	CT28	POWER
671	TYPE OF COOLING SYSTEM	CT,P221	2-C	CT28	POWER
672	FPC LICENCE NUMBER	CT,P222	4-D	CT28	POWER
673	WETLAND IDENTIFIER	CT,P256	19-C	CT33	PRESERVATION
674	MULTI-FUNCTIONAL	CT,P257	1-C	CT33	PRESERVATION
675	WETLAND FUNCTION	CT,P258	2-C	CT33	PRESERVATION
676	GENERATING CAPACITY	NWU,P3-103	8-D		PRESERVATION DATA
677	ANNUAL POWER PRODUCED	NWU,P3-104	10-D		PRESERVATION DATA
678	MONTHLY POWER PRODUCED	NWU,P3-105	10-D		PRESERVATION DATA
679	PRESERVE MANAGEMENT AGENCY	NWU,P3-106	40-C		PRESERVATION DATA
680	PRESERVE WATER BODY	NWU,P3-107	40-C		PRESERVATION DATA
681	PRESERVE MINIMUM FLOW	NWU,P3-108	10-D		PRESERVATION DATA
682	FACILITY IDENTIFIER	CT,P225	19-C	CT29	PRODUCTION
683	PRODUCT CODE	CT,P226	7-D	CT29	PRODUCTION
684	PRODUCT NAME	CT,P227	20-C	CT29	PRODUCTION
685	ANNUAL PRODUCTION	CT,P228	4-D	CT29	PRODUCTION
686	TOTAL ANNUAL ADDED	CT,P229		CT29	PRODUCTION
687	TYPE OF PRODUCT	NWU,P3-76	4-D		PRODUCTION DATA
688	ANNUAL PRODUCTION	NWU,P3-77	25-D		PRODUCTION DATA
689	TOTAL VALUE ADDED	NWU,P3-78	8-D		PRODUCTION DATA
690	POPULATION TYPE	NWU,P3-113	2-C		PUBLIC SUPPLIER DATA
691	POPULATION SERVED	NWU,P3-114	7-D		PUBLIC SUPPLIER DATA
692	CONNECTIONS SERVED	NWU,P3-115	7-D		PUBLIC SUPPLIER DA

694 TREATMENT CAPACITY	CT,P202	9-D	CT25	PUBLIC SUPPLY
695 GROSS ALPHA CONC.	DOH (WELL)	3.1	ANNUALLY	RADIOACTIVITY
696 GROSS BETA CONC.	DOH (WELL)	3.1	ANNUALLY	RADIOACTIVITY
697 TYPE OF RECREATION	CT,P250	2-C	CT32	RECREATION
698 YEARLY VISITS	CT,P251	9-D	CT32	RECREATION
699 INCOME	CT,P252	9-D	CT32	RECREATION
700 MONTHLY NUMBER OF VISITS	CT,P253	7-D	CT32	RECREATION
701 WATER BODY NAME	NWU,P3-109	40-C		RECREATION DATA
702 YEARLY VISITS	NWU,P3-110	7-D		RECREATION DATA
703 INCOME	NWU,P3-111	8-D		RECREATION DATA
704 NUMBER OF VISITS	NWU,P3-112	8-D		RECREATION DATA
705 REGULATING AGENCY IDENTIFIER	CT,P180	10-C	CT22	REGULATING AGENCY
706 REGULATING AGENCY NAME	CT,P181	40-C	CT22	REGULATING AGENCY
707 REGULATING AGENCY ADDRESS	CT,P182	40-C	CT22	REGULATING AGENCY
708 REGULATING AGENCY TOWN	CT,P183	20-C	CT22	REGULATING AGENCY
709 REGULATING AGENCY COUNTY	CT,P184	3-D	CT22	REGULATING AGENCY
710 REGULATING AGENCY STATE	CT,P185	2-D	CT22	REGULATING AGENCY
711 WATER SOURCE IDENTIFIER	CT,P96	19-C	CT14	RESERVOIR FUNCTION
712 RESERVOIR FUNCTION	CT,P97	2-C	CT14	RESERVOIR FUNCTION
713 INVENTORY UNIT IDENTIFIER	CT,P173	19-C	CT21	RESTRICTIONS
714 WITHDRAWAL/RETURN CODE	CT,P174	1-C	CT21	RESTRICTIONS

DATA ELEMENTS GROUPING

NO.	DATA ELEMENT	SOURCE	FORMAT	REMARK	GROUP TITLE
715	MONTH OF RESTRICTION	CT,P175	2-D	CT21	RESTRICTIONS
716	REGULATING AGENCY IDENTIFIER	CT,P176	10-C	CT21	RESTRICTIONS
717	TYPE OF RESTRICTION	CT,P177		CT21	RESTRICTIONS
718	RPA NAME	CT,P37	2-D	CT6	RPA
719	RPA ADDRESS	CT,P38	30-C	CT6	RPA
720	RPA TOWN	CT,P39	16-C	CT6	RPA
721	RPA ZIP CODE	CT,P40	5-D	CT6	RPA
722	FACILITY IDENTIFIER	CT,P73	19-C	CT11	SERVICE AREA
723	SERVICE AREA	CT,P74		CT11	SERVICE AREA
724	POPULATION TYPE	CT,P75	2-C	CT11	SERVICE AREA
725	POPULATION SERVED	CT,P76	7-D	CT11	SERVICE AREA
726	CONNECTION SERVED	CT,P77	7-D	CT11	SERVICE AREA
727	METERED CONNECTIONS	CT,P78	7-D	CT11	SERVICE AREA
728	SIC CODE	CT,P194	4-D	CT24	SIC
729	SIC DESCRIPTION	CT,P195	20-C	CT24	SIC
730	NWUDS USE CATEGORY	CT,P196	2-C	CT24	SIC
731	NWUDS USE SUBCATEGORY	CT,P197	2-C	CT24	SIC
732	FLOW	DEM	1.3	BIMONTHLY	SMALL INDUSTRIAL DISCHARGES
733	OIL AND GREASE	DEM	3.1	BIMONTHLY	SMALL INDUSTRIAL DISCHARGES
734	PH	DEM	2.1	BIMONTHLY	SMALL INDUSTRIAL DISCHARGES
735	TEMPERATURE	DEM	3.	BIMONTHLY	SMALL INDUSTRIAL DISCHARGES
736	BOD % REMOVAL	DEM	2.1	MONTHLY	SMALL PACKAGE PLANTS
737	BOD5 FINAL EFFLUENT CONC.	DEM	3.1	MONTHLY	SMALL PACKAGE PLANTS
738	BOD5 FINAL EFFLUENT LOAD	DEM	3.1	MONTHLY	SMALL PACKAGE PLANTS
739	BOD5 RAW INFLUENT CONC.	DEM	3.1	MONTHLY	SMALL PACKAGE PLANTS
740	BOD5 RAW INFLUENT LOAD	DEM	3.1	MONTHLY	SMALL PACKAGE PLANTS
741	CHLORINE RESIDUAL	DEM	1.1	MONTHLY	SMALL PACKAGE PLANTS
742	FECAL COLIFORMS	DEM	6.1	MONTHLY	SMALL PACKAGE PLANTS
743	FLOW	DEM	6.1	MONTHLY	SMALL PACKAGE PLANTS

745	SETTLEABLE SOLIDS EFFLUENT	DEM	3.1	MONTHLY	SMALL PACKAGE PLANTS
746	TSS % REMOVAL	DEM	2.1	MONTHLY	SMALL PACKAGE PLANTS
747	TSS FINAL EFFLUENT CONC.	DEM	3.1	MONTHLY	SMALL PACKAGE PLANTS
748	TSS FINAL EFFLUENT LOAD	DEM	3.1	MONTHLY	SMALL PACKAGE PLANTS
749	TSS RAW INFLUENT CONC.	DEM	3.1	MONTHLY	SMALL PACKAGE PLANTS
750	TSS RAW INFLUENT LOAD	DEM	3.1	MONTHLY	SMALL PACKAGE PLANTS
751	BENZENE	DOH (WELL)	4.1	ANNUALLY	SPECIAL ORGANICS
752	CARBON TETRA CHLORIDE	DOH (WELL)	4.1	ANNUALLY	SPECIAL ORGANICS
753	CHLOROFORM	DOH (WELL)	4.1	ANNUALLY	SPECIAL ORGANICS
754	TETRACHLOROETHYLENE SURVEY	DOH (WELL)	4.1	ANNUALLY	SPECIAL ORGANICS
755	TOLUENE	DOH (WELL)	4.1	ANNUALLY	SPECIAL ORGANICS
756	TRICHLOROETHENE(1,1,1-)	DOH (WELL)	4.1	ANNUALLY	SPECIAL ORGANICS
757	TRICHLOROETHYLENE	DOH (WELL)	4.1	ANNUALLY	SPECIAL ORGANICS
758	TRIHALOMETHANES	DOH (WELL)	4.1	ANNUALLY	SPECIAL ORGANICS
759	XYLENE	DOH (WELL)	4.1	ANNUALLY	SPECIAL ORGANICS
760	TOWN CODE	CT,P24	3-0	CT3	TOWNS
761	TOWN NAME	CT,P25		CT3	TOWNS
762	BOD5 % REMOVAL	DEM	2.1	MONTHLY	TREATMENT PLANTS
763	BOD5 FINAL EFFLUENT CONC.	DEM	3.1	MONTHLY	TREATMENT PLANTS
764	BOD5 FINAL EFFLUENT LOAD	DEM	6.1	MONTHLY	TREATMENT PLANTS
765	BOD5 RAW INFLUENT CONC.	DEM	3.1	MONTHLY	TREATMENT PLANTS

DATA ELEMENTS GROUPING

NO.	DATA ELEMENT	SOURCE	FORMAT	REMARK	GROUP TITLE
766	BOD5 RAW INFLUENT LOAD	DEM	6.1	MONTHLY	TREATMENT PLANTS
767	FECAL COLIFORMS	DEM	6.1	MONTHLY	TREATMENT PLANTS
768	FLOW	DEM	3.2	MONTHLY	TREATMENT PLANTS
769	TOTAL CHLORINE RESIDUAL CONCERN	DEM	1.1	MONTHLY	TREATMENT PLANTS
770	TOTAL CHLORINE RESIDUAL LOADING	DEM	3.1	MONTHLY	TREATMENT PLANTS
771	TSS % REMOVAL	DEM	2.1	MONTHLY	TREATMENT PLANTS
772	TSS FINAL EFFLUENT CONC.	DEM	3.1	MONTHLY	TREATMENT PLANTS
773	TSS FINAL EFFLUENT LOAD	DEM	6.1	MONTHLY	TREATMENT PLANTS
774	TSS RAW INFLUENT CONC.	DEM	3.1	MONTHLY	TREATMENT PLANTS
775	TSS RAW INFLUENT LOAD	DEM	6.1	MONTHLY	TREATMENT PLANTS
776	FACILITY IDENTIFIER	CT,P205	19-C	CT26	WASTE ASSIMILATION
777	TREATMENT CAPACITY	CT,P206	9-D	CT26	WASTE ASSIMILATION
778	INVENTORY UNIT IDENTIFIER	CT,P154	19-C	CT19	WATER QUALITY
779	WITHDRAWAL/RETURN CODE	CT,P155	1-C	CT19	WATER QUALITY
780	WATER QUALITY ORGANIZATION	CT,P156	30-C	CT19	WATER QUALITY
781	WATER QUALITY ORGANIZATION ADDRESS	CT,P157	40-C	CT19	WATER QUALITY
782	WATER QUALITY ORGANIZATION CITY	CT,P158	20-C	CT19	WATER QUALITY
783	WATER QUALITY ORGANIZATION STATE	CT,P159	2-C	CT19	WATER QUALITY
784	WATER QUALITY ORGANIZATION ZIP	CT,P160	5-D	CT19	WATER QUALITY
785	WATER QUALITY FILE NAME	CT,P161	20-C	CT19	WATER QUALITY
786	WATER QUALITY NAWDEX ID	CT,P162	5-C	CT19	WATER QUALITY
787	RIVER MILE	CT,P81	5-D	CT12	WATER SOURCE
788	WATER SOURCE TYPE	CT,P82	2-C	CT12	WATER SOURCE
789	WATER BODY NAME	CT,P84	10-C	CT12	WATER SOURCE
790	STORAGE CAPACITY	CT,P85	9-D	CT12	WATER SOURCE
791	SAFE YIELD	CT,P86	9-D	CT12	WATER SOURCE
792	SAFE YIELD NOTATION	CT,P87	2-C	CT12	WATER SOURCE
793	SURFACE AREA	CT,P88	7-D	CT12	WATER SOURCE
794	PRIMARY AQUIFER CODE	CT,P89	8-C	CT12	WATER SOURCE

796 COUNTY	DOH (WELL)			WELL IDENTIFIER
797 DEPTH DRILLED	DOH (WELL)	4.1		WELL IDENTIFIER
798 LATITUDE	DOH (WELL)	6.0		WELL IDENTIFIER
799 LOCAL WELL NO.	DOH (WELL)	2.0		WELL IDENTIFIER
800 LONGITUDE	DOH (WELL)	6.0		WELL IDENTIFIER
801 PUMPAGE	DOH (WELL)	4.1		WELL IDENTIFIER
802 FACILITY IDENTIFIER	CT,P67	19-C	CT10	WELLS
803 SAFE YIELD	CT,P68	9-D	CT10	WELLS
804 SAFE YIELD NOTAION	CT,P69	2-C	CT10	WELLS
805 PUMP CAPACITY	CT,P70	5-D	CT10	WELLS
806 WITHDRAWAL/RETURN CODE	NWU,P3-23	1-C		WITHDRAWAL/RETURN DAT
807 WITHDRAWAL/RETURN SEQUENCE	NWU,P3-24	2-D		WITHDRAWAL/RETURN DAT
808 ID POINTER	NWU,P3-25	15-D		WITHDRAWAL/RETURN DAT
809 WITHDRAWAL/RETURN NAME	NWU,P3-26	40-C		WITHDRAWAL/RETURN DAT
810 WITHDRAWAL/RETURN COUNTY	NWU,P3-27	3-D		WITHDRAWAL/RETURN DAT
811 WITHDRAWAL/RETURN STATE	NWU,P3-28	2-D		WITHDRAWAL/RETURN DAT
812 WITHDRAWAL/RETURN NON-U.S. COUNTRY	NWU,P3-29	3-C		WITHDRAWAL/RETURN DAT
813 WITHDRAWAL/RETURN LATITUDE	NWU,P3-30	6-D		WITHDRAWAL/RETURN DAT
814 WUTHDRAWAL/RETURN LONGITUDE	NWU,P3-31	7-D		WITHDRAWAL/RETURN DAT
815 WITHDRAWAL/RETURN HYDROLOGIC UNIT	NWU,P3-32	8-D		WITHDRAWAL/RETURN DAT
816 WITHDRAWAL/RETURN PRINCIPAL AQUIFER	NWU,P3-33	8-D		WITHDRAWAL/RETURN DAT

DATA ELEMENTS GROUPING

NO.	DATA ELEMENT	SOURCE	FORMAT	REMARK	GROUP
817	ANNUAL WATER COST	NWU,P3-34	7-D		WITHDRAWAL/RETURN DAT
818	MONTHLY COST	NWU,P3-35	7-D		WITHDRAWAL/RETURN D
819	ANNUAL AMOUNT WITHDRAWAL/RETURNED	NWU,P3-36	10-D		WITHDRAWAL/RETURN DAT
820	MONTHLY AMOUNT WITHDRAWAL RETURNED	NWU,P3-37	10-D		WITHDRAWAL/RETURN DAT
821	ANNUAL AMOUNT DELIVERED/RELEASED	NWU,P3-38	10-D		WITHDRAWAL/RETURN D
822	MONTHLY AMOUNT DELIVERED/RELEASED	NWU,P3-39	10-D		WITHDRAWAL/RETURN DAT
823	DAY OF MAXIMUM USE	NWU,P3-40	3-D		WITHDRAWAL/RETURN DAT
824	MAXIMUM DAILY USE	NWU,P3-41	10-D		WITHDRAWAL/RETURN D
825	DAY OF MINIMUM USE	NWU,P3-42	3-D		WITHDRAWAL/RETURN DAT
826	MINIMUM DAILY USE	NWU,P3-43	10-D		WITHDRAWAL/RETURN DAT
827	REQUIRED MINIMUM FLOW	NWU,P3-44	10-D		WITHDRAWAL/RETURN D
828	MEASURING METHOD	NWU,P3-45	1-C		WITHDRAWAL/RETURN DAT
829	MEASURING ENTITY	NWU,P3-46	30-C		WITHDRAWAL/RETURN DAT
830	MEASURING ACCURACY	NWU,P3-47	1-C		WITHDRAWAL/RETURN D
831	PERMITTING AGENCY	NWU,P3-48	40-C		WITHDRAWAL/RETURN DAT
832	PERMIT PROVISIONS	NWU,P3-49	1-C		WITHDRAWAL/RETURN DAT
833	RESTRICTIONS	NWU,P3-50	1-C		WITHDRAWAL/RETURN D
834	RESTRICTIONS COMMENT	NWU,P3-51	40-C		WITHDRAWAL/RETURN DAT
835	REPORTING YEAR	NWU,P3-52	4-D		WITHDRAWAL/RETURN DAT
836	SURFACE AREA	NWU,P3-53	9-D		WITHDRAWAL/RETURN D
837	WATER QUALITY AVAILABLE	NWU,P3-54	1-C		WITHDRAWAL/RETURN DAT
838	WATER QUALITY ORGANIZATION	NWU,P3-55	30-C		WITHDRAWAL/RETURN DAT
839	WATER QUALITY ORGANIZATION ADRESS	NWU,P3-56	40-C		WITHDRAWAL/RETURN D
840	WATER QUALITY ORGANIZATION CITY	NWU,P3-57	20-C		WITHDRAWAL/RETURN DAT
841	WATER QUALITY ORGANIZATION STATE	NWU,P3-58	2-C		WITHDRAWAL/RETURN DAT
842	WATER QUALITY ORGANIZATION ZIP	NWU,P3-59	5-D		WITHDRAWAL/RETURN D
843	WATER QUALITY ORGANIZATION COUNTRY	NWU,P3-60	3-C		WITHDRAWAL/RETURN DAT
844	WATER QUALITY FILE NAME	NWU,P3-61	20-C		WITHDRAWAL/RETURN DAT
845	WATER QUAL.NAWDEX ORGANIZATION CODE	NWU,P3-62	5-C		WITHDRAWAL/RETURN D
846	TREATMENT TYPE	[illegible]	[illegible]		[illegible]

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          847 WITHDRAWAL/RETURN TYPE                  NWU,P3-64    2-C              WITHDRAWAL/RETURN DA
  A
          848 WATER TYPE                              NWU,P3-66    1-C              WITHDRAWAL/RETURN D
  A
          849 RECLAIMED WASTE WATER                   NWU,P3-67    1-C              WITHDRAWAL/RETURN DA
  A
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THE EFFICIENCY OF NITROGEN USE BY KENTUCKY BLUEGRASS TURF AS INFLUENCED BY NITROGEN RATE, FERTILIZER RATIO AND NITRIFICATION INHIBITORS

BY

ERIC STEVEN HESKETH

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ERIC STEVEN HESKETH

APPROVED:

Thesis Committee

Major Professor ______________________

Arthur Gold

____

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DEAN OF THE GRADUATE SCHOOL

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ABSTRACT

Increasing the efficiency of nitrogen use by turfgrasses depends upon providing adequate nitrogen throughout the season while minimizing losses due to leaching and denitrification of nitrate, and volatilization of ammonia. Adjusting the rate and timing of nitrogen application, along with the use of nitrification inhibitors, may reduce losses and increase nitrogen use efficiency by lawn turf.

Field plots of Kentucky bluegrass (_Poa pratensis_ L. cv. 'Baron') grown on an Enfield silt loam (coarse-silty over sandy or sandy-skeletal, mixed, mesic Typic Dystrochrepts) were maintained at three nitrogen rates, and four fertilizer ratios: N, NP, NK, NPK. Nitrogen rates in 1983 were 72, 144, 384 kg N/ha and in 1984 they were 120, 240, and 384 kg N/ha. Terrazole (5-Ethoxy-3-trichloromethyl-1,2,4-thiadiazole) was applied in the spring of 1983 at the rate of 1.1 kg/ha. Nitrapyrin (2-Chloro-6-(trichloromethyl) pyridine) was applied in the fall of 1983 at 0.5 kg/ha and in the spring/summer 1984 at 1.7 kg/ha. Dicyandiamide was applied in the fall of 1984 at the rate of 7.2 kg/ha. Clipping samples were analysed for total nitrogen following inhibitor applications. Soil solution samples, derived from suction lysimeters in 1983, and

soil extracts in 1984 were analysed following inhibitor applications for nitrate-nitrogen and ammonium-nitrogen.

Inhibitors did not influence clipping yields, clipping nitrogen content, total nitogen recovered in clippings on an area basis or the concetration of soil inorganic nitrogen species. Nitrogen applied at the rates at or below 240 kg/ha/year in combination with phosphorus and potassium resulted in efficient nitrogen use. The application of nitrogen at 384 kg/ha/year resulted in poor quality turf. Also, leachate nitrate-nitrogen concentrations, 60 cm below the soil surface, exceeded the level considered safe for drinking water when fertilized at the rate of 384 kg N/ha/year.

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INTRODUCTION

Turfgrass is frequently fertilized with nitrogen and other nutrients to maintain acceptable quality. However, fertilizing practices which lead to improved quality do not always increase nutrient use efficiency. Nitrogen, the nutrient most highly correlated with turfgrass quality, can be subject to losses by denitrification, leaching, volatilization of ammonia and clipping removal. Losses of fertilizer nitrogen, due to denitrification have been reported as high as 50% under dry conditions and up to 100% of applied fertilizer nitrogen when the soil was above field capacity (Stephenson et al. 1969 in Huber et al. 1977). Leaching losses usually account for less nitrogen loss, about 5% of that applied, but could be much greater under turfgrass grown on sandy soils and heavily irrigated. Studies on Long Island have implicated nitrogen, used to fertilize turfgrass, as a source of nitrate contamination of ground water (Long Island Regional Planning Board 1978). Other studies have indicated that nitrate leaching under turfgrass may be minimal (Rieke and Ellis 1974; Starr and DeRoo 1981). Techniques for improving nitrogen use efficiency include the use of slow release nitrogen sources, frequent applications of soluble nitrogen sources at low rates and the use of nitrification inhibitors. Although slow release nitrogen and frequent applications of soluble nitrogen sources have been used in turf, nitrification inhibitors have not.

Nitrification inhibitors used on field crops have shown yield increases between 25% and 54% (Frye et al. 1981; Huber et al. 1975; Warren et al. 1975; Swezey and Turner 1962). Total nitrogen in leaf tissue and grain protein have also been increased from 10% to 20% with the use of inhibitors (Warren et al. 1975; Touchton et al. 1979; Swezey and Turner 1962). Little research has been done on the use of nitrification inhibitors on established ground covers such as turfgrass. Waddington et al. (1975) conducted a study which included the use of nitrapyrin. Although no benefits were found by using the inhibitor, they concluded that more research was needed to assess the value of nitrapyrin on turf. The objective of the present study is to determine the usefulness of nitrification inhibitors for increasing nitrogen use efficiency in an established turfgrass stand under several different fertility regimes. Additionally, the effect of fertility regimes on the efficiency of nitrogen use will be examined.

METHODS AND MATERIALS

Field studies were conducted on an established stand of Kentucky bluegrass (*Poa pratensis* L. cv. 'Baron') seeded in 1976 on a Enfield silt loam (coarse-silty over sandy or sandy-skeletal, mixed, mesic Typic Dystrochrepts) at the Rhode Island Agricultural Experiment Station, Turfgrass Research Farm. The study was conducted during the 1983 and 1984 growing seasons. The experimental design was a split block with four replications. Main plots consisted of a nitrification inhibitor treatment and a control which received no inhibitor. Subplots consisted of four fertilizer ratios: nitrogen (N); phosphorus (NP); nitrogen and potassium (NK); and nitrogen, phosphorus, and potassium (NPK). These were further divided randomly into sub-subplots consisting of three fertilizer rates, high (H), medium (M), and low (L). In 1983, the three rates were 384-80-160, 144-40-80, and 72-20-40 kg/ha/yr N, P, and K. For the 1984 growing season the rates were 384-80-160, 240-40-80 and 120-20-40 kg/ha/yr respectively. For twelve years prior to 1983 the nitrogen rates for the high, medium, and low plots were 480, 240 and 120 kg N/ha/yr respectively. Phosphorus and potassium rates were the same prior to and during this experiment. The fertilizer schedules for 1983 and 1984 are listed in Table 1. Fertilizer sources were urea, superphosphate, and KCl.

Table 1. Fertilizer application schedule for the 1983 and 1984 growing seasons.

Date	Fertilizer rate	Fertilizer application		
		Nitrogen	Phosphorus	Potassium
			kg/ha	
5-10-83*	Low	48	10	20
	Medium	96	20	40
	High	96	40	80
6-09-83	High	48	–	–
6-30-83	High	48	–	–
7-28-83	High	48	–	–
8-25-83	High	48	–	–
10-17-83*	Low	24	10	20
	Medium	48	20	40
	High	96	40	80
4-27-84	Low	0	10	20
	Medium	48	20	40
	High	96	40	80
6-06-84*	All	48	–	–
7-13-84	High	48	–	–
8-31-84	High	48	–	–
9-27-84*	All	48	–	–
12-18-84	Low	24	10	20
	Medium	96	20	40
	High	96	40	80

* Inhibitors applied 5-02-83,10-06-83,6-06-84 and 9-27-84

Diammonium phosphate, urea and potassium magnesium sulfate were used for the May 10 1983 application. The list of nitrification inhibitors and the schedule of applications are summarized in Table 2. For the 6 June 1983 inhibitor application, nitrapyrin was applied directly to the urea granules which were kept in an airtight contaianer until broadcast. Inhibitor application was immediately followed by approximately 2 cm of irrigation.

Plots were maintained at a cutting height of 3.8 cm and were mowed weekly during the 1983 growing season, except in the fall when reduced growth permitted less frequent mowing. Mowing during the 1984 growing season occurred on a less regular schedule. All clippings were removed during both growing seasons.

Clipping samples were harvested from a 3.0 by 0.48 m swath prior to regular mowing. Leaf blade tissue samples were dried at 65°C, weighed, and stored dry. Dried samples of leaf clippings were ground in a Wiley mill to pass a 40 mesh sieve. Dry tissue samples weighing from 160 to 170 mg were digested by the micro-Kjeldahl method described by Eastin (1978) and the resulting digest used to determine total nitrogen.

In 1983, soil water samples were collected from those plots receiving N and NPK by means of 20 cm deep suction lysimeters. To construct the suction lysimeters, porous ceramic cups (Soil Moisture Equipment Company,Santa

Table 2. Application time and rate of nitrification inhibitors on Kentucky bluegrass cv. 'Baron'.

Inhibitor		Application		
Common name	Chemical name	Rate	Date	Form
		kg/ha		
Terrazole	5-Ethoxy-3-trichloromethyl-1,2,4-thiadiazole	1.1	5-02-83	granular
Nitrapyrin	2-Chloro-6-(trichloromethyl)pyridine	0.5	10-06-83	liquid
Nitrapyrin	2-Chloro-6-(trichloromethyl)pyridine	1.7	6-06-84	with urea granules
DCD	Dicyandiamide	7.2	9-27-84	liquid

Barbara, CA) were cemented to a length of PVC pipe which had been machined to fit each cup. For each lysimeter, 3.8 cm (inside diameter) by 14 cm long schedule-40 pipe was used. The open end of the lysimeter tube was fitted with a 2.5 cm long collar of 4.4 cm diameter, schedule-80 PVC pipe to provide greater stability, and to prevent mechanical damage to the exposed end. A stopper assembly was made by fitting a 5 to 8 cm long hollow glass tube into a no. 9 1/2 one-hole rubber stopper. Attached to the glass tube was a 10 to 12 cm long piece of neoprene tubing, and a pinch clamp. This stopper assembly was inserted into the open end of the lysimeter. Sixty cm long removable extension tubes made of schedule-40 PVC pipe were fitted onto the 20 cm lysimeters to obtain a sufficient vacuum reservoir. Lysimeters were installed by removing soil cores 10 cm in diameter by 25 cm deep. A slurry of silt and water was poured into the hole and the lysimeter was immediately set into the silt to provide a seal between the lysimeter cup and the soil. The remaining area around the lysimeter was backfilled with soil. The lysimeters were evacuated to a vacuum of 700 mm Hg with an electric vacuum pump and tightly clamped. Soil water samples were collected approximately 24 hours after the vacuum had been applied to the lysimeters. Water samples which were not analysed within 24 hours after collection were fixed by adding 1 ml of 1 M boric acid per 125 ml sample and stored at 4^{o}C.

In 1984, soil samples were collected instead of soil water samples to determine the soil nitrate and ammonium concentrations because of the frequent failure of lysimeters to produce samples. Three soil cores, 3.0 cm in diameter and 15.0 cm long were taken per plot receiving NPK. Soil samples were analysed within 24 hours of collection whenever possible. If the samples were not analysed within 24 hours, they were frozen at -15^{o}C until analysis could be completed. To measure extractable ammonium, 50 mls of 2 M KCl were added to 5 grams of fresh soil, and shaken for 1 hour at room temperature. The KCL solution was filtered through Whatman no.42 filter paper and analysed for ammonium. Ammonium analyses of micro-Kjeldahl digests, soil extracts, and soil water samples were performed by the colorometric salicylate-hypochlorite method described by Bower and Holm-Hansen (1980). Nitrate analyses of soil extracts and soil water samples were performed with an Orion 93-07 nitrate electrode. The method used to determine nitrates in lysimeter derived soil water samples was that outlined in the Orion 93 Series Methods Manual (1976). Nitrate in soil samples was measured by diluting 5 grams of fresh soil with 10 mls of distilled water, stirring occasionally, and assaying the mixture directly after 1 hour with the nitrate electrode. All samples assayed for nitrate were adjusted to a background ionic strength of 0.12 M with ammonium sulfate. In addition, soil extracts and soil water samples from lysimeters, received 1 ml of 64 mM silver sulfate per 25 ml sample to precipitate interfering ions.

Clipping production rates ($g/m^2/d$) were obtained by dividing clipping yields (g/m^2) by the number of days since the previous mowing. Nitrogen recovered in clippings ($mg\ N/m^2/d$) was calculated by multiplying tissue N content (mg N/g tissue) by clipping production rate ($g/m^2/d$).

All data were subject to analysis of variance for a split block design using the general linear models procedure, SAS Institute Inc. (SAS Institute Inc. 1982).

RESULTS

None of the inhibitors studied exhibited any effect on clipping production rate, clipping nitrogen content, or the accumulation rate of nitrogen in clippings on an area basis (Tables 3-10 and A1-A8). Terrazole, applied at the rate of 1.1 kg/ha, (Tables 3,4 and A1,A2) was studied initially. However, questions raised about its future commercial availability and the lack of supporting literature led me to study other commercially avaliable compounds. Nitrapyrin was applied as a liquid at the rate of 0.5 kg/ha and after it was determined that the inhibitor, at this rate was ineffective, (Tables 5,6 and A3,A4) the rate was increased to 1.7 kg/ha and was applied as a liquid coating to urea granules. This treatment also showed results which would indicate lack of inhibitor activity (Tables 7,8 and A5,A6). Since low water solubility and volatility were thought to be a contributing factor to inactivity, a water soluble inhibitor was used: dicyandiamide (DCD). Again, no evidence indicating increased nitrogen use efficiency was obtained by using this inhibitor (Tables 9,10 and A7,A8). While none of the inhibitors exhibited a significant main plot effect, several significant interactions between inhibitor and nitrogen rate and inhibitor and fertilizer ratio did appear. However, these interactions were inconsistent and unpredictable. At no time did a

Table 3. Nitrogen content of clippings and rates of nitrogen accumulation in clippings for Kentucky bluegrass cv. 'Baron' with and without terrazole at three nitrogen rates.

		Date					
		Tissue N content			N accumulation		
Nitrogen rate	Terrazole rate	5-17-83	6-01-83	6-17-83	5-17-83	6-01-83	6-17-83
kg/ha/yr	kg/ha	mg N/g dry matter			mg $N/m^2/d$		
72	0	41.2	46.2	43.5	91.7	129.0	58.6
	1.1	41.6	46.2	42.6	72.4	132.8	63.4
	Mean	41.4	46.2	43.0	82.1	130.9	61.0
144	0	48.2	56.8	50.5	154.4	239.6	129.7
	1.1	45.7	53.7	48.7	138.7	225.7	120.9
	Mean	47.0	55.1	49.6	146.6	232.7	125.3
384	0	48.1	56.7	55.7	52.4	114.4	101.9
	1.1	44.9	56.4	56.5	79.2	122.9	98.8
	Mean	46.5	56.5	56.1	65.8	118.7	100.9
Source	df	F ratio					
Inhib	1	4.57	7.87	2.61	0.01	0.00	0.00
N-Rate	2	8.64*	22.84+	241.06+	8.72*	14.79**	22.29**
Inhib x Rate	2	2.14	7.89*	2.95	1.12	0.71	0.15

*,** Significant at the 0.05 and 0.01 level of probability respectively.

\+ Significant at the 0.001 level of probability.

Table 4. Nitrogen content of clippings and rates of nitrogen accumulation in clippings for Kentucky bluegrass cv. 'Baron' with and without terrazole at two fertilizer ratios.

		Date					
		Tissue N content			N accumulation		
Fertilizer ratio	Terrazole rate	5-17-83	6-01-83	6-17-83	5-17-83	6-01-83	6-17-83
	kg/ha	mg N/g dry matter			mg $N/m^2/d$		
N	0	45.7	52.0	49.2	90.2	140.3	80.4
	1.1	44.4	51.9	49.9	76.7	134.0	79.4
	Mean	45.1	52.2	49.5	83.5	137.2	79.9
NPK	0	46.0	54.3	50.6	108.8	176.5	113.0
	1.1	43.8	52.2	48.0	114.9	186.9	107.1
	Mean	44.9	53.2	49.4	111.9	181.7	110.1
Source	df	F ratio					
Inhib	1	4.57	7.87	2.61	0.01	0.00	0.00
Ratio	1	0.20	2.55	0.00	1.13	12.68*	19.65*
Inhib x Ratio	1	1.26	2.03	11.83*	1.42	1.12	4.54

*,** Significant at the 0.05 and 0.01 level of probability respectively.

+ Significant at the 0.001 level of probability.

Table 5. Nitrogen content of clippings and rates of nitrogen accumulation in clippings for Kentucky bluegrass cv. 'Baron' with and without nitrapyrin at three nitrogen rates.

Nitrogen rate	Nitrapyrin rate	Date Clipping N content 9-30-83	 10-31-83	 12-01-83	 N accumulation 9-30-83	 10-31-83	 12-01-83
kg/ha/yr	kg/ha	mg N/g dry matter			$mg\ N/m^2/d$		
	0	35.1	35.9	37.0	16.0	16.3	2.5
72	0.5	34.7	35.5	38.6	15.5	9.3	2.7
	Mean	34.9	35.7	37.8	15.8	12.8	2.6
	0	37.2	37.1	39.1	20.1	16.2	3.2
144	0.5	39.3	35.4	40.3	23.4	13.0	4.9
	Mean	38.2	36.2	39.7	21.8	14.6	4.1
	0	40.9	41.8	38.7	46.6	13.7	7.9
384	0.5	44.9	45.3	40.0	60.6	16.4	10.2
	Mean	42.6	43.6	39.3	53.6	15.1	9.1
Source	df				F ratio		
Inhib	1	2.83	0.04	1.14	0.63	0.46	2.12
N-Rate	2	25.24**	21.74**	0.69	140.62+	0.26	38.87+
Inhib x Rate	2	2.70	1.29	0.01	1.90	4.72	0.62

*,** Significant at the 0.05 and 0.01 level of probability respectively.

\+ Significant at the 0.001 level of probability.

Table 6. Nitrogen content of clippings and rates of nitrogen accumulation in clippings for Kentucky bluegrass cv. 'Baron' with and without nitrapyrin at two fertilizer ratios.

		Date					
		Clipping N content			N accumulation		
Fertilizer ratio	Nitrapyrin rate	9-30-83	10-31-83	12-01-83	9-30-83	10-31-83	12-01-83
	kg/ha	mg N/g dry matter			mg N/m^2/d		
N	0	40.7	40.5	42.0	25.8	16.6	3.6
	0.5	38.9	39.9	42.0	22.5	13.5	3.9
	Mean	39.9	40.2	42.0	24.2	15.1	3.8
NPK	0	34.8	36.0	34.5	29.3	14.1	5.5
	0.5	39.3	37.6	37.2	38.7	12.3	8.0
	Mean	36.9	36.8	35.9	34.0	13.2	6.8
Source	df	F ratio					
Inhib	1	2.83	0.04	1.14	0.63	0.46	2.12
Ratio	2	1.99	2.36	55.65**	6.96	3.68	10.69*
Inhib x Ratio	2	12.47*	0.33	0.48	45.54**	0.05	3.82

*,** Significant at the 0.05 and 0.01 level of probability respectively.

\+ Significant at the 0.001 level of probability.

Table 7. Nitrogen content of clippings and rates of nitrogen accumulation in clippings for Kentucky bluegrass cv. 'Baron' with and without nitrapyrin at three nitrogen rates.

		Date					
		Clipping N content			N accumulation		
Nitrogen rate	Nitrapyrin rate	6-11-84	6-22-84	7-06-84	6-11-84	6-22-84	7-06-84
kg/ha/yr	kg/ha	mg N/g dry matter			mg N/m^2/d		
120	0	46.3	39.7	43.9	64.0	42.4	54.3
	1.7	47.7	40.3	44.7	72.2	49.8	59.0
	Mean	47.0	40.0	44.3	68.1	46.1	56.7
240	0	51.6	44.3	47.2	110.2	63.0	80.5
	1.7	51.5	42.0	48.2	135.2	71.7	92.0
	Mean	51.6	43.2	47.7	122.7	67.4	86.3
384	0	52.1	45.4	50.9	109.0	53.4	77.1
	1.7	53.9	46.8	52.3	104.4	59.0	84.0
	Mean	53.0	46.1	51.6	106.7	56.2	80.6
Source	df	F ratio					
Inhib	1	7.90	0.01	3.75	0.46	1.17	1.85
N-Rate	2	49.42+	11.96**	692.64+	14.53*	17.42**	12.33**
Inhib x Rate	2	0.59	1.25	0.15	2.50	0.17	0.91

*,** Significant at the 0.05 and 0.01 level of probability respectively.

\+ Significant at the 0.001 level of probability.

Table 8. Nitrogen content of clippings and rates of nitrogen accumulation in clippings for Kentucky bluegrass cv. 'Baron' with and without nitrapyrin at two fertilizer ratios.

		Date					
		Clipping N content			N accumulation		
Fertilizer ratio	Nitrapyrin rate	6-11-84	6-22-84	7-06-84	6-11-84	6-22-84	7-06-84
	kg/ha	mg N/g dry matter			$mg N/m^2/d$		
N	0	50.3	42.8	48.3	83.5	45.6	70.1
	1.7	50.9	44.4	49.8	90.1	52.8	71.6
	Mean	50.6	43.6	49.1	86.8	49.2	70.9
NPK	0	49.7	43.4	46.3	110.9	60.3	71.2
	1.7	51.2	41.7	47.0	117.7	67.6	85.1
	Mean	50.4	42.5	46.7	114.3	64.0	78.2
Source	df	F ratio					
Inhib	1	7.90	0.01	3.75	0.46	1.17	1.85
Ratio	1	0.02	0.34	125.31**	15.46*	7.63	0.99
Inhib x Ratio	1	0.25	3.41	3.54	0.26	0.00	7.53

*,** Significant at the 0.05 and 0.01 level of probability respectively.

\+ Significant at the 0.001 level of probability.

Table 9. Nitrogen content of clippings and rates of nitrogen accumulation in clippings for Kentucky bluegrass cv. 'Baron' with and without DCD at three nitrogen rates.

		Date					
		Clipping N content			N accumulation		
Nitrogen rate	DCD rate	9-20-84	11-01-84	11-28-84	9-20-84	11-01-84	11-28-84
kg/ha/yr	kg/ha	mg N/g	dry matter			mg $N/m^2/d$	
120	0	41.3	39.3	39.6	38.9	35.0	10.5
	7.2	38.1	41.4	38.7	30.0	31.7	9.9
	Mean	39.7	40.4	39.1	34.5	33.4	10.2
240	0	39.0	35.6	40.4	34.6	34.9	10.8
	7.2	39.9	42.3	40.3	39.4	40.5	11.3
	Mean	39.4	39.0	40.4	37.0	37.7	11.1
384	0	49.6	47.0	42.8	93.9	67.5	12.9
	7.2	48.8	47.6	42.5	73.2	64.9	14.3
	Mean	49.2	47.3	42.6	83.6	66.2	13.6
Source	df			F ratio			
Inhib	1	0.96	2.97	0.10	6.81	0.03	0.01
N-Rate	2	29.70+	9.04*	18.30**	71.45+	28.46+	3.37
Inhib x Rate	2	1.26	1.35	0.30	2.33	0.44	0.13

*,** Significant at the 0.05 and 0.01 level of probability respectively.

\+ Significant at the 0.001 level of probability.

Table 10. Nitrogen content of clippings and rates of nitrogen accumulation in clippings for Kentucky bluegrass cv. 'Baron' with and without DCD at four fertilizer ratios.

		Date					
		Clipping N content			N accumulation		
Fertilizer ratio	DCD rate	9-20-84	11-01-84	11-28-84	9-20-84	11-01-84	11-28-84
	kg/ha	mg N/g dry matter			mg $N/m^2/d$		
N	0	43.7	39.7	41.5	46.2	38.7	10.5
	7.2	43.1	44.6	41.1	39.6	43.1	9.6
	Mean	43.4	42.1	41.3	42.9	40.9	10.1
NPK	0	42.9	42.2	40.4	65.4	54.8	12.3
	7.2	41.4	43.3	39.8	55.4	50.0	13.6
	Mean	42.2	42.7	40.1	60.4	52.4	13.0
Source	df	F ratio					
Inhib	1	0.96	2.97	0.10	6.81	0.03	0.01
Ratio	1	1.03	0.14	4.41	7.72	52.04**	3.36
Inhib x Ratio	1	0.49	2.07	0.19	0.13	1.35	0.70

*,** Significant at the 0.05 and 0.01 level of probability repectively.

\+ Significant at the 0.001 level of probability.

significant interaction appear on two consecutive sampling dates or involve more than one variable. Occasionally, when significant interactions occurred, the results were not consistent with what would be expected if nitrification were being inhibited. For example, on 1 June 1983 (Table 3), terrazole-treated plots had a 5 % lower nitrogen content than plots which did not receive terrazole.

Nitrogen rates did significantly influence clipping yield (Tables A1,A3,A5, and A7), clipping nitrogen content and rate of nitrogen accumulation in clippings on an area basis (Tables 3,5,7,9). In the spring/summer of both years, the highest clipping production rates were from plots receiving the medium yearly nitrogen treatment. Plots receiving the highest nitrogen treatment produced fewer clippings than the low nitrogen plots in the spring of 1983 (Table A1) but produced more clippings than the low nitrogen plots in the spring/summer of 1984 (Table A5). In the fall of both years (Tables A3 and A7), the high nitrogen plots yielded greater clipping production rates, probably due to the additional 192 and 96 kg N/ha the high nitrogen plots had received during the summers of 1983 and 1984, respectively (Table 1). Clipping nitrogen content reflected the most recent nitrogen application as well as previous applications of the current year. For example, in the spring of 1983 (Table 3), plots receiving the high and medium yearly application rates had similar clipping nitrogen content after both had received 98 kg N/ha on 10 May. However, the spring/summer 1984 (Table 7) clipping nitrogen contents reflected both the differing nitrogen rates applied on 27 April and the uniform (48 kg N/ha) rate applied on 6 June (Table 1). Plots receiving the medium nitrogen rate recovered more nitrogen, on an area basis, in clippings, during the spring/summer of both years, than plots receiving either low or high nitrogen, primarily due to greater clipping production rates (Tables 3 and 7). Similarly, nitrogen recovered in clippings during the fall of both years was greater from the high nitrogen plots, when their clipping production rates were high (Tables 5 and 9).

Fertilizer ratios influenced nitrogen recovery, on an area basis, in clippings on several dates (Tables 4,6,8,10). In all cases, total nitrogen accumulated in clippings was higher for plots receiving NPK. Clipping nitrogen content, when significantly different, was higher in plots fertilized with N alone.

Nitrate-nitrogen and ammonium-nitrogen concentrations in soil solutions, collected with suction lysimeters, did not demonstrate any significant inhibitor responses (Tables 11 and 12). Nitrogen application rates did influence nitrate-nitrogen concentrations in the soil solution, though not significantly on all dates. This was often due to missing observations resulting from the frequent failure

Table 11. Soil solution nitrate and ammonium concentrations for the spring/summer of 1983 obtained with suction lysimeters placed at a depth of 20 cm.

Nitrogen rate		Date 6-10-83		6-19-83		6-26-83	
		NO3-N	NH4-N	NO3-N	NH4-N	NO3-N	NH4-N
kg/ha/yr				mg/l			
72		1.3	-	0.9	0.07	0.5	0.04
144		29.3	-	26.7	0.40	9.6	0.31
384		55.0	-	48.7	0.24	53.6	0.17
Fertilizer ratio							
N		30.5	-	17.1	0.17	16.7	0.12
NPK		31.0	-	28.6	0.32	26.0	0.24
Source	df						
Inhib	1	1.16	-	2.52	4.99	-	4.52
N-Rate	2	5.86	-	10.98	1.68	10.24	2.33
Ratio	1	4.60	-	-	4.79	514.40*	2.85

*,** Significant at the 0.05 and 0.01 and level of probability respectively.

\+ Significant at the 0.001 level of probability.

Table 12. Soil solution nitrate and ammonium concentration for the fall of 1983 obtained with suction lysimeters placed at a depth of 20 cm.

Nitrogen rate		Date 9-29-83		10-22-83		10-27-83		11-08-83		11-19-83	
		NO3-N	NH4-N	NO3-N	NH4-N	NO3-N	NH4-N	NO3-N	NH4-N	NO3-N	NH4-N
kg/ha/yr						mg/l					
72		1.2	0.13	3.3	1.22	4.5	0.63	14.8	0.02	2.2	0.00
114		1.1	0.07	8.6	1.73	19.2	1.38	20.4	0.12	1.9	0.00
384		38.4	0.15	28.1	5.80	53.7	3.71	57.8	0.21	7.8	0.02
Fertilizer ratio											
N		16.5	0.13	16.5	2.98	26.9	1.26	32.2	0.08	6.1	0.01
NPK		6.6	0.11	11.2	1.98	22.0	1.87	27.6	0.12	1.8	0.00
Source	df					F ratio					
Inhib	1	9.22	1.05	0.60	0.16	0.21	0.11	0.58	14.77	–	–
N-Rate	2	3.47	3.65	17.89**	4.88	67.40+	7.92*	23.73*	11.13*	1.89	0.52
Inhib x Rate	2	5.22	1.39	2.34	1.04	0.22	0.29	–	–	–	–
Ratio	1	1444.53+	0.19	2529.20*	64.52	0.08	0.06	0.01	6.31	14.20	–

*,** Significant at the 0.05 and 0.01 level of probability respectively.

\+ Significant at the 0.001 level of probability.

of lysimeters to produce water samples and high variation between replications. Nitrate-nitrogen concentrations increased between 22 and 27 October while ammonium concentrations decreased, indicating that nitrification of the ammonium applied as urea on 17 October was occurring (Table 12).

The presence of inhibitors did not affect soluble nitrate-nitrogen extracted from soil samples taken in 1984 (Tables 13 and 15). Ammonium-nitrogen concentrations were also not affected by the presence of inhibitors (Tables 14 and 16), with the possible exception of soil samples taken on 10 October (Table 16). On this date, the soil from inhibitor treated plots within the medium nitrogen treatment contained more extractable ammonium-nitrogen than plots without inhibitor. This difference was not found on subsequent sampling dates making it difficult to argue for inhibitor activity. Extractable nitrate-nitrogen was affected to a small extent by nitrogen application rate, with plots receiving the highest nitrogen treatment having higher values (Tables 13 and 15). Extractable ammonium-nitrogen was affected by the rate of yearly nitrogen application twice during the ten weeks that soil samples were taken (Tables 14 and 16).

Table 13. Soluble nitrate in soil sampled to a depth of 15 cm under plots maintained at three nitrogen rates with and without Nitrapyrin.

Nitrogen rate	Nitrapyrin rate	Date				
		6-11-84	6-19-84	6-26-84	7-02-84	7-11-84
kg/ha/yr	kg/ha	ug NO_3^--N/g dry wt. soil				
	0	5.8	4.8	2.0	3.2	1.6
120	1.7	5.3	5.1	2.3	3.2	1.8
	Mean	5.6	4.9	2.1	3.2	1.7
	0	11.2	4.4	2.7	3.2	3.4
240	1.7	10.9	6.9	4.3	3.3	2.0
	Mean	11.0	5.7	3.5	3.2	2.7
	0	9.5	12.5	3.7	3.3	4.9
384	1.7	8.2	9.2	6.4	4.8	4.1
	Mean	8.8	10.8	5.0	4.0	4.5
Source	df	F ratio				
Inhib	1	0.10	0.02	7.26	0.71	1.92
N-Rate	2	1.82	8.71*	1.38	1.93	8.66*
Inhib x Rate	2	0.03	0.73	0.53	1.14	0.50

*,** Significant at the 0.05 and 0.01 level of probability respectively.

\+ Significant at the 0.001 level of probability.

Table 14. Extractable ammonium in soil sampled to a depth of 15 cm under plots maintained at three nitrogen rates with and without nitrapyrin.

Nitrogen rate	Nitrapyrin rate	Date				
		6-11-84	6-19-84	6-26-84	7-02-84	7-11-84
kg/ha	kg/ha	ug NH_4^+-N/g dry wt. soil				
120	0	7.1	5.3	4.2	11.9	12.6
	1.7	9.3	5.1	4.6	12.9	13.7
	Mean	8.2	5.2	4.4	12.4	13.1
240	0	5.5	5.5	3.9	12.4	14.1
	1.7	4.8	5.1	4.7	14.9	19.0
	Mean	5.1	5.3	4.3	13.6	16.5
384	0	3.5	5.4	4.2	10.1	13.7
	1.7	3.6	5.0	5.0	9.5	11.9
	Mean	3.5	5.2	4.6	9.8	12.8
Source	df	F ratio				
Inhib	1	0.14	0.87	3.25	0.23	0.48
N-Rate	2	12.19**	0.10	0.25	2.42	1.94
Inhib x Rate	2	1.03	4.82	0.03	1.71	2.14

*,** Significant at the 0.05 and 0.01 level of probability respectively.

\+ Significant at the 0.001 level of probability.

Table 15. Soluble nitrate in soil sampled to a depth of 15 cm under plots maintained at three nitrogen rates with and without DCD.

Nitrogen rate	DCD rate	Date 10-10-84	 10-17-84	 10-24-84	 10-31-84	 11-07-84
kg/ha/yr	kg/ha			ug NO_3^--N/g dry wt. soil		
	0	1.5	1.2	1.2	3.6	2.8
120	7.2	0.8	0.9	1.2	3.1	2.9
	Mean	1.2	1.0	1.2	3.4	2.9
	0	2.0	1.7	1.2	3.2	2.5
240	7.2	1.6	1.3	1.5	2.5	2.4
	Mean	1.8	1.5	1.4	2.9	2.5
	0	7.0	4.6	3.1	3.2	3.5
384	7.2	5.5	5.0	2.4	3.1	2.9
	Mean	6.2	4.8	2.7	3.2	3.2
Source	df			F ratio		
Inhib	1	1.03	0.04	0.15	2.95	0.38
N-Rate	2	64.72+	35.61+	9.70*	1.96	1.35
Inhib x Rate	2	0.17	0.12	0.23	0.19	4.05

*,** Significant at the 0.05 and 0.01 level of probability respectively.

\+ Significant at the 0.001 level of probability.

Table 16. Extractable ammonium in soil sampled to a depth of 15 cm under plots maintained at three nitrogen rates with and without DCD.

Nitrogen rate	DCD rate	Date				
		10-10-84	10-17-84	10-24-84	10-31-84	11-07-84
kg/ha/yr	kg/ha	ug NH_4^+-N/g dry wt. soil				
120	0	16.8	15.0	11.6	11.4	13.9
	7.2	14.7	14.5	13.3	9.9	11.7
	Mean	15.8	14.8	12.4	10.6	12.8
240	0	16.0	14.8	11.5	14.8	12.5
	7.2	20.0	12.7	14.2	15.4	13.3
	Mean	18.0	13.7	12.8	15.1	12.9
384	0	14.7	15.0	12.6	8.9	13.1
	7.2	15.2	12.2	10.4	12.0	14.2
	Mean	15.0	13.7	11.6	10.7	13.7
Source	df	F ratio				
Inhib	1	0.30	3.59	1.10	1.08	0.02
N-Rate	2	3.47	0.81	0.63	8.61*	0.52
Inhib x Rate	2	13.47**	0.81	1.02	2.98	2.01

*,** Significant at the 0.05 and 0.01 level of probability respectively.

\+ Significant at the 0.001 level of probability.

DISCUSSION

Although nitrification in the soil beneath the turfgrass sod was never specifically measured, the soil temperature and pH should have been conducive to fairly rapid ammonium oxidation. pH values taken from the plot site in 1982 averaged 6.7, with a range of between 5.7 to 7.2. These values are within the range at which nitrification occurs rapidly (Morrill and Dawson 1967; Dancer et al. 1973). Soil temperatures were also probably not limiting. A fifteen year average of monthly soil temperatures taken at 10 and 20 cm under sod, in May, June and late September-October, when inhibitors were applied, averaged 12.7, 18.6 and 13.8°C respectively. Assuming monthly soil temperatures in 1983 and 1984 approximated the 15 year averages, nitrification should have occurred. Severe temperature retardation of nitrification occurs at temperatures between 5 to 0°C (Russell 1973; Thompson and Troeh 1973).

The reasons why nitrification inhibitors failed to increase nitrogen use efficiency in this study are not clear. Based on reported conditions under which nitrification inhibitors are most effective, several reasons can be proposed to explain their lack of effectivness in a turfgrass situation.

First, the inhibitors may never have reached the soil where nitrification is occurring. The inherent nature of a turfgrass system does not lend itself to soil incorporation of applied chemicals. Many of the techniques used with inhibitors in field crops such as band placement of the inhibitor with the fertilizer, or disking in the inhibitor after application, are not suitable for turfgrass. In established turfgrass sod, the most practical and common method of incorporating chemicals, especially fertilizers, is with irrigation. Irrigation followed all inhibitor applications made in this study.

Although nitrapyrin and terrazole have low water solubilities, the quantitiy of irrigation water applied after inhibitor appication should be sufficient to dissolve the amount of inhibitor applied. Subsequent infiltration of the solubilized chemical however, could have been complicated by the thatch layer present in every plot. Thatch can form a barrier to water (Beard 1973; Smiley 1983) and pesticide (Smiley 1983) movement into the soil. In addition nitrapyrin and terrazole may be adsorbed on the organic matter that makes up this thatch layer. Benomyl, Dyrene, and Maneb, previously found to inhibit nitrification (Smiley and Craven 1979; Prasad et al. 1971; Mazur and Hughes 1975), did not affect nitrification under turfgrass in the field (Mazur and Hughes 1975). Failure was thought to be due in part to the immobilization and degradation of the chemicals in the thatch layer. Smiley and Craven (1979) found no inhibition of nitrification when a wide range of fungicides including terrazole were topically applied to turf. The reseachers presumed that these fungicides were retained at the soil surface due to low water solubility and sorption by organic matter and clay minerals.

Goring (1962a) reported a high correlation between soil organic matter and sorption of nitrapyrin. Soils high in organic matter retain nitrapyrin much longer than do soils low in organic matter (Briggs 1975). Bioactivity, described by Keeney (1980) as the relative inhibition of nitrification, has been found to decrease with increased soil organic matter. That is, the ability of the inhibitor to inhibit nitrification declines as the organic matter content of the soil increases. Much less is known about the sorption and inactivation of terrazole. Decreased activity of terrazole as organic matter increases has been reported (Gilmour 1984; McClung et al. 1983) suggesting that thatch inactivation via sorption may be occurring.

Volatilization of nitrapyrin is quite high and could also account for the lack of activity in this study. The vapor pressure of nitrapyrin is $3.7\text{x}10^{-3}$ mbar at 23°C (McCall and Swann 1978) , with a calculated evaporation rate of $7.7\text{x}10^{-3}$ umol/cm^2/hr at 20°C (Briggs 1975). Heavy volatilization losses were reported by the same author after a May broadcast application of nitrapyrin.

Four hours after application 40 % of the nitrapyrin had volatilized and only 16 % remained in the soil the following morning. Goring (1962b) reported decreasing effectiveness of nitrapyrin when broadcast onto bare soil if a substantial interval between nitrapyrin application and the first irrigation event occurred. He concluded that this decrease in effectiveness was due to volatilization of the chemical. The volatility of terrazole is much less than nitrapyrin, with a vapor pressure of $1.3x10^{-4}$ mbar at 20°C (Worthington 1983). This is almost identical to the vapor pressure of the herbicide Trifluralin; $1.0x10^{-4}$ mbar at 23°C (McCall and Swann 1978). Recommended application proceedure for this herbicide is to incorporate it into the soil after broadcast application since failure to do so can result in evaporative losses which can impair effectiveness (Briggs 1975; McCall and Swann 1978).

Dicyandiamide, the third inhibitor used in this study, has properties much different from the other two compounds and should be discussed separately. Dicyandiamide is water soluble and is not volatile. This chemical has been shown to inhibit nitrification and has been used as a slow release fertilizer yet, in this study, was no more effective than the other inhibitors. The presence of a thatch layer could have provided a barrier to immediate infiltration into the soil. However, water penetration of the thatch layer must have occurred because adequate moisture was available for plant growth. Therefore some infiltration of a water soluble compound such as DCD is to be expected. Immobilization and/or inactivation of DCD could be occurring in the thatch, although Bock et al. (1981) found that the rate of vertical movement of DCD in soils approximates that of urea. Urea has also been found to leach readily through thatch (Nelson et al. 1980) suggesting that if DCD moves similarly to urea, immobilization and/or inactivation is not likely. A high correlation has been found between the retention of DCD and the organic matter content and cation exchange capacity of the soil (Bock et al. 1981). In addition, DCD's bioactivity decreases with increasing soil organic matter (Reddy and Datta 1965). The retention of DCD in a soil profile might be associated more with hydraulic flux than sorption on either organic material or clay particles, since the hydraulic conductivity of soil is altered by organic matter and clay content (Hillel 1982). The influence of organic matter on DCD decomposition may be related to microbial populations. Studies reported by Reddy (1964) found that bioactivity of DCD decreased when sucrose was added to soil, apparently because it provided a readily available source of energy for microbes which metabolize DCD.

In the present study, any of the inhibitors which were able to pass through the thatch, would confront several major factors affecting their bioactivity. Keeny (1980) has reviewed the persistence and bioactivity of nitrification inhibitors in soils, so a detailed discussion of this problem will not be presented here. However, several of these factors should be mentioned. One problem involves the relative movement of the inhibitor in the soil column compared to the movement of fertilizer ammonium. The leaching and diffusion of ammonium in soil has been found to be more rapid than nitrapyrin, thus fertilizer ammonium may move out of the inhibitor treated zone (Briggs 1975). The extent of inhibitor movement can be limited as well. Briggs (1975) found negligible movement of nitrapyrin more than 2 cm below the depth of incorporation. Following band application, movement in soil was limited to 7.5 cm from the point of application and was most concentrated within the first 2.5 to 5 cm (Touchton et al. 1978). Limited inhibitor movement could prevent inhibiting concentrations of these chemicals from reaching much of the actively nitrifying soil volume. As previously mentioned, increased soil organic matter decreases movement of all the inhibitors, although not to the same extent.

Volatility of the chemicals is another problem which is related to movement. Volatility, while contributing to chemical loss when not incorporated into the soil, also increases the ability of the chemical to diffuse within the soil profile once incorporated (Munnecke 1972). While nitrapyrin and terrazole are considered to be volatile, DCD is not and it's movement would depend solely upon hydraulic flux.

Another factor that could account for lack of plant response to nitrification inhibitors is that conditions favoring nitrogen loss may not have occured. Leaching estimates which were calculated from the 60 cm lysimeter data (Appendix III) only indicated losses of between 0.4 to 5.9 % of the nitrogen applied. Denitrification, which also may cause considerable nitrogen loss, was not measured here, making firm conclusions on the extent or mechanism of nitrogen loss impossible. Even if nitrogen losses were minimal, it would be expected that soil ammonium or nitrate concentrations would be different between inhibitor and non inhibitor-treated plots if nitrification inhibition were occurring. No evidence for this was obtained in the present study.

Clipping growth in 1983 and 1984 was almost always significantly affected by nitrogen application rates (Tables A1,A3,A5, and A7). Plots receiving the medium nitrogen treatment produced the highest clipping growth rates in the spring of 1983 (Table A1) and in the spring/summer of 1984 (Table A5). The low clipping production rates at these times exhibited by the high nitrogen plots could be due to increased disease and/or winter injury. Excessive amounts of nitrogen applied to turf is known to stimulate shoot growth over root growth and decrease resistance to heat, cold and drought stress (Beard 1973). Turfgrass maintained at high levels of nitrogen fertility is also more susceptable to several diseases (Beard 1973) including stripe smut (Hull et al. 1979). All plots in this study showed signs of stripe smut infection. Hull et al.(1979) studied the Kentucky bluegrass cultivar 'Merion' growing on the plot area used in the current study and found the severity of stripe smut infection to increase as the rate of nitrogen fertilization increased.

Plots receiving the nitrogen treatment alone, without P and K, generally had lower clipping yield than did plots receiving the NPK treatment (Tables A2,A4,A6, and A8). Again, this could be due to increased stripe smut. Hull et al. (1979) also found that plots fertilized with N alone, contained a significantly higher percentage of stripe smut infected tillers than plots maintained with NP,NK, or NPK. The data are also consistent with work which shows that, independent of disease, the presence of P and especially K in combination with N can increase plant yield over nitrogen alone (Turner and Waddington 1983; Christians et al. 1981; Monroe et al. 1969). Clipping growth response to NP and NK varied from year to year and with season.

Nitrogen accumulation rates in clippings on a square meter basis indicate the ammount of nitrogen which is being removed from the soil by the grass sods and is dependent on the nitrogen content of clippings along with clipping production rates. In the spring of both years, medium nitrogen plots exhibited the highest clipping nitrogen recovery mostly due to the higher clipping production rates (Tables 3 and 7). This demonstrates that nitrogen recovery on an area basis can be greater with moderate amounts of nitrogen when plants are healthy and actively growing, over higher nitrogen rates which can encourage disease development and aggravate other stresses.

In terms of the percentage of total fertilizer nitrogen applied prior to and during each season, more fertilizer nitrogen was recovered in clippings from medium plots than from high nitrogen plots by 2.5x and 1.7x during the spring 1983 (Table 3) and spring/summer 1984 (Table 7) seasons, respectively. Low nitrogen plots, though recovering less total nitrogen in terms of mg $N/m^2/d$, recovered a higher percentage of fertilizer nitrogen, than did medium nitrogen plots during the spring/summer of both years. Low nitrogen plots recovered 2.9x and 2.1x more fertilizer nitrogen in the spring/summer of 1983 and 1984 respectively. Again, during the fall of both years, plots receiving the lowest fertilizer nitrogen treatment recovered a higher percentage of the nitrogen applied than either medium or high plots by as much as 2x. This demonstrates that the percent of fertilizer nitrogen recovered in turfgrass clippings decreases with increasing nitrogen application rates. This is similar to what Lathwell has found for field crops, as cited in a review by Parr (1973).

The presence of P and K also influenced nitrogen recovery as shown by higher accumulation rates from plots receiving the NPK treatment (Tables 4,6,8 and 10). The higher nitrogen recovery was primarily due to the greater yields exhibited by the NPK plots. As mentioned earlier, disease could have been a significant confounding factor in decreasing yields on the plots receiving nitrogen alone. This suggests again, that a complete NPK fertilizer program will increase fertilizer nitrogen recovery by contributing to the maintainance of a healthy, actively growing turf.

Soil solution nitrate-nitrogen and ammonium-nitrogen concentrations were much more variable during the first year of the study (Tables 11 and 12) than the second (Tables 13,14,15,and 16), due mostly to the difference in sampling techniques. The lysimeter samples frequently were highly variable between replications within the same treatment. Also, the failure of many lysimeters to produce soil water samples caused difficulties in the statistical analysis of these data. However, certain trends were found during the first year. Soil water concentrations of both nitrate and, to a lesser extent ammonium, paralleled the yearly nitrogen application rates (Tables 11 and 12).

Nitrification of fertilizer ammonium applied on 17 October can be seen between 22 and 27 October as an increase in soil solution nitrate-nitrogen and a decrease in soil solution ammonium-nitrogen (Table 12), indicating that nitrification is occurring rapidly. If nitrification were being inhibited, it should have been detected during this sampling period. No inhibition of nitrification was apparent. Low concentrations of nitrate-nitrogen in soil water from the low nitrogen plots during the spring and fall of 1983 suggests continual depletion of nitrogen by the turf roots along with immobilization by soil microbes. Plots receiving the medium nitrogen rate frequently had a higher soil solution nitrate-nitrogen concentration than the low nitrogen plots due to higher nitrogen application rates. Depletion of nitrate-nitrogen in plots receiving the medium treatment does occur over time and is much greater than that of the high nitrogen plots even after both plots received similar nitrogen treatments (Table 11). This futher confirms that nitrogen recovery by turfgrass sod, fertilized at high rates is much less efficient than sod fertilized at a moderate rate.

Extractable soil nitrate-nitrogen showed significant nitrogen rate effects on 5 of the 10 sampling dates (Tables 13 and 15). When significant, plots receiving the high nitrogen treatment had higher soil nitrate-nitrogen values. This confirms again that fertilization at higher nitrogen rates will increase nitrate concentrations under turf sods. Differences between lysimeter derived nitrate-nitrogen values and those obtained from soil extraction can be explained by the different units in which nitrogen concentration is expressed. Lysimeter values are expressed in a mg nitrate-nitrogen/l soil solution basis while soil samples are expressed on a mg nitrate-nitrogen/gram dry weight soil. Assuming for example, that a 1 gram soil sample has a wet weight of 1.20 grams, and all the nitrate-nitrogen is in solution in the 0.20 grams of water, the concentration expressed as soil solution would be 5x greater than if it were expressed on a gram dry weight soil basis. Soil ammonium-nitrogen was less affected by nitrogen application rates than was nitrate-nitrogen (Tables 14 and 16). This could be due to rapid plant uptake, microbial immobilization and/or nitrification of the free ammonium in the soil. Low free ammonium-nitrogen concentrations are confirmed by the soil solution samples obtained with lysimeters (Tables 11 and 12).

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APPENDIX I

(Ancillary Tables)

Table A1. Clipping growth rates of Kentucky bluegrass cv 'Baron' with and without terrazole at three nitrogen rates.

Nitrogen rate	Terrazole rate	Date					
		5-17-83	5-25-83	6-01-83	6-10-83	6-17-83	Cumulative
kg/ha/yr	kg/ha			g/m^2/d			g/m^2
72	0	1.95	3.14	2.73	2.18	1.37	69.3
	1.1	1.87	3.00	2.93	2.34	1.51	70.2
	Mean	1.91	3.07	2.83	2.26	1.44	69.8
144	0	2.98	4.23	3.98	3.34	2.43	102.5
	1.1	2.72	4.34	4.07	3.45	2.50	103.4
	Mean	2.85	4.29	4.03	3.40	2.47	103.0
384	0	1.10	1.73	2.08	2.06	1.75	50.7
	1.1	1.46	2.03	2.14	2.13	1.67	55.6
	Mean	1.28	1.88	2.11	2.10	1.71	53.2
Source	df			F ratio			
Inhib	1	0.05	0.24	0.16	0.46	0.13	0.25
N-Rate	2	8.77*	18.72**	18.13**	28.85+	24.59**	18.41**
Inhib x Rate	2	0.63	0.59	0.38	0.21	0.65	0.16

*,** Significant at the 0.05 and 0.01 level of probability respectively.

\+ Significant at the 0.001 level of probability.

Table A2. Clipping growth rates of Kentucky bluegrass cv. 'Baron' with and without terrazole at four fertilizer ratios.

Fertilizer ratio	Terrazole rate	Date					
		5-17-83	5-25-83	6-01-83	6-10-83	6-17-83	Cumulative
	kg/ha			g/m^2/d			g/m^2
N	0	1.95	2.68	2.65	2.31	1.62	67.3
	1.1	1.70	2.57	2.54	2.23	1.66	64.3
	Mean	1.82	2.62	2.60	2.27	1.64	65.8
NP	0	2.07	3.40	3.05	2.59	1.87	78.5
	1.1	2.11	3.16	2.96	2.70	1.87	76.9
	Mean	2.09	3.28	3.01	2.65	1.87	77.7
NK	0	1.65	2.71	2.71	2.39	1.71	66.6
	1.1	1.63	3.21	3.08	2.59	1.92	73.3
	Mean	1.64	2.91	2.90	2.49	1.82	70.0
NPK	0	2.37	3.35	3.31	2.82	2.20	84.4
	1.1	2.63	3.65	3.57	3.05	2.14	91.2
	Mean	2.49	3.50	3.44	2.94	2.17	87.8
Source	df			F ratio			
Inhib	1	0.05	0.24	0.16	0.46	0.13	0.25
Ratio	3	1.04	6.37*	3.77	4.95*	7.97*	7.61*
Inhib x Ratio	3	0.79	0.39	0.72	1.04	0.26	0.47

*,** Significant at the 0.05 and 0.01 level of probability respectively.

\+ Significant at the 0.001 level of probability.

Table A3. Clipping growth rates of Kentucky bluegrass cv. 'Baron' with and without nitrapyrin at three nitrogen rates.

Nitrogen rate	Nitrapyrin rate	Date			
		9-30-83	10-31-83	12-01-83	Cumulative
kg/ha/yr	kg/ha	$g/m^2/d$			g/m^2
72	0	0.47	0.37	0.07	9.7
	0.5	0.46	0.33	0.07	6.6
	Mean	0.47	0.35	0.07	8.1
144	0	0.56	0.37	0.08	10.1
	0.5	0.62	0.34	0.12	10.0
	Mean	0.59	0.36	0.10	10.0
384	0	1.24	0.42	0.22	12.3
	0.5	1.41	0.53	0.26	14.0
	Mean	1.33	0.48	0.24	13.2
Source	df	F ratio			
Inhib	1	0.32	0.00	1.32	0.07
N-Rate	2	242.97+	3.81	35.09+	7.53*
Inhib x Rate	2	0.98	1.04	0.53	5.35*

*,** Significant at the 0.05 and 0.01 level of probability respectively.

\+ Significant at the 0.001 level of probability.

Table A4. Clipping growth rates of Kentucky bluegrass cv. 'Baron' with and without nitrapyrin at four fertilizer ratios.

Feritilizer ratio	Nitrapyrin rate	Date 9-30-83	 10-31-83	 12-01-83	 Cumulative
	kg/ha		$g/m^2/d$		g/m^2
N	0	0.61	0.41	0.09	9.6
	0.5	0.64	0.34	0.09	8.6
	Mean	0.63	0.38	0.09	9.1
NP	0	0.74	0.28	-	-
	0.5	0.75	0.45	-	-
	Mean	0.75	0.37	-	-
NK	0	0.84	0.45	-	-
	0.5	0.99	0.52	-	-
	Mean	0.92	0.49	-	-
NPK	0	0.84	0.40	0.16	11.8
	0.5	0.92	0.31	0.21	11.8
	Mean	0.88	0.36	0.19	11.8
Source	df		F ratio		
Inhib	1	0.32	0.00	1.32	0.07
Ratio	3	2.64	0.99	12.00*	3.13
Inhib x Ratio	3	0.16	0.87	2.48	0.26

*,** Significant at the 0.05 and 0.01 level of probability respectively.

\+ Significant at the 0.001 level of probability.

Table A5. Clipping growth rates of Kentucky bluegrass cv. 'Baron' with and without nitrapyrin at three nitrogen rates.

Nitrogen rate	Nitropyrin rate	Date			
		6-11-84	6-22-84	7-06-84	Cumulative
kg/ha/yr	kg/ha		g/m^2/d		g/m^2
	0	1.38	1.12	1.31	30.4
120	1.7	1.50	1.25	1.43	32.9
	Mean	1.44	1.19	1.37	31.6
	0	2.18	1.48	1.69	42.2
240	1.7	2.36	1.68	2.00	48.1
	Mean	2.27	1.58	1.85	45.2
	0	1.82	1.10	1.57	35.5
384	1.7	1.61	1.10	1.62	34.9
	Mean	1.72	1.10	1.60	35.2
Source	df		F ratio		
Inhib	1	0.00	0.78	3.39	1.15
N-Rate	2	17.74**	12.66**	10.12*	16.14**
Inhib x Rate	2	2.59	2.29	4.11	7.00*

*,** Significant at the 0.05 and 0.01 level of probability respectively.
\+ Significant at the 0.001 level of probability.

Table A6. Clipping growth rates of Kentucky bluegrass cv. 'Baron' with and without nitrapyrin at four fertilizer ratios.

Fertilizer ratio	Nitrapyrin rate	Date			
		6-11-84	6-22-84	7-06-84	Cumulative
	kg/ha		$g/m^2/d$		g/m^2
N	0	1.65	1.06	1.45	32.8
	1.7	1.77	1.20	1.43	35.4
	Mean	1.71	1.13	1.44	34.1
NP	0	1.71	1.13	1.48	34.1
	1.7	1.53	1.14	1.65	34.6
	Mean	1.62	1.14	1.57	34.4
NK	0	1.70	1.35	1.65	37.3
	1.7	1.71	1.38	1.86	39.9
	Mean	1.71	1.37	1.76	38.6
NPK	0	2.20	1.39	1.52	39.8
	1.7	2.26	1.62	1.80	44.6
	Mean	2.23	1.51	1.66	42.2
Source	df	F ratio			
Inhib	1	0.00	0.78	3.39	1.15
Ratio	3	12.08**	4.97*	0.88	4.94*
Inhib x Ratio	3	0.73	0.42	0.87	0.51

*,** Significant at the 0.05 and 0.01 level of probability respectively.

\+ Significant at the 0.001 level of probability.

Table A7. Clipping growth rates of Kentucky bluegrass cv. 'Baron' with and without DCD at three nitrogen rates.

Nitrogen rate	DCD rate	Date			
		9-20-84	11-01-84	11-28-84	Cumulative
kg/ha/yr	kg/ha		$g/m^2/d$		g/m^2
	0	0.85	0.79	0.25	17.0
120	7.2	0.75	0.73	0.24	15.8
	Mean	0.80	0.76	0.25	16.4
	0	0.80	0.93	0.25	18.9
240	7.2	0.91	0.94	0.29	19.8
	Mean	0.86	0.94	0.27	19.3
	0	1.75	1.49	0.29	27.4
384	7.2	1.58	1.43	0.32	27.1
	Mean	1.67	1.46	0.31	27.2
Source	df	F ratio			
Inhib	1	2.44	3.35	1.94	0.59
N-Rate	2	48.32+	27.86+	4.05	24.40**
Inhib x Rate	2	1.17	0.11	0.41	0.23

*,** Significant at the 0.05 and 0.01 level of probability respectively.

\+ Significant at the 0.001 level of probability.

Table A8. Clipping growth rates of Kentucky bluegrass cv. 'Baron' with and without DCD at four fertilizer ratios.

Fertilizer ratio	DCD rate	Date			
		9-20-84	11-01-84	11-28-84	Cumulative
	kg/ha		$g/m^2/d$		g/m^2
	0	1.04	0.97	0.25	19.5
N	7.2	0.90	0.95	0.24	18.8
	Mean	0.97	0.96	0.25	19.2
	0	0.76	0.81	0.20	16.3
NP	7.2	0.92	0.90	0.22	18.0
	Mean	0.84	0.86	0.21	17.2
	0	1.29	1.21	0.31	24.0
NK	7.2	1.23	1.13	0.33	23.4
	Mean	1.26	1.17	0.32	23.7
	0	1.43	1.27	0.31	24.5
NPK	7.2	1.28	1.13	0.34	23.3
	Mean	1.36	1.20	0.33	23.9
Source	df		F ratio		
Inhib	1	2.44	3.35	1.94	0.59
Ratio	3	7.57*	8.54**	4.19	9.04**
Inhib x Ratio	3	1.74	0.29	0.18	0.09

*,** Significant at the 0.05 and 0.01 level of probability repectively.

+ Significant at the 0.001 level of probability.

APPENDIX II

LITERATURE REVIEW

LITERATURE REVIEW

As the cost of fertilizers climb and the recognition of fertilizers as a potential source of ground water contamination increases, methods must be developed by which nutrient use efficiency is increased while the quality and quantity of agricultural commodities are not compromised. One method of increasing nitrogen use efficiency, which has gained considerable attention within the past decade, is the use of nitrification inhibitors. However, little attention has been given to the use of nitrification inhibitors on turf.

The inhibiting effect of certain chemicals on the microbial oxidation of ammonium to nitrate has been known for over 70 years (Prasad et al. 1971). Most of these chemicals were not specific inhibitors of the nitrification process but broader range herbicides, insecticides, fungicides and fumigants. Goring (1962a) introduced the concept of using nitrification inhibitors as a way of increasing the efficiency of nitrogen. Using the specific inhibitor of nitrification 2-chloro-6-(trichloromethyl)-pyridine (nitrapyrin), he retarded ammonium oxidation for at least 6 weeks by using concentrations as low as 0.05 mg/kg and as high as 20 mg/kg of soil. The toxicity of this chemical, marketed as N-Serve, to soil bacteria, fungi, and several plant seedlings was also studied. Those findings demonstrated that the activity of this chemical was specific for Nitrosomonas, the bacterium responsible for the oxidation of ammonium to nitrite, but had a low order of toxicity to other soil microoganisms and many of the plant seedlings studied. Since then, other compounds have been patented for use as nitrification inhibitors; 2,4-diamino-6trichloromethyl-s-triazine (CL-1580 American Cyanamid Co.), 4-amino-1,2,4-triazole (ATC Ishahara Industries), 2-amino-4-chloro-6-methyl-pyrimidine (AM, Toyo Koatsu Industries), sulfathiazole (ST, Toyo Koatsu Industries) dicyandiamide (DCD, SKW Trostberg) and 5-ethoxy-3-(trichloromethyl)-1,2,4-thiadiazole (Dwell, terrazole, Olin Corporation).

The value of these chemicals rests in the fact that nitrogen in the ammonium form is less likely to be lost from the root zone of an agricultural crop than is nitrate. The ammonium ion is positively charged and therefore is held by the negatively charged soil colloids. Nitrate, on the other hand, is a negatively charged ion and therefore is not attracted to soil colloids and is free either to be leached from the root zone or reduced by other soil microorganisms to N_2 and/or N_2O.

Nitrate losses through leaching and denitrification can be considerable. Loss of fertilizer applied nitrogen due to denitrification alone has been reported to be as high as 50% (Stephenson et al. 1969 in Huber et al. 1977) although 10 to 30% may be more reasonable (Parker 1972 in Huber et al. 1977). The nitrate lost to leaching is estimated to be much less, about 5% (Huber et al. 1977). When shallow rooted crops such as turf, where 95% of the root system is in the upper 15 cm of soil are grown on coarse sandy soils, leaching losses may be significantly higher than 5%.

Many factors affect nitrate leaching, including the rate of N applied, source of N, soil type, amount and timing of irrigation or rainfall, environmental conditions, plant uptake rate and microbial immobilization and gasseous N losses (Starr and De Roo 1981; Bauder and Montgomery 1980; Brown et al. 1977; Rieke and Ellis 1974) Over 50% of fertilizer nitrogen can leach through golf greens in two weeks if heavy irrigation follows the application of soluble nitrogen sources (Duble and Brown 1973). Brown et al. (1977) at Texas A & M reported that leachate concentrations of NO_3^--N from sand and sand/soil putting greens, could be as high as 412.7 mg/l when heavy rates of irrigation followed a February application of 163 kg N/ha as NH_4NO_3. Greens constructed of soil alone, produced a maximum leachate concentration of 170 mg/l NO_3^--N for the same treatment. Brown et al. (1982) calculated the loss of NO_3^--N for soil plots receiving the 163 kg-N/ha NH_4NO_3 treatment mentioned above, to be

8.6% of the applied nitrogen. For sand and sand/soil mixtures receiving the same treatment, losses were calculated to be nearly 22% of the nitrogen applied. Experiments using 146 kg-N/ha as a 12-12-12 fertilizer with urea and $(NH_4)_2SO_4$ as the N source on the sand and sand/soil greens yielded leaching losses of 9.5 and 8.7%. of the total N applied, respectively. When Milorganite and IBDU were used as nitrogen sources on sand, sand/soil and soil greens, very little NO_3^--N was leached (Brown et al. 1977 and 1982) although leachate concentrations under Milorganite and IBDU fertilized plots were recorded as high as 49.3 and 18 mg NO_3^--N/l respectively (Brown et al. 1977). Mitchell et al. (1978) found leachate concentrations under golf greens fertilized with 292 kg N/ha as UF to average over 24 mg NO_3^--N/l , with a range of 17.5 to 38.3 mg NO_3^--N/l.

In a weigh type non suction lysimeter study, Jones et al. (1974), found an apparent leaching loss of 37% of the fertilizer nitrogen applied to the annual forage grass, soft chess in California. In another lysimeter study with soft chess using ^{15}N, Jones et al. (1977) determined leaching losses to be 10 to 16% of fertilizer nitrogen, applied in an inorganic ammoniacle form at the rate of 100 kg-N/ha in October. At 500 kg-N/ha applied in October leaching losses accounted for 14% of the fertilizer nitrogen, while it was estimated that 28% was lost to denitrification.

Rieke and Ellis (1974) found nitrate leaching when high rates of a soluble nitrogen source, 390 kg N/ha NH_4NO_3, were applied to a Kentucky bluegrass sod grown on sandy soil. Even under those conditions nitrate concentrations never exceeded 28.4 ppm NO_3^--N. It should be noted that this value was not significantly different from the value obtained from plots receiving no nitrogen, indicating that leaching of fertilizer nitrogen under turfgrass may not be a significant problem. When IBDU, UF and activated sewage sludge were used as nitrogen sources, no apparent leaching occurred. Similarly, Starr and De Roo (1981) found NO_3^--N concentrations ranging from 0.03 to 10 mg NO_3^--N/l in soil solution samples obtained with suction lysimeters placed to a depth of 180 to 240 cm under a Kentucky bluegrass-red fescue sod. Mean nitrate nitrogen concentrations for those samples were approximately 2 mg NO_3^--N/l which is not above the maximum acceptable nitrate content in drinking water set by the U.S. Public Health Service (1962).

Success in using nitrification inhibitors on various crops has been reported by several authors. Prasad (1976) found that sugar cane yields were significantly higher when nitrapyrin was used in conjunction with banded $(NH_4)_2SO_4$ at 103 kg N/ha over that of $(NH_4)_2SO_4$ alone. Yields with the inhibitor were similar to those obtained at 206 kg N/ha $(NH_4)_2SO_4$ without the inhibitor. Soil ammonium levels in all experiments were higher in the inhibitor treated plots although increased yields were not obtained at the higher N rates of 206 and 306 kg N/ha with nitrapyrin. Huber et al. (1969) reported that yields of winter wheat were 37 to 42% greater when nitrapyrin was added to fall banded $(NH_4)_2SO_4$. At a soil depth of 0 to 30.5 cm, ammonium levels were more than three times greater when $(NH_4)_2SO_4$ was applied with the inhibitor. Total inorganic soil N was approximately 25% higher at that same depth in nitrapyrin treated plots. Applications of nitrapyrin with anhydrous ammonia resulted in an overwinter inorganic nitrogen retention twice that without nitrapyrin, which was reflected in a significant increase in corn yields the following season. Yields at 134 kg N/ha with the inhibitor were not significantly different from those at 244 kg N/ha without nitrapyrin (Warren et al. 1975). In another experiment by the same authors, corn yields, grain protein, leaf weight, and leaf nitrogen content all increased with the addition of nitrapyrin. Similarly, yields of seed cotton were increased significantly when nitrapyrin was used with anhydrous and aqueous ammonia, $(NH_4)_2SO_4$, or urea (Swezey and Turner 1962). Further, it was found that yields of corn and sugar beets increased when nitrapyrin was used with anhydrous ammonia and $(NH_4)_2SO_4$. Total

N in leaf tissue of both corn and sugar beet was higher in nitrapyrin treated plots. In all of the above studies, nitrapyrin was applied directly to the nitrogen source, which was banded, or the inhibitor was injected into bands of anhydrous ammonia. Caution should be used in interpreting these results in the context of established ground covers such as turfgrass sod where banding is not an acceptable method of fertilizer application. Studies involving broadcast inhibitor applications are few since banding is widely practiced in row crops. Nitrapyrin, having a vapor pressure of 3.7×10^{-3} mbars at 23°C (Mc Call and Swann 1978) is highly volatile and could be subject to considerable vapor loss if not incorporated into the soil during or immediatly after application. Waddington et al. (1975) conducted a study which included the use of nitrapyrin. Although no benefits were found by using the inhibitor, they concluded that more research was needed to assess the value of nitrapyrin on turf. If nitrification can be inhibited, it will be necessary to evaluate the agronomic and managerial advantages resulting. This study will address these concerns.

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APPENDIX III

ESTIMATED NITRATE LEACHING

PRELIMINARY ESTIMATES OF NITRATE-NITROGEN LEACHING FROM A KENTUCKY BLUEGRASS TURF

INTRODUCTION

In recent years, nitrogen applied to agricultural crops has been implicated as a source of ground water contamination. Excessive nitrate in drinking water can cause serious health risks to both humans and livestock. The nitrate-nitrogen level in potable water cannot exceed 10 mg NO_3^--N/l (10 ppm) according to standards set by the U.S. Public Health Service (1962). The Long Island Regional Planning Board (1978) concluded that the nitrogen used to fertilize turfgrass has contributed significantly to elevated nitrogen levels observed in aquifers of eastern Long Island. Little published research has focused on the potential for nitrate leaching from turfgrass systems. That research which has been done, generally has found nitrate leaching to occur when heavy rates of irrigation follow infrequent heavy applications of a soluble nitrogen source on coarse sandy soils (Rieke and Ellis 1974; Brown et al. 1977; Brown et al. 1982; Snyder et al. 1984; Mosdell and Schmidt 1985). Estimates of potential nitrate leaching through an established turfgrass stand growing on a silt loam soil and maintained at three nitrogen levels will be presented. Similar work has been reported on Bermudagrass (Snyder et al. 1984). Using soil water nitrate concentrations, collected with suction lysimeters and a hydrological mass balance model they estimated nitrogen leaching to range between 1 and 56% of the nitrogen applied. By using soil nitrate concentrations and a hydrological mass balance model to estimate hydrologic flux, it is hoped that preliminary data can be developed to determine if nitrate leaching from cool-season turfgrasses constitutes a serious threat to ground water quality in the northeast.

METHODS AND MATERIALS

Studies were conducted on an established stand of Kentucky bluegrass (_Poa_ _pratensis_ L. cv. 'Baron') at the Turfgrass Research Farm of the Rhode Island Agricultural Experiment Station, Kingston. The plots were seeded in 1976 on an Enfield silt loam (coarse silty over sandy or sandy skeletal, mixed, mesic, Typic Dystrochrepts). The experimental design was a split plot with four replications. Main plots consisted of two fertilizer nutrient ratios: nitrogen alone (N); and nitrogen, phosphorus, and potassium (NPK). These were divided randomly into subplots consisting of three fertilizer rates: high, medium and low. In 1983 the three rates were 384-80-160, 144-40-80, and 72-20-40 kg/ha/yr N, P, and K respectively while in 1984 the rates were 384-80-160, 240-40-80, and 120-20-40 kg/ha/yr. For 12 years prior to 1983, the nitrogen rates for the high medium and low plots were 480, 240, and 120 kg N/ha/yr respectively. Annual phosphorus and potassium rates were the same prior to and during this experiment. The fertilizer application schedules for 1983 and 1984 are outlined in Table 1. Fertilizer sources were urea, superphosphate and KCl, except for the 10 May 1983 application when diammonium phosphate, urea and potassium magnesium sulfate were used. Plots were maintained at a cutting height of 3.8 cm and all clippings were removed.

The soil solution was sampled in each plot with suction lysimeters placed at a depth of 20 and 60 cm. Because the 20 cm lysimeters frequently failed to produce water samples, in 1984, soil samples were taken to a depth of 15 cm and extracted for nitrate with water. All nitrate analyses were performed with a an Orion 93-07 nitrate electrode. The method used to determine nitrate in lysimeter derived samples was that outlined in the Orion 93 Series Methods Manual (1976). Nitrate in soil samples was measured by diluting 5 grams of fresh soil with 10 mls of distilled water, stirring occasionally and assaying the mixture directly after 1 hour with the nitrate electrode.

Table 1. Fertilizer application schedule for the 1983 and 1984 growing seasons.

Date	Fertilizer rate	Fertilizer application		
		Nitrogen	Phosphorus	Potassium
			kg/ha	
5–10–83	Low	48	10	20
	Medium	96	20	40
	High	96	40	80
6–09–83	High	48	–	–
6–30–83	High	48	–	–
7–28–83	High	48	–	–
8–25–83	High	48	–	–
10–17–83	Low	24	10	20
	Medium	48	20	40
	High	96	40	80
4–27–84	Low	0	10	20
	Medium	48	20	40
	High	96	40	80
6–06–84	All	48	–	–
7–13–84	High	48	–	–
8–31–84	High	48	–	–
9–27–84	All	48	–	–
12–18–84	Low	24	10	20
	Medium	96	20	40
	High	96	40	80

All samples assayed for nitrate were adjusted to a background ionic strength of 0.12 M with ammonium sulfate. In addition, soil extracts and soil water samples from lysimeters received 1 ml of 64 mM silver sulfate per 25 mls of sample to precipitate interfering ions. Lysimeter samples not analysed within 24 hours of sampling were either fixed with 1 ml of 1 M boric acid per 125 mls of sample and kept at 4°C or were frozen at -15°C. Soil samples not extracted within 24 hours of sampling were frozen at -15°C.

Estimates of potential nitrate leaching were calculated based on a hydrological mass balance analysis and the nitrate concentration of soil water. A hydrologic model was created to compute the soil moisture content on a daily basis. Soil moisture for a given day (i) was computed as:

$SM(i) = PPT - ET - L - RO + SM(i-1)$ where:

SM(i) = Soil moisture content for a given day (cm)

PPT = Precipitation or irrigation (cm)

ET = Measured evapotranspiration (cm)

L = Water leaching from the root zone (cm)

RO = Surface runoff (cm)

SM(i-1) = Previous day's soil moisture content (cm)

Potential evapotranspiration (ETP) was computed using the modified Penman equation (Doorenbos and Pruitt 1977). A crop coefficient of 1.0 was used to determine ETP.

Meteorological data were obtained from the Rhode Island Agricultural Experiment Station weather station, 200 meters from the study site. To account for drought stress, estimated evapotranspiration was assumed to equal potential evapotranspirtion until 50% of the available moisture capacity within the root zone was depleted. Below the 50% level estimated evapotranspiration was computed as:

$$\text{Estimated ET} = \frac{\text{Available Soil Moisture}}{\text{Available Moisture Capacity}} \times 2 \times \text{ETP}$$

No surface runoff was assumed because the study site was flat, well drained (US, SCS hydrological class B) and in mature turf. Infiltration rates exceeded most precipitation rates under these conditions.

ETP estimates derived from the modified Penman equation were verified by weighing lysimeter based measurements of actual ET (Aronson 1986). The weighing bucket lysimeters were designed after those of Feldhake et al. (1983). These were installed in turf plots and weighed periodically throughout the growing season, June through October, 1984. Seasonal ratios, ET crop coefficients, based on 33 observation dates of measured ET over predicted ET, varied from 0.99 to 1.02 for 'Baron' Kentucky bluegrass turf.

Leaching was assumed to occur whenever the soil moisture within the upper 15 cm exceeded field capacity. Field capacity was defined as the soil moisture content when the soil water potential is -0.1 bars based on tensiometer readings taken 24 hours after saturation. The root zone of mature turf was assumed to extend to a 15 cm depth. Once the soil solution containing nitrate moved below the root zone, it was assumed to be free to move to ground water.

In 1983, concentrations of nitrate-nitrogen in soil water obtained with 20 cm suction lysimeters were coupled with estimates of hydraulic flux derived from the model to predict nitrate loading of ground water. The seasonal estimates are based on 13 separate sampling periods. In 1984, the soil water nitrate concentrations were derived from 60 cm suction lysimeters sampled on five dates extending over the growing season. In addition, the soil water nitrate concentration was calculated for soil samples. This was done by assuming that all nitrate was soluble in the water fraction of the soil. The volumetric water content of the soil during periods of leaching was assumed to be midway between total saturation and field capacity in order to estimate nitrate concentrations in the leachate. Combining water flux with nitrate concentrations obtained from soil samples is not a well documented procedure and represents only relative approximations of potential ground water loading.

All data were subject to an analysis of variance for a split plot design using the general liner models procedure, SAS Institute Inc. (SAS Institute Inc. 1982)

RESULTS

Generally, the greatest leaching of nitrate-nitrogen was estimated from plots receiving the high nitrogen treatment (Tables 2 and 4). Though not always significantly different, high nitrogen rates produced leaching estimates between 2x (Table 2) to 25x (Table 4) greater than low or medium nitrogen plots. In 1983, leaching estimates for low and medium plots exceeded 10 kg N/ha during only one leaching period, while plots receiving the high nitrogen treatment exceeded 10 kg N/ha during all but one leaching period. In 1984, low and medium nitrogen plots produced nitrogen leaching values of less than 0.5 kg N/ha for all leaching periods (Table 4). Total nitrogen leached for approximately the entire season (14 June through 31 December) for both low and medium nitrogen plots was estimated to be under 1 kg N/ha. Unlike 1983, leaching estimates for high nitrogen plots rarely exceed 10.0 kg N/ha and did so only during one leaching period.

Differences in estimated leaching based on the different sampling methods are also apparent. Nitrogen leaching estimates calculated from soil water samples taken with 20 cm lysimeters (Table 2), were considerably greater

Table 2. Estimated nitrogen flux from the root zone of Kentucky bluegrass derived from lysimeters placed at a depth of 20 cm.

Nitrogen treatment		Leaching period 1983									Season total	% of N applied
		6/1–14	6/23–7/10	8/1–14	9/8–21	9/22–10/11	10/12–24	10/25–11/2	11/3–12	11/13–30		
kg/ha						kg N/ha						
72		0.4	0.1	1.0	0.1	0.3	1.7	2.3	7.6	5.5	19.0	26.4
144		9.5	2.3	0.6	2.0	0.3	4.3	9.9	10.5	4.5	43.9	30.5
384		17.9	12.6	18.0	8.0	10.2	14.0	27.7	29.8	19.1	157.3	41.0
N		9.9	3.9	9.3	4.1	4.4	8.3	13.9	16.6	15.0	85.4	–
NPK		10.1	6.1	3.2	3.6	1.8	5.6	11.3	14.2	4.3	60.2	–
Source	df					F ratio						
Ratio	1	1.37	0.15	2.47	0.02	2.83	0.01	0.14	0.14	3.69	–	
N-rate	2	10.14**	10.13	6.58	3.12	3.76	11.65**	24.91+	5.46*	4.49	–	
N-rate* Ratio	2	1.15	1.78	2.47	0.77	1.23	1.03	0.43	1.29	0.09	–	
						m^3/ha						
Estimated water leached		325.0	235.0	286.0	199.0	266.0	500.0	515.0	516.0	2453.0	5295.0	

*,** Significant at the 0.05 and 0.01 levels of probability respectively.

+ Significant at the 0.001 level of probability.

Table 3. Leachate nitrate-nitrogen concentration under Kentucky bluegrass determined with lysimeters placed at a depth of 20 cm.

Nitrogen treatment		Leaching period 1983									Season average
		6/1–14	6/23–7/10	8/1–14	9/8–21	9/22–10/11	10/12–24	10/25–11/2	11/3–12	11/13–30	
kg/ha						g N/m^3 water					
72		1.2	0.4	3.5	0.5	1.1	3.4	4.5	14.7	2.2	3.6
144		29.2	9.8	2.1	10.1	1.1	8.6	19.2	20.3	1.8	8.3
384		55.1	53.6	62.9	40.2	38.3	28.0	53.8	57.8	7.8	29.7
N		30.5	16.6	32.5	20.6	16.5	16.6	27.0	32.2	6.1	16.1
NPK		31.1	26.0	11.2	18.1	6.8	11.2	21.9	27.5	1.8	11.3
Source	df					F ratio					
Ratio	1	1.37	0.15	2.47	0.02	2.83	0.01	0.14	0.14	3.69	–
N-rate	2	10.14**	10.13	6.58	3.12	3.76	11.65**	24.91+	5.46*	4.49	–
N-rate* Ratio	2	1.15	1.78	2.47	0.77	1.23	1.03	0.43	1.29	0.09	–
						m^3/ha					
Estimated water leached		325.0	235.0	286.0	199.0	266.0	500.0	515.0	516.0	2453.0	5295.0

*,** Significant at the 0.05 and 0.01 levels of probability respectively.

+ Significant at the 0.001 level of probability.

Table 4. Estimated nitrogen flux from the root zone of Kentucky bluegrass derived from lysimeters placed at a depth of 60 cm.

Nitrogen treatment		Leaching period 1984 6/14–7/19	7/20–8/19	9/1–10/3	10/20–11/26	11/27–12/31	Season total	% of N Applied
kg/ha				kg N/ha				
120		0.13	0.01	0.08	0.25	0.44	0.91	0.8
240		0.33	0.01	0.05	0.10	0.35	0.84	0.4
384		3.62	0.55	2.19	5.25	11.20	22.81	5.9
N		1.27	0.40	1.76	5.34	5.99	14.76	
NPK		1.70	0.06	0.07	0.95	3.70	6.48	
Source	df			F ratio				
Ratio	1	0.02	1.37	1.16	0.45	0.39		
N-rate	2	1.06	2.75	0.84	12.38**	10.52**		
N-rate* Ratio	2	0.37	2.08	0.59	8.61*	1.56		
				m^3/ha				
Estimated water leached		974.0	46.0	255.0	389.0	814.0	2478.0	

*,** Significant at the 0.05 and 0.01 levels of probability respectively.

than those calculated from 60 cm lysimeters (Table 4). In terms of the percentage of fertilizer nitrogen applied, 20 cm lysimeter derived values estimated leaching losses between 26 and 41%. Conversly leaching estimates derived from soil water samples taken with 60 cm lysimeters accounted for leaching losses between 0.4 and 5.9% of the nitrogen applied. Although differences in the quantity of nitrogen estimated to have leached were also noted between the 20 cm lysimeter method (Table 2) and the 15 cm soil sample extraction method (Table 6), seasonal average leachate concentrations from low and medium nitrogen plots were similar between the two methods (Tables 3 and 7). Differences in the estimates of nitrogen leached between those two methods can be explained by the time span of each leaching period and the quantity of water that leached within each period. Leachate concentrations averaged over the season, from low and medium nitrogen treated plots as estimated from 60 cm lysimeter samples (Table 5), show that the nitrate-nitrogen concentration of water leaching below the turf root zone is well below the acceptable nitrate level for drinking water. Soil extracts (Table 7) and 20 cm lysimeter samples (Table 3) also produced nitrate-nitrogen concentrations within the acceptable range for the low and medium nitrogen plots, though not as low as those obtained from the 60 cm lysimeters. High nitrogen plots consistantly produced estimated leachate

Table 5. Leachate nitrate-nitrogen concentration under Kentucky bluegrass determined with lysimeters placed at a depth of 60 cm.

Nitrogen treatment		Leaching perioid 1984 6/14-7/19	7/20-8/19	9/1-10/3	10/20-11/26	11/27-12/31	Season average
kg/ha				g N/m^3 water			
120		0.13	0.22	0.31	0.64	0.54	0.4
240		0.34	0.22	0.20	0.26	0.43	0.3
384		3.72	11.96	8.59	13.50	13.76	9.2
N		1.30	8.70	6.90	13.73	7.36	6.0
NPK		1.75	1.30	0.27	2.44	4.55	2.6
Source	df			F ratio			
Ratio	1	0.02	1.37	1.16	0.45	0.39	-
N-rate	2	1.06	2.57	0.84	12.38**	10.52**	-
N-Rate* Ratio	2	0.37	2.08	0.59	8.61*	1.56	-
				m^3/ha			
Estimated water leached		974.0	46.0	255.0	389.0	814.0	2478.0

*,** Significant at the 0.05 and 0.01 level of probability respectively.

Table 6. Estimated nitrate-nitrogen flux from the root zone of Kentucky bluegrass derived from soil sampled to a depth of 15 cm.

Nitrogen treatment		Leaching period 1984 6/23-29	7/8-14	10/28-11/3	11/4-10	Total
kg/ha				kg N/ha		
120		0.81	1.23	1.26	0.20	3.50
240		1.34	1.94	1.07	0.17	4.52
384		1.90	3.23	1.19	0.22	6.54
Source	df			F ratio		
N-rate	2	1.38	8.66*	1.96	1.35	
				m^3/ha		
Estimated water leached		147.5	280.0	145.3	27.0	599.8

*,** Significant at the 0.05 and 0.01 level of probability respectively.

Table 7. Estimated leachate nitrate-nitrogen concentration under Kentucky bluegrass derived from soil sampled to a depth of 15 cm.

Nitrogen treatment		Leaching period 1984 6/23-29	7/8-14	10/28-11/3	11/4-10	Average
kg/ha				g N/m^3 water		
120		5.49	4.39	8.67	7.41	5.84
240		9.08	6.93	7.36	6.30	7.54
384		12.88	11.54	8.19	8.15	10.90
Source	df			F ratio		
N-rate	2	1.38	8.66*	1.96	1.35	
				m^3/ha		
Estimated water leached		147.5	280.0	145.3	27.0	599.8

*,** Significant at the 0.05 and 0.01 level of probability respectively.

concentrations which approached or exceeded the safe level for nitrate-nitrogen in drinking water, regardless of the sampling method used.

While not statistically significant, general trends in estimated leaching were found between plots fertilized with N alone or with a complete NPK fertilizer (Tables 2 and 4). Plots receiving only N generally produced higher leaching values than those receiving NPK, since plots receiving N alone generally had higher soil solution nitrate concentrations (Tables 3 and 5).

DISCUSSION

Unfortunately, due to the frequent failure of lysimeters to produce soil water samples, statistical significance between fertilizer treatments was frequently not obtained. In most cases however, treatment means were obviously different and several consistant trends can be observed. The two factors most affecting estimated nitrogen loss from the root zone of turf were: 1). the concentration of nitrate-nitrogen in the soil solution, which translates into the concentration of nitrate-nitrogen in the leachate 2). the amount of water estimated to have drained from the root zone.

The concentration of nitrate-nitrogen in the soil solution and hence the concentration in the leachate was generally most dependent on the nitrogen regime under which plots were maintained. Most striking were leachate concentrations from high nitrogen plots. That high nitrogen plots (384 kg N/ha) maintained leachate nitrate concentrations above the safe drinking water limit of 10 ppm (U.S. Public Health Service 1962), when collected at both 20 (Table 3) and 60 cm (Table 5) below the soil surface, indicates that high rates of fertilization can cause a serious pollution threat to underlying aquifers. Similar leachate concentrations have been found at a depth of 50 cm under a mature bermudagrass sod when ammonium nitrate was applied bimonthly at the rate of 100 kg N/ha (Snyder et al. 1984).

Plots receiving low and medium nitrogen treatments, while sometimes having high leachate concentrations when sampled at 20 cm eg.: > 10 mg NO_3^--N/l (Table 3), did not produce comparably high values when sampled at 60 cm (Table 5). Although data collected from 20 and 60 cm lysimeters were taken during two different years,1983 and 1984, seasonal variation is probably not the cause of the differences found between leachate concentrations at those two depths. Leachate concentrations estimated from extracts of soil sampled to a depth of 15 cm during the same year,1984, as the 60 cm lysimeters, reveal leachate concentrations (Table 7) very similar to those found with the 20 cm lysimeters in 1983. The fact that lower soil solution nitrate-nitrogen concentrations were found at a depth of 60 cm than were found within the top 20 cm of soil, indicates that not all of the soil solution nitrate-nitrogen within the root zone is free to leach into underlying ground water. It is reasonable to believe that nitrate-nitrogen contained within the top 20 cm of soil is being actively immobilized by soil microorganisms in addition to being absorbed by growing plant roots. Also, denitrification of nitrate-nitrogen is probably occurring when favorable conditions arise. It is also not known whether, once leached beneath the top 20 cm of soil, if, and at what depth, microbial immobilization and denitrification are occurring. Generally though, nitrate-nitrogen which is found at 60 cm is most likely stable and would be free to leach into underlying aquifers, since plant roots and microoganisms are not abundant at that depth.

The other factor which must be considered in any leaching model is the amount of water estimated to have leached from the root zone. Under ideal moisture conditions for turfgrass, grown on medium textured soils, the soil water potential will be between field capacity and -0.4 bars (Aronson 1986). In the spring and fall however, periods of heavy rainfall coupled with low evaporative demand, frequently cause soil moisture to exceed field capacity. The result is water flux through the root zone into the ground water. Spring and fall are also commonly considered the best times for turfgrass fertilization. Generally though, if low rates of nitrogen are applied during periods of active turfgrass growth and rapid immobilization by soil microbes, soil solution nitrate-nitrogen can be maintained at a sufficiently low concentration to reduce the potential of nitrate-nitrogen flux into ground water. This can be seen in the leachate concentrations and quanity of nitrogen leached under low and medium nitrogen plots derived from 60 cm lysimeters (Tables 4 and 5).

If nitrogen fertilizer is applied when plant growth and microbial immobilization are depressed: ie. late fall, conditions may exist under which the nitrate-nitrogen content of the upper 20 cm of soil accurately estimates the amount of nitrogen which would be free to leach. If this were the case, leaching losses could equal those found in the early fall as estimated with 20 cm lysimeters (Table 2), given comparable volumes of water flux. Over-winter losses of late fall applied nitrogen could pose a serious threat to underlying aquifers. The fact that late fall fertilization provides early spring green-up without lush top growth, while an early spring fertilization does stimulate lush top growth, indicates that only residual amounts of the late fall fertilization are actually present during the following spring. Perhaps fertilization in the early spring, using a fraction of that recommended for late fall, might produce acceptable turf color and density without excessive top growth.

The general trend for greater nitrate leaching under turfgrass fertilized with N alone over turf fertilized with a complete NPK fertilizer underscores the importance of providing a balanced nutritional program. Plots fertilized with NPK appeared to have less disease and possessed a greater tiller density than those fertilized with N alone. Other data including clipping yields and the amount of nitrogen removed in clippings (Data not shown), indicate that fertilization with a balanced NPK fertilizer can increase nitrogen recovery by turfgrass plants. Lower soil solution nitrate concentrations found under plots fertilized with NPK further support these findings.

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APPENDIX IV

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FISCAL YEAR 1987 PROGRAM REPORT

Water Resources Research Institute
University of Rhode Island
Rhode Island

Report No.
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FISCAL YEAR 1987 PROGRAM REPORT
Grant No. 14-08-0001-G1447

for

U. S. Department of the Interior
Geological Survey

by

Water Resources Center
University of Rhode Island
Kingston, R. I. 02881

Calvin P. C. Poon, Director
July, 1988

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ABSTRACT

The 1987 program objective was to conduct studies and research of value to the New England region as well as to assist in the solution of problems in the State of Rhode Island. Current and anticipated state and regional water problems are contamination of surface and groundwater by natural radioactivity such as radon, by chemicals from industrial and agricultural activities, septic tank and leach field, improperly managed landfills and the lack of public awareness and public participation in water quality protection and management. It was found in the 1987 program that an epithermal neutron activation analysis was best suitable for measuring uranium and thorium of which radon is the decayed product. Lower U and Th were found in calc-alkalic and mafic volcanic rocks while higher concentrations were found in the alkalic and peraluminous rocks. A computer model using finite element method to simulate fluid flows through fractured porous media was developed for predicting the extent of groundwater contamination in the State. Techniques were developed to use metal resistant bacteria *Arthrobacter* HC823 for metal removal from plating wastes. Nitrogen and phosphorus contaminants were found short distances from the drainage field of septic tank systems. Educational programs in water resources issues included conference, fact sheet publication, citizen watershed watch. Handbook and short courses were either conducted or being initiated. Mixed ash from a mass-burn incinerator containing sufficient cadmium to be classified as toxic substance using TCLP procedure but sufficient lead to be classified as toxic using either EPTC or TCLP procedure. This Center works closely with the R.I. dept. of environmental Management; USGS subdistrict office, R.I. Solid Waste Management Corp., and other New England Water Resources Centers for program planning and research coordination.

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WATER PROBLEMS & ISSUES OF RHODE ISLAND

In Rhode Island and New England region as a whole, groundwater constitutes the major water resources for domestic, commercial, and agricultural activities. Most of the groundwater in Rhode Island is confined to shallow aquifers which are overlain by sandy soils suitable for agriculture and suburban development. The rapid housing and commercial development in Rhode Island in recent years presents a potential threat of groundwater contamination which threatens the quality of groundwater in the state. An industrial waste pretreatment is not yet fully implemented in the state. This, coupled with the inadequate treatment of municipal wastewaters, leads to the contamination of the surface water in many parts of the state.

Known petrologic and geochemical characteristics of geologic materials in Rhode Island suggest anomalously high concentrations of radioactive parent nuclides of radon and radium. Radon is an enert gas which is relatively soluble in water. These properties allow it to readily diffuse into the atmosphere including the confined household space or into groundwater aquifers. Characterization of radon in groundwater and radioactive parents in host aquifers will permit the state to focus on specific geographic areas where health hazards are likely to exist.

One of the threats to both the surface water and groundwater quality is the occurrence of spills and leaks of organic chemicals such as petroleum products which occur during their transport, storage, and disposal. The infiltration and migration of petroleum products in the subsurface is a complex process. There is a number of groundwater contamination case histories in Rhode Island where the subsurface medium in fractured rocks. Therefore, there is a need for the development and verification of a computer model for analyzing the areal flow under transient conditions of an immiscible contaminant fluid in fracture rocks.

Many metal platers and finishers in Rhode Island are not in compliance with the pretreatment regulations that limit the discharge of toxic metals and cyanide into public sewers. The existing technology of chemical treatment is beyond the capability of small platers who do not have the capital resources for this type of investment. A less expensive and simpler means of pollution control is needed to assist this large number of small companies in meeting their effluent standards.

On the southern shore of Rhode Island, the coastal pond region is experiencing groundwater pollution and surface water eutrophicaton resulting from a three-fold increase in housing since 1950 which threatens to diminish the recreational, commercial, and ecological values of the coastline. A large number of seasonally used homes use individual sewage disposal systems. Studying of the migration and attenuation of contaminants from these seasonally used individual sewage disposal systems will be useful in improving the future septic system design and establishing the minimum setback/separation distances from septic systems to wells and groundwater table for coastal regions.

The state of Rhode Island, as in other states in the nation, find it very difficult to find new sites for landfills. Municipal waste incinerators will be built as part of an integrated scheme of solid waste management in the state. Incinerator ash is a potentially hazardous material. Information on ash characterization and the possibility of toxic chemicals leachating out from a landfill for ash disposal is needed for future landfill design.

PROGRAM'S GOALS AND PRIORITIES

The research needs on water resources in the New England region as identified by the New England Council of Water Center Directors have been:

- Groundwater Quality Control
  - Sources of toxic materials
  - Fate and transport of chemicals
- Management of groundwater Supplies
  - Location and extent
  - Rural and small town water supply systems
  - Recharge characterization
- Surface Water Quality Control
  - Acid precipitation
  - Eutrophication
  - Watershed management
- Management of Surface Water Supplies
  - Land use/hydrology interactions
  - Water reuse and conservation
- Institute Frameworks
  - Water use planning and management
  - Water allocation and reallocation
  - Conflict resolution among competing users
- Ecological and Health Relationships
  - Wetland ecology
  - Effect of chemicals in water on human health

Using these research needs as a guide, the Rhode Island Water Resources Center developed its program goal to meet some of these research needs as well as to transfer the information of water resources research/management to the public. Both the State Advisory Committee and the University Water Resources Coordinating Committee for the Center finalized the specific research needs for the FY-1987 program with heavy emphasis on groundwater protection. Project proposals were reviewed and selected on the criteria of (1) satisfying the state and regional research needs, (2) technical competency, and (3) reasonable budget.

Three projects addressed the groundwater quality problems and met the research needs identified by the Center. Project 02 on Uranium-Thorium Concentrations in Bedrock and Surficial Materials: Primary Sources of Radon in Rhode Island Aquifers developed a new, modified technique of neutron activation analysis. Using this epithermal neutron activation procedure, background levels of uranium and thorium were established for a broad group of volcanic and plutonic rocks in Rhode Island. These background levels are used against which anomalous concentrations can be compared. The second phase of this research (in the FY-1988 program) will collect and analyze more samples with the final data integrated into a Geographical Information System in order to generate a dynamic working map identifying areas of potentially low, intermediate, and high levels of radon. The information is intended to be available to help guide future radon programs undertaken by the R. I. State Department of Health as well as state and local planners.

Project 03 on Numerical Model Study of Contaminant Flow in Fractured Rock responded to the research need in Rhode Island where a number of groundwater contamination case histories has been found where the subsurface medium is fractured rock. The computer model is available to state agencies or other interest groups for predicting the extent of groundwater contamination in fractured rock for existing and future problems. The same model can also be used to estimate the most efficient pumping rates in a clean-up process.

Project 05 on Microbial and Phosphorus Migration in Groundwater from Seasonally-Used Septic Systems monitored the occurrence of nitrate nitrogen and phosphorus at various distances from the septic drainage fields of seasonally used vacation homes. Effect of sand filters on the removal of phosphorus was monitored. With more data to be collected in the summer of 1988, important questions can be answered on the attenuation of contaminants in the drainage field as well as the pollutant removal efficiency of the seasonal systems compared to a continuously used recirculating sand filter system.

Project 04 on A Microbial Method for Removal of Metals, Cutting Oils and Cyanide from Polluted Water - Phase I, used a serial enrichment-adaptation procedure to expand the resistance spectrum of _Arthrobacter_ HC823 to a combined mixture of heavy metals commonly found in plating wastes. Studies of the required cell mass, energy supply and kinetic were carried out. Experiments will be continued into the FY-1988 program to include biodegration of cyanide and cutting oil. Either single reactor or multiple-reator system will be tested in order to obtain data useful for future system design. The system would be inexpensive and simple to operate so that small plating companies would be able to apply the technology for meeting the wastewater pretreatment requirements.

Project S1 on Study of Flyash and Bottom Ash and Their Leachate Characteristics in a Simulated Landfill condition, a privately funded project started on December 1987, performed extensive chemical analyses on incinerator ash and ash extracts. Multiple columns were set up to simulate landfill conditions for separate or co-disposal of ash and municipal waste. Acid rainfall condition typical of the Rhode Island situation was applied while the simulated landfill leachate was collected for analysis. Pollutants in the leachate were monitored and chemical interactions within the simulated landfill were being identified. The objective of the project is to investigate the fate of the pollutants and the amounts leaching out in the acid rain condition. The project will be completed in May 1989 with data available to engineers designing the landfill for ash disposal in Rhode Island.

Sources and level of funding for the various projects including the information transfer activities are listed below.

		Project	Funding*	Source
Research	02	Uranium-Thorium Concentrations in Bedrock & Surficial Materials: Primary Sources of Radon in R. I. Aquifers	$13,730 41,643	U.S Geological Survey University of R. I.
	03	Numerical Model Study of Contaminant Flow in Fractured Rock	18,028 35,378	USGS University of R. I.
	04	A Microbial Method for Removal of Metals Cutting Oils & Cyanide from Polluted Water	14,000 34.884	USGS University of R. I.
	05	Microbial & Phosphorus Migration in Groundwater from Seasonally-Used Septic Systems	14,000 36,760	USGS University of R. I.
	S1	Study of Flyash & Bottom Ash & Their Leachate Characteristics in a in a Simulated Landfill Condition	10,875 1,955	R. I. Solid Waste Management Corp. University of R. I.
Information Transfer Activities (See information transfer project description later in this report. Quarterly newsletters were published with the Center adminiatrative fund).			$15,000 39,171	USGS University of R. I.
Center Administration (publication of newsletters included)			$30,372 44,906	USGS University of R. I.

*Ending May 31, 1988

PROJECT NUMBER: 02

DURATION: June 1, 1987 to May 31, 1988

TITLE: URANIUM-THORIUM CONCENTRATIONS IN BEDROCK AND SURFICIAL MATERIALS: PRIMARY SOURCES OF RADON IN RHODE ISLAND AQUIFERS

PRINCIPAL INVESTIGATOR:

O. DON HERMES
GEOLOGY DEPARTMENT
UNIVERSITY OF RHODE ISLAND
KINGSTON, RHODE ISLAND

COWRR CATEGORY: O2-K

CONGRESSIONAL DISTRICT: SECOND

DESCRIPTORS: URANIUM, RADIOACTIVITY, GRANITES, AQUIFERS, URANIUM RADIOISOTOPES, WATER QUALITY

PROBLEM AND RESEARCH OBJECTIVES:

Radon, a naturally occurring gas which has been recognized as a significant and widespread environmental health problem, forms by radioactive decay of primary ^{238}U:

$$^{238}U — ^{234}Th — ^{234}Pa — ^{234}U — ^{230}Th — ^{226}Ra — ^{222}Rn$$

^{222}Rn decays with a half life of 3.8 days, undergoing several rapid disintegrations leading to ^{210}Pb, which has a half life of 22 years. The ^{210}Pb ultimately decays to ^{206}Pb, which is stable.

The primary geologic sources of uranium, and hence radon, are igneous rocks, especially alkali enriched granitic rocks, and sedimentary and metamorphic materials subsequently derived from these igneous protoliths. Radon is an inert gas which is relatively soluble in water. These properties allow it to readily diffuse into the atmosphere and into groundwater aquifers that are in contact with rocks of high uranium content. Previous studies (King and others, 1982) have shown that high radon levels in groundwater show a positive correlation with high radium levels, and that both radon and radium may correlate with high U and Th in the geologic materials that comprise the aquifers.

Known petrologic and geochemical characteristics of geologic materials in Rhode Island suggest anomalously high concentrations of radioactive parent nuclides of radon and radium. The primary object of this project has been to quantitatively determine uranium and thorium contents in crystalline bedrock, metasedimentary rocks of the Narragansett Basin, and surficial glacial deposits, in an attempt to identify and map groundwater aquifers that are potential geochemical sinks for daughter products radon and radium.

Characterization of radon in groundwater and radioactive parents in host aquifers will permit the state to focus on specific geographic areas where health hazards are likely to exist. At present, reports of anomalous radon findings are sporadic, that is their significance is uncertain because we do not know much about the magnitude and distribution of such occurrences. Although radon distribution must relate in some way to geologic control, specifics are far from conclusive. Hence it is unclear whether radon is, or is not, a potential health problem in Rhode Island.

Uranium and thorium are present in nearly all geological materials, but their concentrations are usually so low that trace level techniques are necessary. The determination of U and Th contents requires the establishment of new analytical techniques not previously available to the URI community. The proposed method is a modified technique of neutron activation analysis called epithermal neutron activation analysis, and as a result of this work will be performed for the first time at the Rhode Island Reactor Facility. The setup of this method entails the development of a suitable procedure based on trial irradiations, experimentation and on recent related literature. The establishment of this technique will constitute a major early effort of this project and is intended to be a valuable by-product of our work.

METHODOLOGY

EPITHERMAL NEUTRON ACTIVATION ANALYSIS

The basic principle of activation analysis is that a stable isotope, when irradiated by neutrons (or charged particles), can undergo a nuclear transformation to produce a radioactive nuclide (Lyon, 1964). The emanations from this formed radionuclide are measured using radiation detection instruments, such as a scintillation counter, thus allowing quantitative determination of the elemental composition of the sample before irradiation. A special method of neutron irradiation, epithermal irradiation, is necessary when determining concentrations of heavy elements such as U and Th in geologic materials as the ratio of these trace elements to the light matrix elements is extremely small.

The neutron energy distribution in the nuclear reactor core is divided into three neutron flux components. The fast neutron component are those neutrons above about 0.1 MeV; the epithermal component are those with energies between 0.2 ev to 0.1 MeV; and the thermal component consists of neutrons below 0.2 ev. In most cases irradiation with the whole reactor neutron spectrum is performed, with most nuclides capturing the thermal neutrons with a relatively high probability (cross sections) and epithermal neutrons with very low probability (the resonance integral).

Epithermal neutron activation allows the activation rate of some nuclides relative to others to be enhanced by shielding the rock sample from the thermal flux component. If a sample is irradiated in a cadmium cover, which has a very high absorption cross-section in the thermal neutron region, the thermal neutrons are excluded, and only the neutrons with energies greater than 0.4 ev will contribute to the activation process (Steinnes and Brune, 1969). For heavy elements such as U and Th, the fractions of activations by epithermal neutrons exceeds the fraction of activations via thermal neutron capture. Therefore, for complex matrices such as geological samples, the activity level of abundant light matrix radionuclides such as ^{24}Na ($T_{1/2}$=15h) and ^{56}Mn ($T_{1/2}$=2.58h) will be suppressed to a much greater extent than the activities of Th and U (Meyer, 1971; Parry, 1982). As a result the radioactivity level of the U and Th is enhanced, thus permitting detection to approximately 0.1 ppm levels.

PROCEDURE

A broad spectrum of volcanic and plutonic rocks, representative of the major igneous rock groups in Rhode Island, have been analyzed for U and Th content. After field collection, the rock samples for geochemistry were ground and prepared for analysis using equipment in the Geology Department. Routine major and trace chemistry analysis was done, as needed, on a Kevex ED-XRF system that is fully operational in the Geology Department.

Splits of each powdered sample were analyzed for U and Th by epithermal neutron activation techniques at the Rhode Island Nuclear Science Center. To prepare each sample approximately 300 mg of powdered rock sample was weighed into 2/5 dram polyethylene capsules and heat sealed to avoid post – irradiation spillage of the radioactive sample. Iron wires, about 5 cm in length, served as flux monitors for each sample. Each cleaned and weighed iron wire was wrapped and taped around a sealed sample capsule, essentially recording the neutron flux on each individual sample, as this flux is not uniform among all samples.

The samples and respective flux wires were then placed in one of two cadmium vials which have been designed to hold nine sample capsules each. Each Cd vial measures 7.75 cm in height with a diameter of 2.92 cm. These two Cd vials were in turn placed in a rabbit and irradiated at a flux of 4 x 10^{12} n/cm^2-sec for two hours. Irradiations were done in the late afternoon on any given day to ensure that the rabbit would remain in the reactor following shutdown and overnight. This necessary precaution allowed the cadmium isotopes produced sufficient decay time before being released to the rabbit station the following day.

After removal from the rabbit the samples were separated from the encapsulating cadmium, thus immediately lowering exposure levels, and stored in the appropriate facility in the reactor. The samples and standards were measured for their gamma-ray spectra on a lithium drifted germanium detector (Ge(Li)) with an energy resolution of 0.5 KeV/channel and an efficiency of 39% . Counting of each 18 samples was done 7 to 9 days after irradiation in order to obtain the gamma- ray spectra indicative of ^{238}U. The samples were counted a second time 25 to 30 days following irradiation for the spectra resulting from the ^{234}Th in the sample. In both cases the 18 samples were placed in an automatic sample changer and counted for 2 hours each. Each of the spectra were recorded and stored on a magnetic tape.

The gamma-ray spectra were then evaluated using the total peak area method. A peak height analysis program was run, which identifies and labels the energy (KeV) of each peak and the corresponding intensity (counts/second) for each of the spectra. The data from the peak analysis program were then entered into a Lotus program on an IBM PC in the Geology Department, resulting in final concentrations (ppm) of U and Th. Thus, there was approximately one month between the time of irradiation and final compilation of results for each irradiation.

PRINCIPAL FINDINGS AND SIGNIFICANCE

A major early effort of our study has been to develop and perfect the above analytical techniques to quantitatively determine U and Th concentrations in geological material. Compared to several alternative analytical techniques for U and Th analyses, the chosen method requires a simpler setup, less preparation per sample and has been proven quantitatively accurate and statistically reproducable. This method is now of potential use to other researchers and constitutes a valuable by-product of our work.

Preliminary results from a broad group of volcanic and plutonic rocks in Rhode Island indicate a considerable range in U and Th values (Table 1). The lower concentrations are consistently found in the calc-alkalic and mafic units, as expected. These units include the Esmond granodiorite, Dedham granite and Lynn volcanics (Figure 1). Such data are necessary to establish backround levels against which anomalous concentrations can be compared. The higher values are found in the alkalic and peraluminous rocks which are known to be of appropriate mineralogy and geochemistry to be suspected of containing anomalously high U and Th concentrations.

Approximately 70% of the state is underlain by granitic rock, and the remaining 30% consists of sedimentary strata derived from this granitic substrata. Of importance is the widespread occurence of alkalic rich igneous rocks in Rhode Island (Hermes and others, 1981; Hermes and Zartman, 1985), rock types which are amongst the most enriched in primary U and Th. Commonly, granitic rocks enriched in U and Th also show high concentrations of other high field strength elements such as Zr, Nb, Ta, Y, and Zn (Harris and Marriner, 1980). In Rhode Island, the Scituate granite and Quincy Granite (Figure 1) are K-Feldspar, potash rich granites that contain anomalously high values of Zr, Nb, Y, and Zn. Thus, it is no suprise that these units are among the most U and Th rich of the rocks analyzed in this study to date (Table 1).

This project is part of an ongoing study, to be completed in June, 1989. The analyses of the igneous and metasedimentary rocks are to date incomplete as an additional twenty five samples have been irradiated and will be measured for their gamma-ray spectra in the next twenty days.

The final data will be integrated into the Geographical Information System (GIS), run by the Environmental Data Center at URI, as part of a multiple natural resource analysis. The GIS will generate a dynamic working map identifying areas of potentially low, intermediate, and high levels of radon. Digitization of radon-related geographic information has already been started with the GIS. This geographic information is intended to be available to help guide future radon programs undertaken by the Department of Health as well as state and local planners. The results of this project also will serve to complement the latest studies dealing with groundwater in fractured bedrock, and the nature of its flow through such aquifers.

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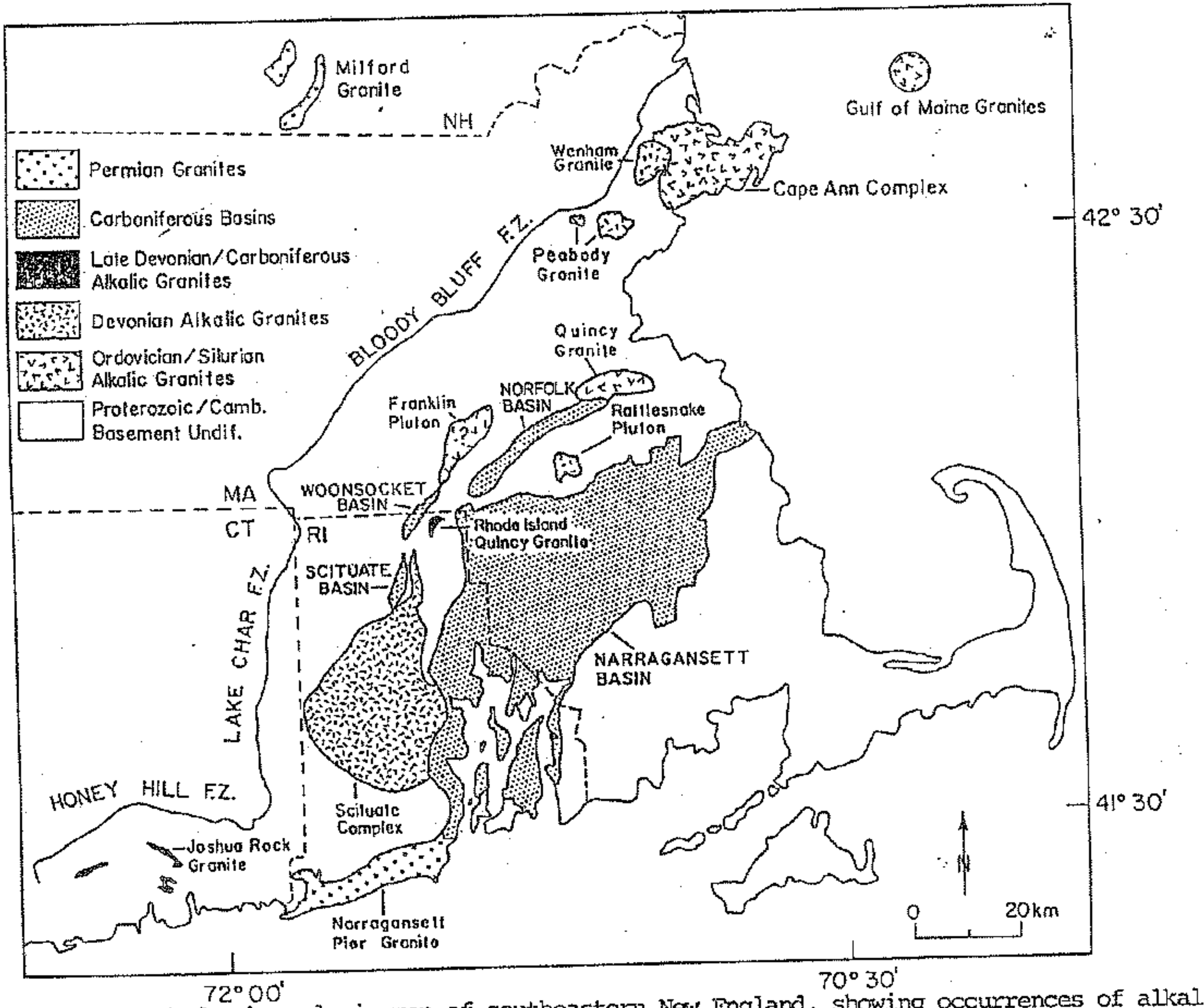

Figure 1: Generalized bedrock geologic map of southeastern New England, showing occurrences of alkalic rock units characterized by anomalous concentrations of high-field strength trace elements, such as Nb, Zr, Y, Ta, Zn (Hermes and Zartman, 1985). Elsewhere granitic rocks high in these elements also contain anomalous concentrations of U and Th (Harris and Marriner, 1980).

VOLCANIC ROCKS

MAP UNIT	ROCK TYPE	U (ppm)	TH (ppm)
WAMSUTTA	ALKALIC FELSITE	7.4	13.7
		3.2	14.5
WAMSUTTA	ALKALI-OLIVINE BASALT	0.7	3.0
		0.6	1.9
SPENCER HILL	ALKALIC	14.0	13.2
	ALKALIC FELSITE	8.1	33.8
		2.4	22.5
LYNN	CALC-ALKALIC	3.5	12.3
		3.2	11.9
MATTAPAN	CALC-ALKALIC	3.9	10.7
HUNTING HILL	CALC-ALKALIC	0.3	0.5

PLUTONIC ROCKS

MAP UNIT	ROCK TYPE	U (ppm)	TH (ppm)
NPG	PERALUMINOUS	13.4	22.5
		10.2	6.7
		3.9	64.6
		3.9	55.9
		13.1	11.7
		4.1	39.2
COWESETT	ALKALIC	8.4	29.3
RI QUINCY	ALKALIC	16.8	67.9
SCITUATE GRANITE	ALKALIC	2.4	15.2
		4.8	20.3
		3.7	18.7
		5.6	25.7
		3.4	19.7
ESMOND	CALC-ALKALIC	1.7	11.8
		1.8	13.3
		1.8	9.5
DEDHAM	CALC-ALKALIC	3.5	13.3
		2.3	16.3
		1.4	5.8
HOPE VALLEY ALASKITE	ALKALIC	4.0	5.8

Table i: Results from a range of RI lithologies.
(NPG=Narragansett Pier Granite)

SYNOPSIS

Project number: 03

Start 6/01/87

End 5/31/88

Title: Numerical Model Study of Contaminant Flow in Fractured Rock

Investigator: Cheng-Jung Chang
Dept. of Civil and Envir. Engineering
University of Rhode Island
Kingston, R.I.

COWRR: 05 Water Quality Management and Protection
C Effect of Pollution

Congressional District: 2nd

Descriptors: Gasoline, Groundwater Contamination, Model Studies, Multiple Flow, Oil, Petroleum Products

Problem and Research Objectives:

Contamination of groundwater by industrial products has become a problem of growing concern for years. They pose a potential threat to large volumes of groundwater if they are somehow introduced into the subsurface. One of such threats to groundwater resources is the widespread occurence of contamination due to spills and leaks of organic materials such as petroleum products which occur during their transport, storage and disposal. These organic materials contain compounds that are immiscible or slightly soluble in water and can be a long term source of contaminants. They can migrate with water through the soils or fractured rocks and within a certain period of time can spread over a considerable area.

The infiltration and migration of petroleum products in the subsurface is a complex process. Most numerical models either consider the flow domain to be a porous medium or deal with the qualitative analysis of the contamination problems. Difficulty, however, arises when such assumptions are utilized for quantifying flow through fractured rock. This is because fractured rock has two distinctly different porosities - one due to interconnected fracture network and the other due to the inherent porosity of the rock mass itself. In general, the interconnected fractures form a system of channels in such a manner that the entire porous domain is made up of a large number of porous blocks, each completely surrounded by the void space of the channel and the fracture system. Thus, accurate prediction of immiscible organic contaminants as a separate phase in fractures and pores is a prerequisite to the development of models describing the flow of immiscible contaminants in fractured rock.

The objective of this study is the development and verification of a numerical model for the analysis of areal flow under transient conditions of an immiscible contaminant fluid in fractured rock. The procedure towards this objective consists of the following:

1) Development of the numerical model from the basic partial differential equations describing the immiscible fluids in two overlapping continuums using necessary physical and mathematical assumptions.

2) Development of a computer software which can be used for predicting horizontal spread of various hydrocarbon spills.

Methodology:

Two sets of governing equations are required to describe the flow in fractured porous media, one for each type of porosity. These sets of equations are coupled by the interaction of fluid in the primary pores with the fluid in the fractures. The continuity equations for the flow of two immiscible fluids, water and oil, are given by:

for oil in fractured medium,

$$\frac{\delta}{\delta t}[n_f \rho_o(P_f) S_{of} + n_f \rho_w(P_f) s(P_f) S_{wf}] + \nabla[\rho_o(P_f) q_{of}] = m_o^* \text{-------}(1)$$

for oil in porous blocks,

$$\frac{\delta}{\delta t}[n_p \rho_o(P_p) S_{op} + n_p \rho_w(P_p) s(P_p) S_{wp}] + \nabla[\rho_o(P_p) q_{op}] = -m_o^* \text{------}(2)$$

for water in fractured medium,

$$\frac{\delta}{\delta t}\left[n_f \rho_w(P_f) S_{wf} \right] + \nabla\left[\rho_w(P_f) q_{wf} \right] = m_w^{*} \text{---}(3)$$

for water in porous blocks,

$$\frac{\delta}{\delta t}\left[n_p \rho_w(P_p) S_{wp} \right] + \nabla\left[\rho_w(P_p) q_{wp} \right] = -m_w^{*} \text{--}(4)$$

where subscripts 'f', 'p', 'o' and 'w' have been used for fractured medium, porous medium, oil phase and water phase respectively, n is the porosity of the medium, ρ is the density of the fluid, S is the degree of saturation, s is the solubility of oil in water, q is the specific discharge vector given by Darcy's Law and m^* is the transfer of fluid from porous blocks to fissures per unit bulk volume of the flow domain and per unit time.

The above set of partial differential equations can be simplified with the assumptions that densities are independent of pressure and oil is insoluble. The mass flow rates, m_o^* and m_w^*, per unit time per unit volume of medium are the average interactions of the fluids in the primary blocks with the fluids in the fractures. These terms are, therefore functions of time and space and can be formulated in terms of fluid pressures in fractured and porous mediums.

Equations (1), (2), (3) and (4) form a system of coupled nonlinear partial differential equations, closed form solution of which is intractable. Therefore, these equations are solved numerically using finite element technique. Since variational formulation of this problem is rather complicated, Galerkin finite element procedure has been used in this research. Time integration of the heads and the interface elevation is done using fully implicit backward finite difference scheme.

Principal Findings and Significance:

The solution scheme that has been used in the present study is based on some of the existing models for simulating fluid flow in porous medium. They have been associated and modified to take into account flow through fractured medium. A computer software has been developed based on the mathematical formulation. This computer model can be used to simulate flow of any two immiscible fluids through fractured rock consisting of both fractures and pores or through only fractured or porous medium. The medium can have different porosities in x and y directions. The injection of contaminant can be through a nodal source or an elemental source. The rate of recharging can be varied through different time increments. Another important feature which the computer model is capable of simulating is that for a given existing plume, it can predict the plume profile after certain amount of time. Therefore, during the clean-up process with a particular rate of discharge the model gives a very good idea about when the pumping should be stopped and started again to have maximum efficiency.

Fully implicit finite difference scheme has been used for time integration so that the user need not concern about the stability problems. The element library of the model consists of three different types of element. They are three noded linear triangular element, six noded quadratic triangular element and four noded isoparametric quadrilateral element. However, it has been observed that the benifit obtained from the use of higher order functions is very minimal.

In the past, virtually no numerical work has been done in the area of flow of contaminant through fractured rock. As a result, development of numerical procedures to analyse the flow of contaminant through fractured rock, like the present one, is very important. The Rhode Island Department of Environmental Management has a number of groundwater contamination case histories in the state where the medium is a fractured one. With laboratory tested contaminants and explored geological data available, this model is able to predict the potential and extent of groundwater contamination in fractured rock for existing as well as future such problems in Rhode Island. Moreover, the model can be used to find efficient ways of cleaning the groundwater for the above cases. It can also be used by other potential users like researchers, consulting engineers and environmental regulating agencies in the United States.

SYNOPSIS

Project Number: 04

Start 6/1/87
End 5/31/88

Title: A Microbial Method For Removal Of Metals, Cutting Oils And Cyanide From Polluted Water - Phase II

Investigators: Dr. R. W. Traxler, Univ. of Rhode Island
Dr. Tung-Ching Lee, Univ. of Rhode Island
Dr. D. R. Nelson, Univ. of Rhode Island

COWRR: 05D Waste Treatment Process

Descriptors: Bacteria, Biodegradation, Heavy Metals, Waste Disposal, Pollution Control

Problem & Research Objectives:

Rhode Island regulations limiting the discharge of toxic metals and cyanide into public sewers have been in effect for five years but the majority of affected platers and finishers are not in compliance with these regulations. Many of the larger firms meet discharge standards or are expected to do so in the near future but the smaller companies have not had the resources to effectively meet these standards.

The magnitude of the problem is seen by the amount of heavy metal entering the Narragansett Bay Commission sewer system in recent years. The peak was in 1981 with 956,099 pounds release with a drop in 1985 to 409,657 pounds. The interim goal is to reduce this volume to about 200,000 pounds within a year. The existing technology for solution of this problem by chemical means is expensive. One of the larger companies was forced to spend $500,000 for a pretreatment system. This type of a solution to the problem is beyond the capability of the smaller operator who does not have the capital resources for even a 5th of this type of investment. The ultimate result is that without a less expensive system these small companies will be forced out of business. This project is aimed at the small operation to provide to these companies a relatively simple, inexpensive but effective means of pollution control. The project while of extreme potential value to Rhode Island can also be applied to the same problem in other states.

A. The FY 1987 Objectives Phase I Metal Removal:

1. Expand resistance spectrum in one isolate, if possible, to include resistance to Cu, Pb, Ag, Cr, Zn, Cd, Ni and Hg.

2. Determine the kinetics of metal removal.

3. Determine the saturation level of cell mass.

4. Determine the effect of nutrients on metal removal.

5. Perform bioreactor studies with simulated and real waste for metal removal.

6. Determine the presence or absence of plasmid DNA which is linked to the objectives of Phase II.

Methodology:

a. Enrichment Isolations: The basic procedure is to use a chemically defined mineral salts medium minus one essential nutrient (in this series either carbon or nitrogen). For isolation of hydrocarbon degraders, oil (or pure hydrocarbon) is added to this medium at a final concentrations of 1% (V/V). The medium contains a nitrogen source which is usually ammonium nitrate. An inoculum source (from an oil polluted area) is added at about 1% volume and the flask incubated with shaking at 25-30 C until visible growth occurs. At visible turbidity, 1.0 ml of this primary enrichment is transferred to a second flask of the same medium. When growth occurs the growth is streaked for isolation on a general purpose medium and the isolation medium solidified with 1.5% washed agar-agar. One of each colony type that grows on the isolation medium is streaked for purity then reinoculated into sterile mineral-salts substrate broth. Growth in this flask indicates a successful enrichment isolation. In the same way a non-repressive substrate is used as a carbon source in a nitrogen free medium for the isolation of cyanide utilizers with cyanide as the nitrogen source. The non-repressive substrate can be sucrose (not glucose) or any of a variety of substances such as glycerol, acetate which do not contain nitrogen. Also, simple complex media are used in diluted form, i.e. nutrient broth 1/10 formulation with cyanide added at varied concentrations (0.02 to 0.5%). This work is performed in a fume hood at an air flow rate of 100 cu.ft/sec. to ensure safety of personnel. Disposable gloves are used in all handling of materials and placed in a closed container in the hood after use. It is not necessary to sterilize the cyanide salts which are prepared as stock solutions and aseptically added to sterile medium. KCN is the salt normally used in this type of experiment

b. Bioreactor testing: One organisms has been selected for this system and the nutrient supplement needs established. The experiments will be conducted in a two liter fermenter structured for continuous flow at a working volume of 1350 ml. This reactor is part of the New Brunswick Scientific Co. C-30 Bioflow unit equipped with pH, agitation, temperature and aeration control. A variable speed peristaltic pump is used to flow an effluent waste to the reactor at variable dilution rates which determines the residence time in the system. The effluent from the reactor flows by gravity to an effluent collection reservoir. The effluent stream is sampled at time intervals and analyzed for pollutant residues. The parameters to be studied are biomass loading, uptake and degradation kinetics, determination of optimum pollutant feed rate and time for biomass saturation from metal uptake.

The final phase of the study is conducted in the same fermenter system but using a non-continuous flow reactor vessel. In these experiments the reactor content is pumped via a high speed pump to a tangential flow filter which separates cells and aqueous phase. The retentate flow (containing cells) is returned directly to the bioreactor while the permeate (aqueous phase) stream is split with partial flow to waste and the remainder of the flow back to the bioreactor. The volume of permeate to waste is set to equal the rate of waste feed into the bioreactor. The system is adjusted to a steady state for optimum pollutant removal. Concentrated waste would be diluted with makeup water to desired feed concentration and fed on a continuous basis to the bioreactor. Supplemental nutrients are fed to the reactor by addition to the waste stream. In this second phase of the project we will use actual waste from metal working operations,

Principal Findings & Significance:

Objective 1.

Using a serial enrichment-adaptation procedure we have been able to expand the resistance spectrum of Arthrobacter HC823 to a combined mixture of eight metals, each at a concentration of 50 ppm. The eight metals are: Cu, Pb, Ag, Cr, Zn, Cd, Ni, and Hg. This is a combined total metal ion load of 400 ppm of metal ion in the test system. We are delighted to be able to achieve this resistance pattern in one isolate.

Objective 2.

Kinetic studies were initiated in November using Cu as the first metal in non-nutrient supplemented experiments. The first experiments indicate a much more rapid removal of the metal from a microbial suspension in distilled water than anticipated. We expect on the basis of the data that the bulk of the copper is removed within the first few minutes of the experiment. Copper is apparently distinct from the other metals in that it may be chelated by a low molecular weight protein or peptide and effectively co-precipitated with the cells. Similar experiments have been performed with other metals and a mixture of metals. In these experiments we have encountered reduced levels of metal binding, which at this time have not been explained. Experiments in May have used more concentrated cell mass in small scale experiments. It was expected that the amount of metal removed from aqueous solution would be directly related to the dry weight mass of cells used in the reactor. This is true up to approximately 20 mg/ml then there is an actual decline in metal removal. Our normal procedure is to shake the bioreactor during the experiment which provides aerobic conditions. An experiment under anaerobic conditions demonstrated a significant reduction in metal removal, indicating an aerobic process. It would appear that when increased cell mass is used we are unable to provide a sufficient dissolved oxygen for metal removal. Experiments are being prepared to used enhance aeration system to resolve this question.

Objective 3.

We now know that saturation of the cell mass with metal occurs at a metal:cell dry weight in the range of 1:1.4 to 1:2.8 mg metal:mg cell dry weight. From this data we now have a guide to the amount of cell mass needed to clear a waste water. This baseline information will be used as we structure the bioreactor studies.

Objective 4.

We know that glucose used as a energy source (1%) enhances metal removal from a water solution but is not as effective as small quantities of yeast extract (0.01%). Using a mixture of glucose and yeast extract offers no advantage over yeast extract alone.

Phosphate would appear to enhance Cu and Pb cell association but lowers the association of Cr and cells. Phosphate also has a chemical reaction with Ag (apparently the formation of silver orthophosphate which is insoluble) which removes the silver from solution.

Yeast extract is a complex mixture of compounds which are to a large extent amino acids, peptides and vitamins. It is a very promising supplement for this project in that low concentration is required for enhanced activity and it is a relatively cheap product.

Objective 6.

A variety of procedures have been used in the digestion of Gram positive bacteria for the release and recovery of plasmid DNA. In early experiments only nuclear DNA was recovered. Different digestion methods have been used, along with known plasmid bearing organisms as a control on the method. This work is complicated by the fact that molecular studies are not well known for members of the genus Arthrobacter. We have just recently demonstrated what appears to be two regions of non-chromosomal DNA on gels and are in the process of restricting these regions from the gels. The next step will be to transfer this DNA to a non-resistant organism such as E coli to determine if metal resistance is carried on these DNA segments.

Publications & Professional Presentations

None to date, a preliminary publication is in preparation.

M.S. Theses:

J. S. Wang, To be complete by August, 1988.

Ph.D. Dissertations:

M-C. Lai, underway.

SYNOPSIS

Project Number: 05

Start: 6/1/87
End: 11/1/88 Anticipated

TITLE: Microbial and Phosphorus Migration in Groundwater from Seasonally Used Septic Systems

Co-Principal Investigators:

Arthur J. Gold, Associate professor, Natural Resources Science, URI

Charles G. McKiel, Associate Professor, Natural Resources Science, URI

George W. Loomis, Research Associate III, Natural Resources Science, URI

COWRR: 05A, 05B, 05D, 05G

Descriptors: Groundwater pollution, septic wastewater, soil disposal fields, nitrogen, phosporus, sewage bacteria, monitoring.

STATEMENT OF PROBLEM:

The population of the United States in recent years has migrated towards the nations coastlines. It is estimated that by the end of this decade that 75% of the populace will reside within 50 miles of tidal waters and the Great Lakes (Carter, 1980). Development pressures are particularly heavy along the shoreline as the result of rapidly expanding seasonal coastal communities. The southern shore of Rhode Island exemplifies this trend. The coastal pond region is now experiencing ground water pollution and surface water eutrophication resulting from a three-fold increase in housing since 1950 (RIPE, 1981; Olsen and Lee, 1985). The commercial, recreational, residential, and ecological values associated with the Rhode Island coastline warrants staunch protection of these water resources. Recently, seasonally used individual sewage disposal systems (ISDS) have come under increased scrutiny as a major source of water quality deterioration for several reasons:

i) their inherent proximity to coastal waters

ii) their installation in highly permeable coarse grained soils

iii) the high density of homes associated with seasonal communities

iv) their lack of continuous operation time to produce an adequate clogging layer.

The objective of this thesis research is to determine the migration and attenuation of selected contaminants from seasonally used ISDS. Sand filter components of existing alternative septic system (i.e. recirculating sand filter system and RUCK) will also be compared to the seasonally used ISDS in an attempt to assess sand filter efficiency for selected contaminant removals. The result of this study will aid in establishing recommendations on future septic system design and minimum setback/separation distances from septic systems to wells and groundwater table for coastal regions.

Methodology:

Three seasonally used ISDS were selected for detailed study. Potential study sites were first delineated based upon the following geologic criteria :

i) coarse outwash or beach soils

ii) unconfined water table within 2 meters of the surface.

The state of Rhode Island possesses approximately 5500 hectacres which satisfy these requirements (Rector,1981). Final site selection was determined by requiring that all ISDSs meet modern (post 1969) RI-DEM specifications, and be used seasonally. Suitable sites were found on the barrier spit complex of Charlestown and permission was obtained to investigate 3 suitable homes.

The first stage of instrumentation involved determining the exact location of the septic systems for each of the 3 homes on the barrier. This was accomplished by probing and excavating to expose the various system components. Once the perimeter of the drain field had been staked, samples of the groundwater were obtained at discrete distances around the field and tested for electrical conductivity and relative chloride content to estimate leachate plume migration direction.

A groundwater well instrumentation plan was then devised to intersect the plume and allow for tidal and seasonal flow variations. Wells were constructed of 10 foot lengths of 2 inch PVC pipe, equipped with plastic well points and slotted along the lower half. Seventeen to twenty wells were installed at 1, 3, and 5 meter distances away from the drain field for each home. Bentonite seals were installed around the well to prevent surface waters from channeling down the well casing. In addition an upgradient well was installed to determine background concentrations. To discourage tampering, the wells were secured at ground level with standard PVC female threaded adapters and punctured inverted male caps. The wells were then covered with ventilated well covers to prevent dust contamination.

Experimental sand filters are presently instrumented and in operation at Peckham Farm on the University of Rhode Island campus. Influent and effluent from these systems will be tested for nitrate-N, phosphorus and bacterial pollutant removal and compared to the results obtained from the Charlestown sites.

Sampling was conducted monthly during the period between March 1 and May 15, 1988. Sampling frequency will then be increased to bi-weekly until September 1. Thereafter monthly sampling will occur for the duration of the study.

Sampling procedures will include evacuation of three well volumes of water prior to sample extraction to remove any contamination build up that may have occurred. Samples are then collected into acid washed polyethylene plastic bottles to be analyzed within 12 hours for anionic pollutants (nitrate-N and phosphate) using a Water's Ion Chromatograph. Wells within the leachate plume, wells, along with several background wells, are then be resampled and subjected to microbial analysis. Five hundred milliliter samples are then taken using separate sterilized poly tubing and glass bottles for each well. Samples are stored at 4°C for no more than 6 hours to insure the integrity of the results and prevent any cross contamination. Samples are analyzed within this 6 hour period for fecal coliforms. All laboratory procedures will be completed in accordance with the standard methods outlined in APHA (1985).

Results and Discussion:

This study focuses on seasonally used individual sewage disposal systems, thus the period of continous use extends only from Memorial Day weekend (May 27) to Labor Day weekend (September 5). During the summer of 1987, 280 seasonal residents of Charlestown and South Kingston were contacted by mail to assist in this project. Approximately 10% of those contacted responded to this request and by October 1, three homes had met the above mentioned criteria and had been instrumented. This implementational setback rendered the summer of 1987 useless for the collection of data; consequently, this synopsis and the July 15 report are only interim reports. A final report will be submitted in the fall of 1988 when complete results have been obtained. This project also represents the M.S. thesis research of Frank B. Postma and will be completed in the winter of 1988. Data collection began on March 15, 1988 and will continue according to the above mentioned schedule at no additional cost to the Water Resource Center.

Preliminary results have been obtained for the months of March, April, and May from the Charlestown sites. Several results have also been obtained from the recirculating sand filter and RUCK systems, however, an accidental introduction of a toxic substance into this system has stalled attempts to obtain microbial data. This problem has recently been corrected and sampling of these systems is scheduled to resume by June 6, 1988.

The Charlestown sites (individually identified as: sites M, S, and K) during the months of March, April, and May 1988 demonstrated minute quanties of nitrogen and sporatic presence of phosporus from the monitoring wells and while all upgradient wells remained free of these contaminents. From sites M and K only 17.1% of the wells tested positive for nitrate-N with a mean concentration of 1.89 mg/l and a range of 0.45 - 11.3 mg/l. Site S demonstrated a greater number of wells contaminated with nitrate-N (38.2%). Site S has experienced far greater usage during these months than the other two sites. Phosphorus has been confirmed in only one well at the Charlestown sites. In well 5, site S a phosphorus concentration of 7.5 mg/1 at a distance of 3 meters was detected from the septic field. No fecal coliform movement has yet been measured from any of these Charlestown sites.

Samples from the recirculating sand filter were also tested specifically for phosphorus concentrations. An ortho-phosphorus concentration mean of 1.02 mg/1 and range of 0.16 - 2.68 mg/1 were obtained for the effluent leaving the sand filter. These results should in no way be compared those obtained from the Charlestown sites due to the limited uses of the homes due preliminary sampling periods.

Drawing conclusions from this limited data set is not yet feasible; however, several interesting questions have surfaced from this initial research:

i) what is the loading rate of pollutants to the environment?

ii) what quantity of pollutants is attenuated by the soil and clogging mat?

iii) does a clogging mat develop in seasonally-used homes?

iv) how much attenuation and dilution of various contaminants occurs with distance from drainfield?

v) how does the pollutant removal efficiency of these seasonal systems compare to a continously used recirculating sand filter system?

With the completion of this study, these questions will be futher addressed.

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SYNOPSIS

Project Number: S1

Start: 12/87
End: 05/89

Title: Study of Flyash & Bottom Ash & Their Leachate Characteristics in a Simulated Landfill Condition

Investigators: Poon, Calvin P. C., University of Rhode Island

COWRR: 05A 05B, Congressional District: Second

Descriptors: Acid Rain, Drainage, Heavy Metals, Infiltration, Leaching, Incinerator Ash, Sanitary Landfill

Problem & Researh Objectives:

The state of Rhode Island is going to build three solid waste incinerators in the near future. Incinerator operations in other states show that the ash is a potentially hazardous waste material. In light of the unique design using high-alkaline flu gas scrubber and the new USEPA extraction protocol (TCLP) in defining hazardous waste, it is necessary to study the characteristics of the ash using both the existing EPTC protocol and the proposed TCLP protocol. Special attention will be given to heavy metals cadmium (Cd) and lead (Pb) as they are most commonly found in incinerator ash. With the acid rainfall in the northeast region, it is a major concern if the leachate from a landfill for ash disposal would contain Cd and Pb. Therefore, simulated landfill studies using columns in laboratory will be useful to characterize the leachate quantity as well as quality. The result will be useful for future design of landfill used for ash disposal.

Methodology:

Columns containing a sand layer in the bottom with drains, and ash or ash/municipal solid waste layers, were used to simulate landfills. Artificial acid rains were introduced to the columns based on a typical Rhode Island rainfall condition. Leachate and gas samples were collected for chemical analysis. Interactions of Cd and Pb with other substances in the columns were examined. Mass balance of fluid infiltration, leachate collected, Cd, Pb, and other chemicals that control the fate of Cd and Pb in the columns will be carried out.

Principal Findings and Significance:

Using the existing EPTC extraction procedure, the incinerator ash used in this study shows that it is not a hazardous substance in referance to Cd, however, the ash is a hazardous substance in reference to Cd when the newly proposed TCLP procedure by USEPA is used. Either procedure shows that the ash is a hazardous substance in reference to Pb. Deionized water extraction (pH=4.95) shows that the ash is nonhazardous for both Cd and Pb.

Column study up to the present time shows that the leachate from acid rains contains both 2 to 3 ppm of Pb and 0.3 ppb of Cd. The study will be continued for another 10 months to show the fate of both Pc and Cd in the simulated landfill and acid rain conditions.

Thesis:

A Ph.D. Dissertation is underway.

INFORMATION TRANSFER ACTIVITIES:

The information transfer activities can be divided in two parts: (a) Newsletter, and (b) coordinated efforts in environmental education (Project 22, FY-1987).

(a) Newsletter, published on September 1, and December 1, 1987, and on March 1, and June 1, 1988 by this Center were distributed to the public as well as water agencies and the research community in Rhode Island, and all other 54 water Resources Research Institutes. Items covered in the newsletter included research project accomplishments, on-going research works, the planning activities of this Center, announcements of the activities of part (b), as well as, discussions on water related environmental issues relevant to the State of Rhode Island such as groundwater legislation, real estate transactions, outlook of water pollution and hazardous waste control.

(b) Project 22, coordinated efforts in Environmental Education Water Protection, Management and Conservation, aimed at key groups and disseminated information on planning strategies for effective land use and water protection with official as well as private citizens' participation.

The following activities were carried out in FY-1987:

(a) Questionnaires regarding topics for two conferences (Waste Water Management Districts and Groundwater Issues) were sent to Town Councils, Planning/Zoning Boards, Conservation Commissions, and other planning officials in the 39 Rhode Island municipalities.

(b) Dialogue with various state, local, and private agencies was established to ensure coordination of water quality programs. Meetings were held with Rhode Island Audubon Society, the Department of Environmental Management, Save the Bay, Chariho Water Resources Group, Wood-Pawcatuck Watershed Association, Sierra Club. South County Planners, and the Coastal Resources Management Council.

(c) A series of factsheets was developed for use by municipal planning officials and the general public. Topics reflect specific environmental concerns and solutions incorporating University of Rhode Island and national research.

(d) A conference on Waste Water Management Districts, developed jointly with the Rhode Island Audubon Society and co-sponsored by Rhode Island League of Cities and Towns, EPA Small Flows Clearinghouse, URI Water Resources Center, and URI Cooperative Extensions, was held on April 30, 1988. The purpose of the conference was to offer municipalities information needed to take advantage of the new enabling legislation and to plan for septage disposal. Participants were municipal planning officials, septage haulers, consultants, environmental groups, and public works officials. Participants received a Natural Resources Science Facts notebook with URI factsheets and other relevant materials.

(e) WATERSHED WATCH, the citizen monitoring program in the Pawcatuck Basin, was begun in cooperation with the Wood-Pawcatuck Watershed Association. Volunteers participated in several training sessions and received a Natural Resources Science Facts notebook with monitoring protocol and factsheets on water quality issues. Monitoring will be conducted on 15 lakes during the months of May through October,1988. Collected data will be given to the Department of Environmental Management as a part of their effort to develop a pool of lake quality information.

(f) Technical support was provided to complete the EPA petition for Sole Source Aquifer Designation for the Pawcatuck Basin. A series of slides were developed to explain the impact of the designation to the involved municipalities (14 towns).

(g) A handbook on strategies for groundwater protection for local officials is in the development stage. It is expected to be in its final draft form August, 1988.

(h) A short course on groundwater protection is being planned for the fall of 1988. The objectives of the course are: 1. to educate local officials and interested citizens about basic groundwater hydrology and groundwater protection, and 2. to provide local communities with the tools to develop and implement community-based management program.

There were many benefits to the programs which were developed. Better informed planning officials, as well as the general public, lead to land use decisions which ensure potable water supplies for the state. Working with environmental groups and state agencies allowed the University to give technical assistance and to strengthen existing water quality programs.

The response to the questionnaires indicated that municipal officials are interested in taking advantage of programs offered throughout the University. Programs developed by the University add an important contribution to the various strategies being developed by state agencies and private organizations. Various state task forces have been established to review current state regulations and to establish guidelines for innovative land use policies. Many municipalities are revising their comprehensive land use plans and are seeking technical assistance.

The conference on Waste Water Management Districts was attended by a wide variety of people and provided the forum for initial distribution of

Natural Resource factsheets. The conference provided a forum for federal, state, and local officials to exchange information on implementing Waste Water Management Districts. Several speakers from other states and several speakers from various departments in the University presented the workshop. The conference dealt with such issues as the community benefits of Waste Water Management Districts, the legal and financial aspects of districts, the importance of planning for sewage disposal, considerations in evaluating large and small septic systems, and the financial resources at state, federal and private levels. In view of the growing concern over water quality issues and the increasing rate of development in Rhode Island, the conference provided an important informational base to towns dealing with these critical issues. Additional factsheets and conferences will provide further technical assistance.

The WATERSHED WATCH program has received enthusiastic support from the volunteers and the State. The program will contribute water quality data to the State's limited information base. It will indicate trouble spots so that the appropriate state agency may be alerted. Additionally, it will become a part of the public education program on water quality issues. The program joins the growing number of national grassroots volunteer monitoring programs. It is the second program in Rhode Island, following the successful Salt Pond Waters, whose 30 member volunteer force has been collecting valuable water quality data on the salt ponds for three years.

The Water Resources Center at the University of Rhode Island can serve an important function improving water resource management within the state. The legislative and regulatory mechanisms necessary to protect water resources can be realized more readily if technical information needed for informed decisions is centralized and accessible.

The following is a list of professional publications published during the grant period resulting from institute-supported research.

1. Estimates of Specific Yield With the Geoelectric Resistivity Method in Glacial Aquifers, by R. K. Frohlich and W. E. Kelly. Jour. of Hydrology, 97, 33-44, 1988.

2. Leaching of 2, 4-D and Dicamba from Home Lawns, by A. J. Gold et al., 37, 121-129, 1988.

3. Evapotranspiration of Cool-Season Turfgrasses in the Humid Northeast, L. J. Aronson, A. J. Gold, R. J. Hull et al., Agronomy Jour., 79. No. 5, 1987.

4. Cool-season Turfgrass Responses to Drought Stress, by L. J. Aronson, A. J. Gold, R. J. Hull et al., Crop Science, 27. 1261-1266, 1987.

5. Acid Precipitation and Its Effects on Water Quality of Small River Basins in Rhode Island, by C. P. C. Poon and T. Chaplin, Environmental Systems, 17, No. 2 79-92, 1987-88.

6. Factsheets

   Homeowner's Guide to a Green Lawn and Clean Water
   Site Evaluation for On-Site Sewage Disposal
   Maintaining Your Septic System
   Septic Systems: Pollution Abatement
   Available Resources
   Protecting Water Resources
   Watershed Watch
   Defining Our Watershed

COOPERATIVE ARRANGEMENTS:

The Center has two advisory committees, one that State Advisory Committee and the other the University Water Resources Coordinating Committee, By recommendation from the federal inspection team in FY-1986, both committee memberships have been expanded.

State Advisory Committee

Peter P. Calise, Manager, R. I. Water Resources Board
Rodney Driver, State Legislator
James W. Fester, Assistant Director of Regulation, R. I. Dept. of Environmental Management
Ellen Greiner, R. I. League of Women Voters
Herbert E. Johnston, Subdistrict Chief, U. S. Geological Survey
Vincent Rose, Chairman of Board, Save the Bay
Daniel W. Varin, Chief, Div. of Planning, R. I. Dept. of Administration
In addition, Mr. Alfred L. Hawkes, Director of the Audubon Society of R. I. will be joining the committee starting FY-1988.

University Water Resources Coordinating Committee

Pei Wen Chang, Animal Pathology
Frank DeLuise, Mechanical Engineering
Reinhard K. Frohlich, Geology
Scott W. Nixon, Oceanography and Sea Grant Coordinator
James Opaluch, Resources Economics
Calvin P. C. Poon, Environmental Engineering
Leonard Worthen, Pharmacognosy

As in the past years, both committees have contributed significantly to the development and direction of the FY-1987 program.

Project 02 worked closely with the R. I. Dept. of Health and the GIS system of the R. I. Dept. of Environmental Management at the University of Rhode Island for data processing and mapping.

Project 03 received guidance and information from the R. I. Dept. of Environmental Management, Water Resources Division, in developing the project work. With some explored geological data available, the result of this project could be used to predict the extent of groundwater contamination in fractured rocks in Rhode Island.

Project 05 worked closely with U. S. Dept. of Agriculture, soil Conservation Service, on site selection and project design.

The project on information transfer worked with Rhode Island Town Councils, R. I. Audubon Society, R. I. Dept. of Environmental Management, Save the Bay, Chariho Water Resources Group, Wood-Pawcatuck Watershed Association, Sierra Club, South County Planners, R. I. Coastal Resources Management Council, League of Cities and Towns, USEPA Small Flow Clearinghouse to develop the program comprising the workshop, Watershed Watch, Technical Support for Sole Source Aquifer Designation Application, and Publication of Factsheets.

In addition, the Center participated, with cooperations from the New England Center, New England Water Resources Research Centers, and other interstate and federal agencies, in the development of the program as well as assisted the conference on "A New Age for Decision Making---Using GIS: A call for regional action and cooperation" which took place at the University of New Hampshire on February 1 and 2, 1988. Most of the issues addressed in the conference were water resources related. The Center also participated in the pilot program of National Network for Water Policy Research and Analysis of the USEPA Office of Water by coordinating the effort of matching topics with student candidates from departments of various disciplines at the University of Rhode Island.

TRAINING ACCOMPLISHMENT:

Academic Disciplines		Academic Level			
	Undergraduate	Master's degree	Ph.D degree	Post Ph.D	Total
Engineering					
Agricultural					
Civil			1		1
Environmental					
Industrial					
Ocean					
Biology					
Ecology					
Agronomy					
Chemistry					
Hydrology					
Resources Planning					
Natural Resouce Sci.	1	3			4
Geology		1			1
Plant & Soil Science					
Microbiology	1		1		2
Food Science		1			1
Total	2	5	2		9

RHODE ISLAND
WATER RESOURCES CENTER

UNIVERSITY OF RHODE ISLAND
1892

COMPLETION REPORT FY-1987 PROGRAM

A MICROBIAL METHOD FOR REMOVAL OF METALS, CUTTING OILS AND CYANIDE FROM POLLUTED WATER—PHASE I

by

R.W. Traxler, T.C. Lee, D.R. Nelson

COMPLETION REPORT

Title: A Microbial Method for Removal of Metals, Cutting Oils and Cyanide From Polluted Water - Phase I.

Duration: June 1987 to May 1988

Principal Investigators: Dr. Richard W. Traxler
Dr. Tung-Ching Lee
Dr. David R. Nelson

Date: August 1, 1987

INTRODUCTION

Regulations limiting the discharge of toxic metals and cyanide into public sewers have been in effect for three years but the majority of affected platers and finishers are not in compliance with these regulations. Many of the larger firms meet discharge standards or are expected to do so in the near future.

The magnitude of the problem is seen by the amount of heavy metal entering the Narragansett Bay Commission sewer system in recent years. The peak was in 1981 with 956,099 pounds release with a drop in 1985 to 409,657 pounds. The interim goal is to reduce this volume to about 200,000 pounds within a year. The existing technology for solution of this problem by chemical means is expensive. One of the larger companies was forced to spend $500,000 for a pretreatment system. This type of a solution to the problem is beyond the capability of the smaller operator who does not have the capital resources for even a 5th of this type of investment. The ultimate result is that without a less expensive system these small companies will be forced out of business. This project is aimed at the small operation to provide to these companies a relatively simple, inexpensive but effective means of pollution control. The project while of extreme potential value to Rhode Island can also be applied to the same problem in other states.

A. The FY 1987 Objectives Phase I Metal Removal:

1. Expand resistance spectrum in one isolate, if possible, to include resistance to Cu, Pb, Ag, Cr, Zn, Cd, Ni and Hg.
2. Determine the kinetics of metal removal.
3. Determine the saturation level of cell mass.
4. Determine the effect of nutrients on metal removal.
5. Perform bioreactor studies with simulated and real waste for metal removal.
6. Determine the presence or absence of plasmid DNA which is linked to the objectives of Phase II.

B. Phase I Results and Discussion

Objective 1.

Using a serial enrichment-adaptation procedure we have been able to expand the resistance spectrum of Arthrobacter HC823 to a combined mixture of eight metals, each at a concentration of 50 ppm. The eight metals are: Cu, Pb, Ag, Cr, Zn, Cd, Ni, and Hg. This is a combined total metal ion load of 400 ppm of metal ion in the test system. We are delighted to be able to achieve this resistance pattern in one isolate.

In addition, we have determined the metal resistance of a natural isolate identified as a *Flavobacterium* sp. and a member of the genus *Pseudomonas* labeled strain PxR824, isolated from heavily metal polluted sediment. Tests have not been run to enhance the resistance of these isolates. Those metal listed as R (resistant) were resistant to 50 ppm of the metal while those listed as S (sensitive) would not grow in the presence of 1 ppm of the metal (Table 1.).

On isolation, the *Flavobacterium* sp. required 1 ppm of zinc for growth in solid or liquid medium. After sub-culture the organism no longer shows a Zn requirement for growth.

Table 1. Resistance spectrum of two environmental isolates.

Cation	Flavobacterium sp	Pseudomonas HC824
Pb	R	R
Zn	R	R
Cd	R	R
Cr	R	S
Cu	R	R
Ni	R	R
Ag	R	S
Hg	S	S

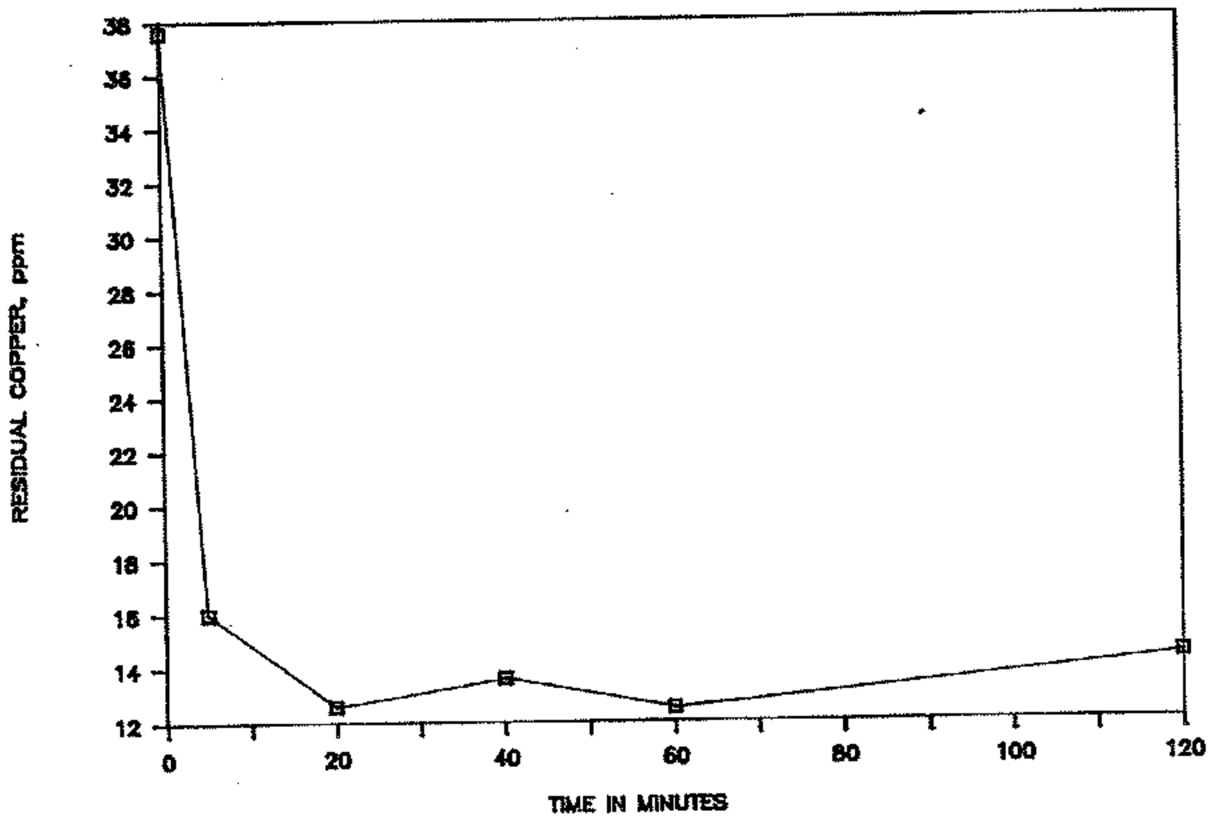
Objective 2.

Kinetic studies were initiated in November using Cu as the first metal in non-nutrient supplemented experiments. The first experiments indicate a much more rapid removal of the metal from a microbial suspension in distilled water than anticipated. We find the same rapid uptake by *Arthrobacter* HC824 with Pb, Zn, Ni, and Cr (Figures 1-5). Uptake of Ni and Cr are initially rapid for the first 5 minutes then the uptake rate is reduced. These differences in kinetics suggest different mechanisms associated with cell binding. Also, it is seen from these data that binding or uptake is highly efficient with Pb and Zn, less so with Cu and Ni, and poor with Cr.

Arthrobacter HC824 was tested in a mixture of Pb, Cu, Zn, and Ni suspended in distilled water plus yeast extract (Figure 6), and the metal content of the aqueous phase determined as an index of metal removal from solution. Lead was rapidly cleared from the aqueous phase. The efficiency of metal removal was less for Cu, Zn and Ni.

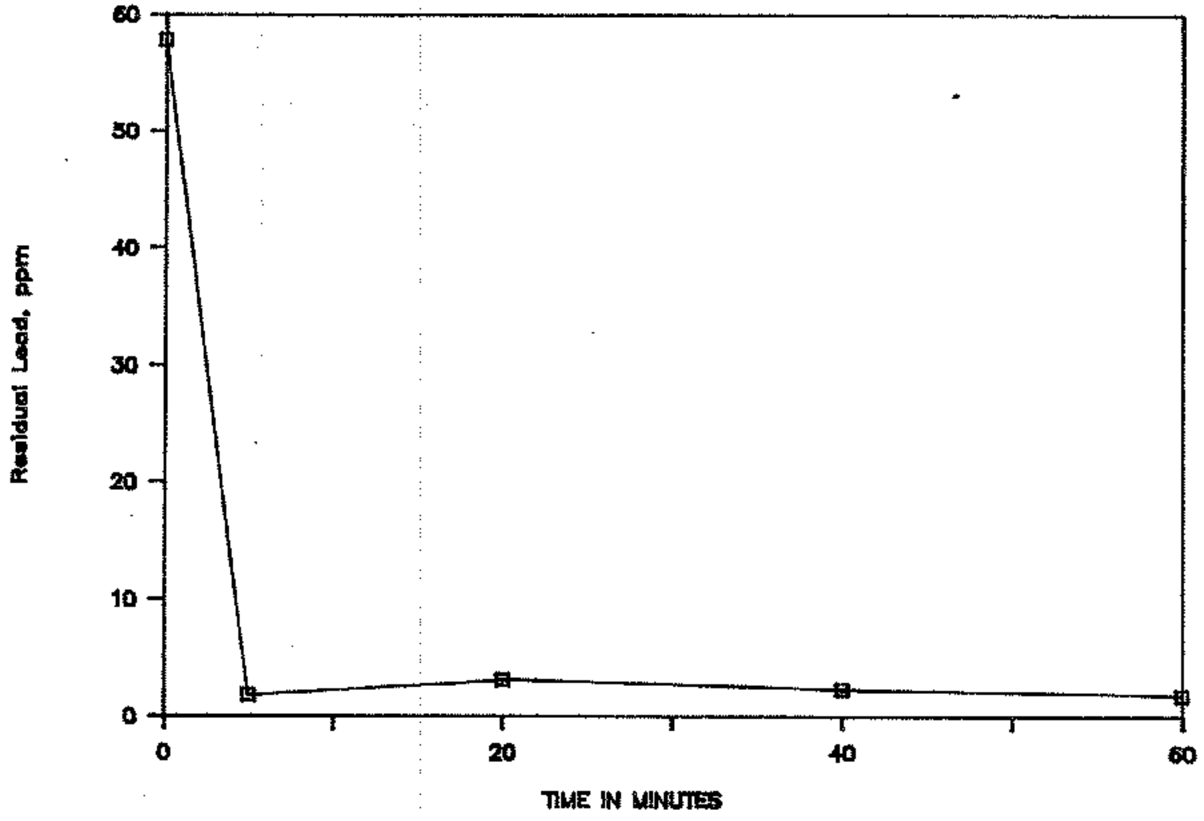
The first experiment with *Pseudomonas* PxR was conducted in a dilute mineral medium with glucose as the carbon source, and amended with Cu at 50 ppm. The cell mass (mg/ml dry weigh basis) was varied from 12-48 mg/ml (Figure 7). In this 3 hour

Figure 1. Kinetics of Cu uptake By Arthrobacter HC824



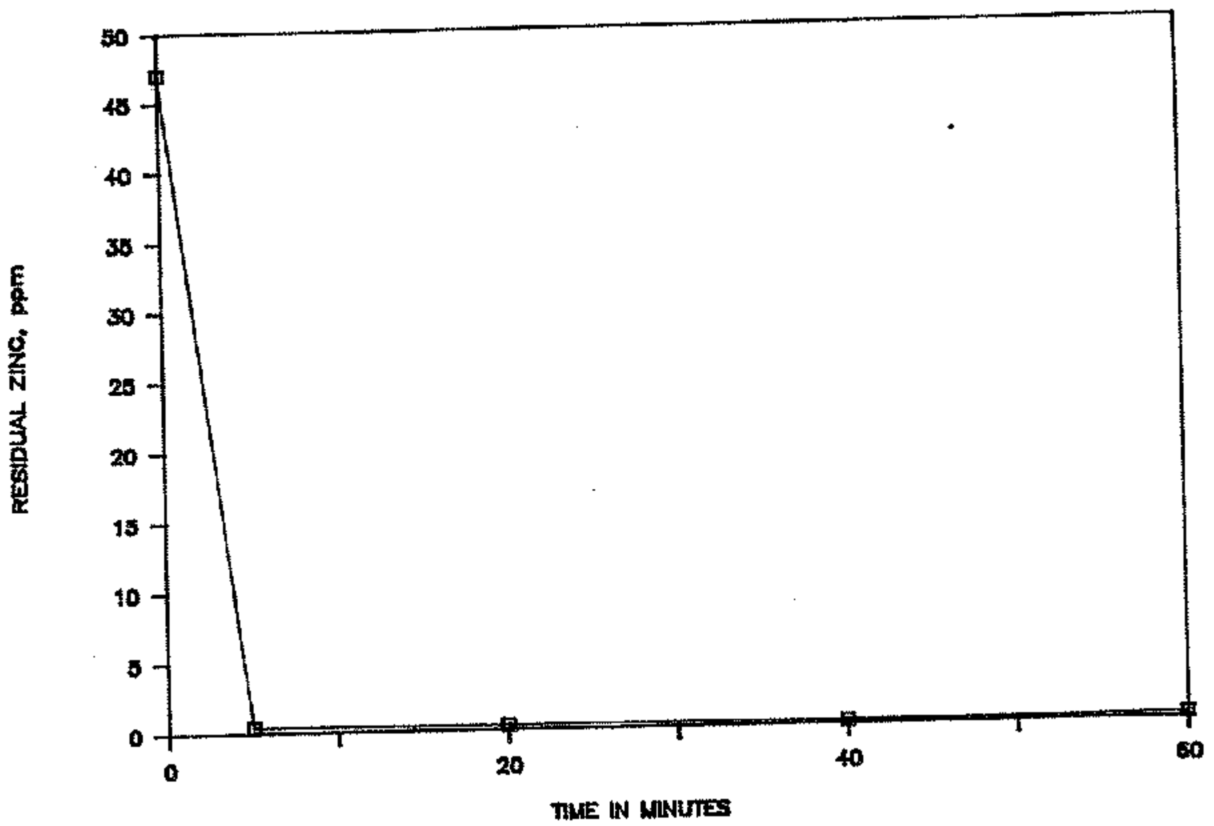
9.2 mg/ml of cells in distilled water + 0.01% yeast extract

Figure 2. Kinetics of Pb uptake by Arthrobacter HC824



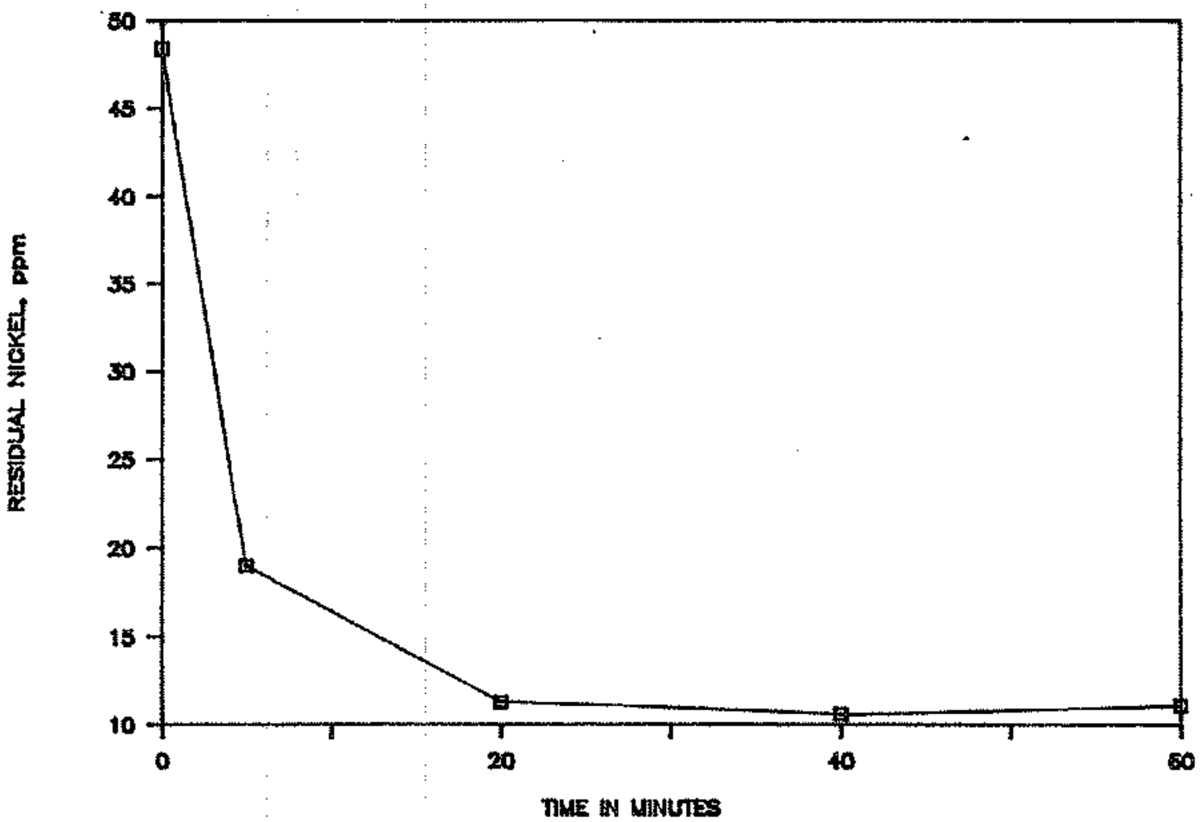
7.5 mg/ml of cells in distilled water + 0.01% yeast extract

Figure 3. Kinetics of Zn uptake by Arthrobacter HC824



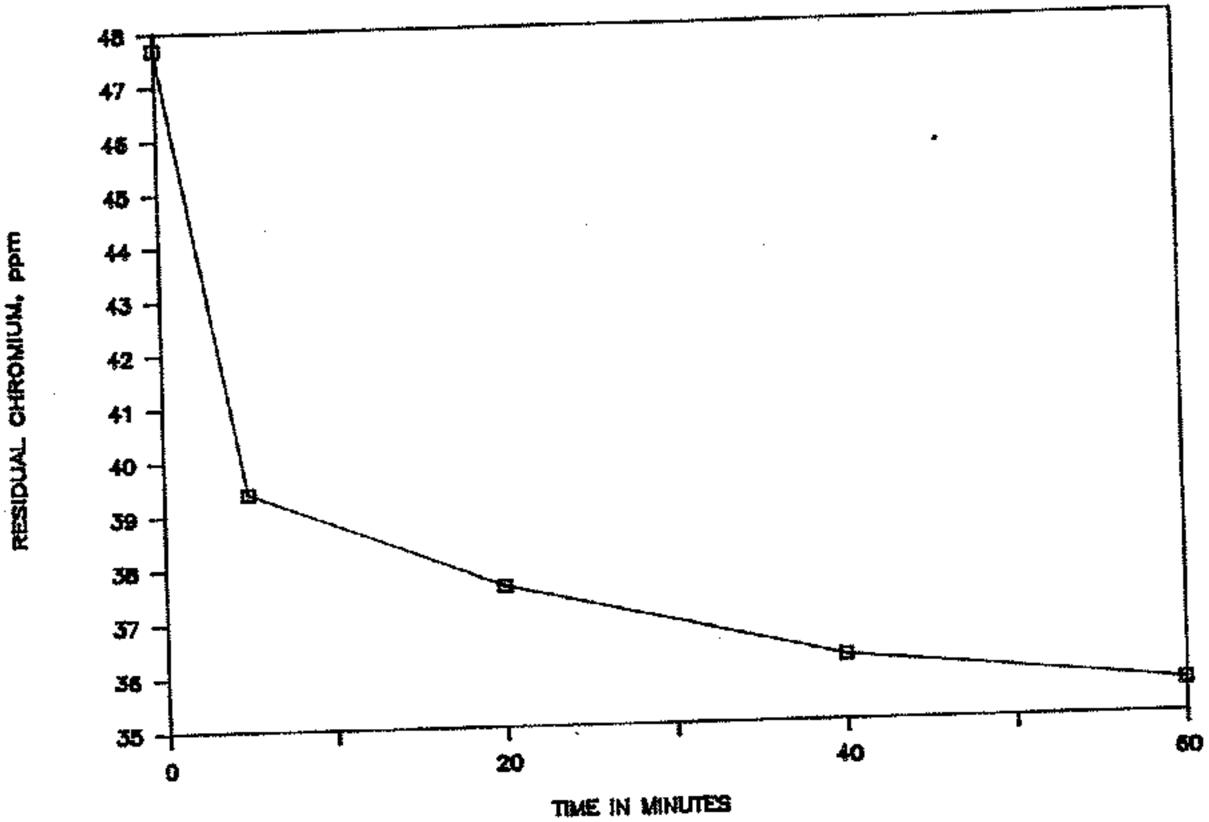
6 mg/ml of cells in distilled water +0.01% yeast extract

Figure 4. Kinetics of Ni uptake by Arthrobacter HC824



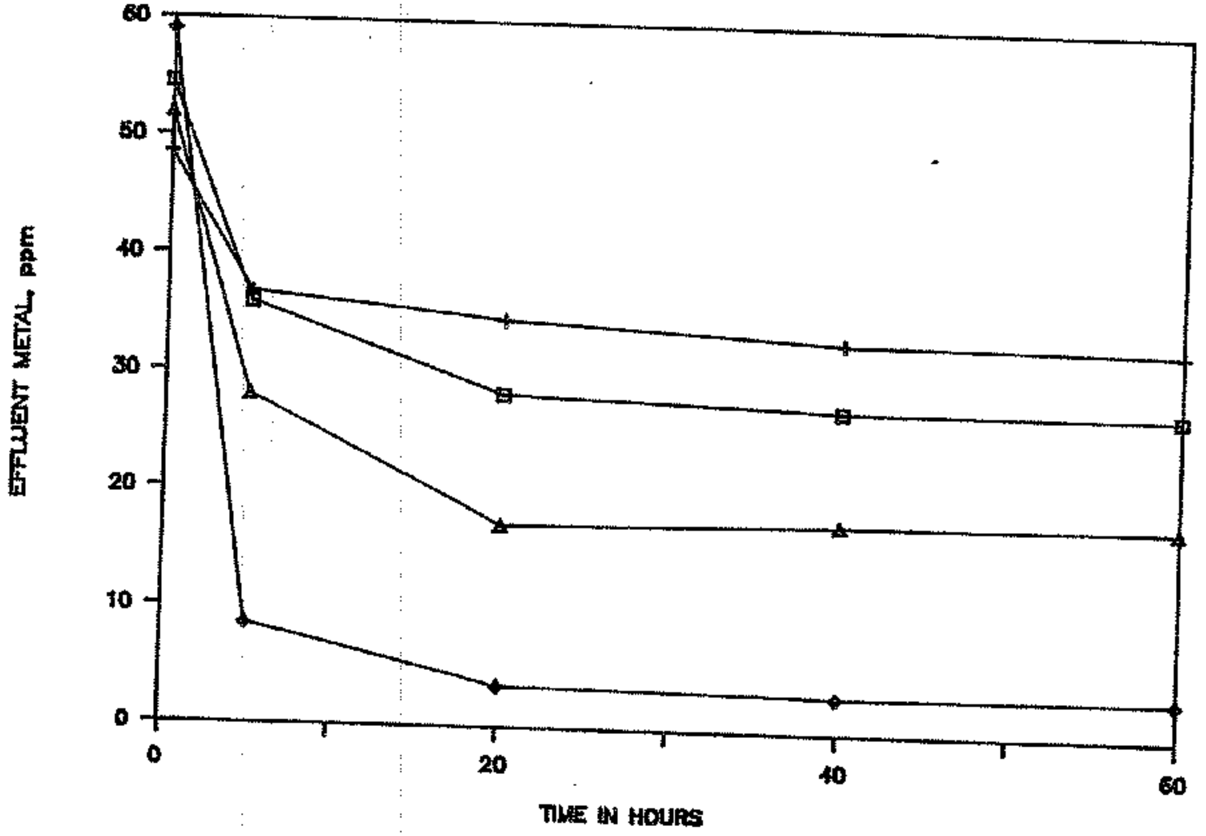
6.5 mg/ml of cells in distilled water + 0.01% yeast extract

Figure 5. Kinetics of Cr upatke by Arthrobacter HC824



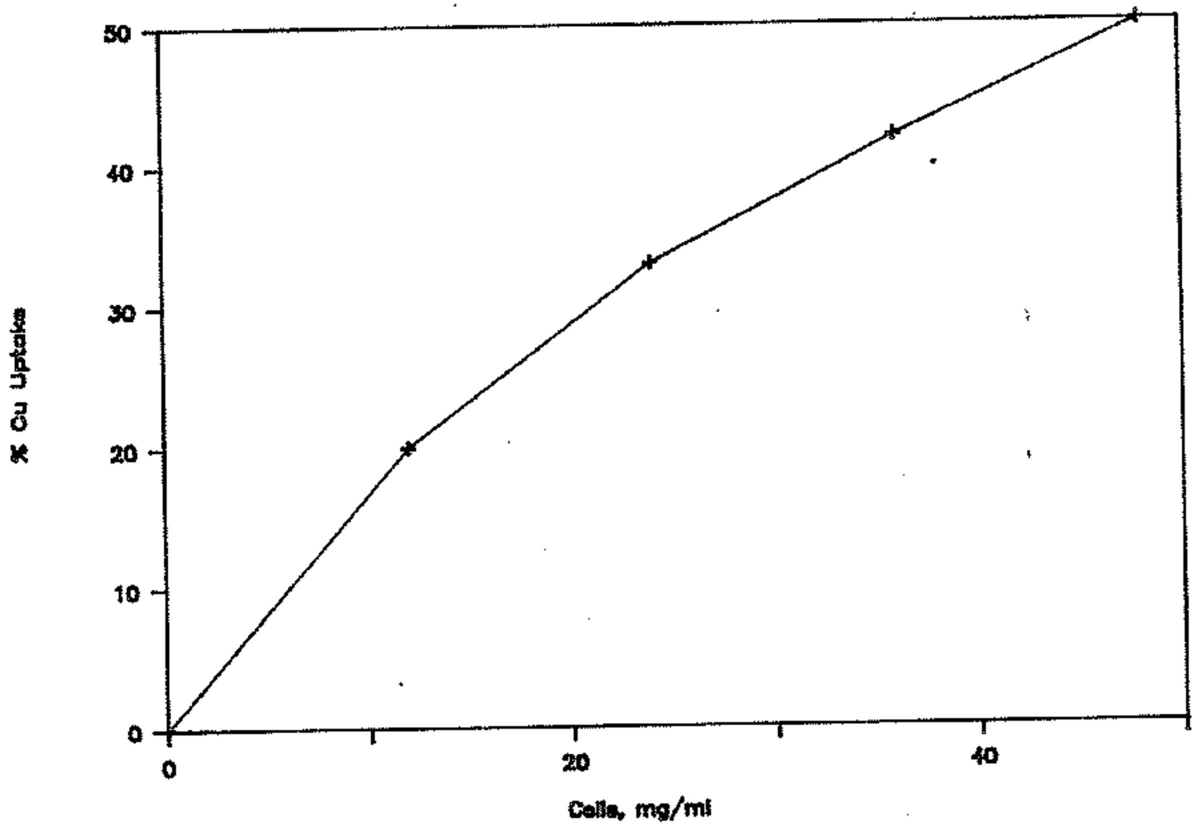
6.5 mg/ml of cells in distilled water + yeast extract

Figure 6. Kinetics of uptake of a metal mixture by Arthrobacter HC824 in distilled water plus yeast extract



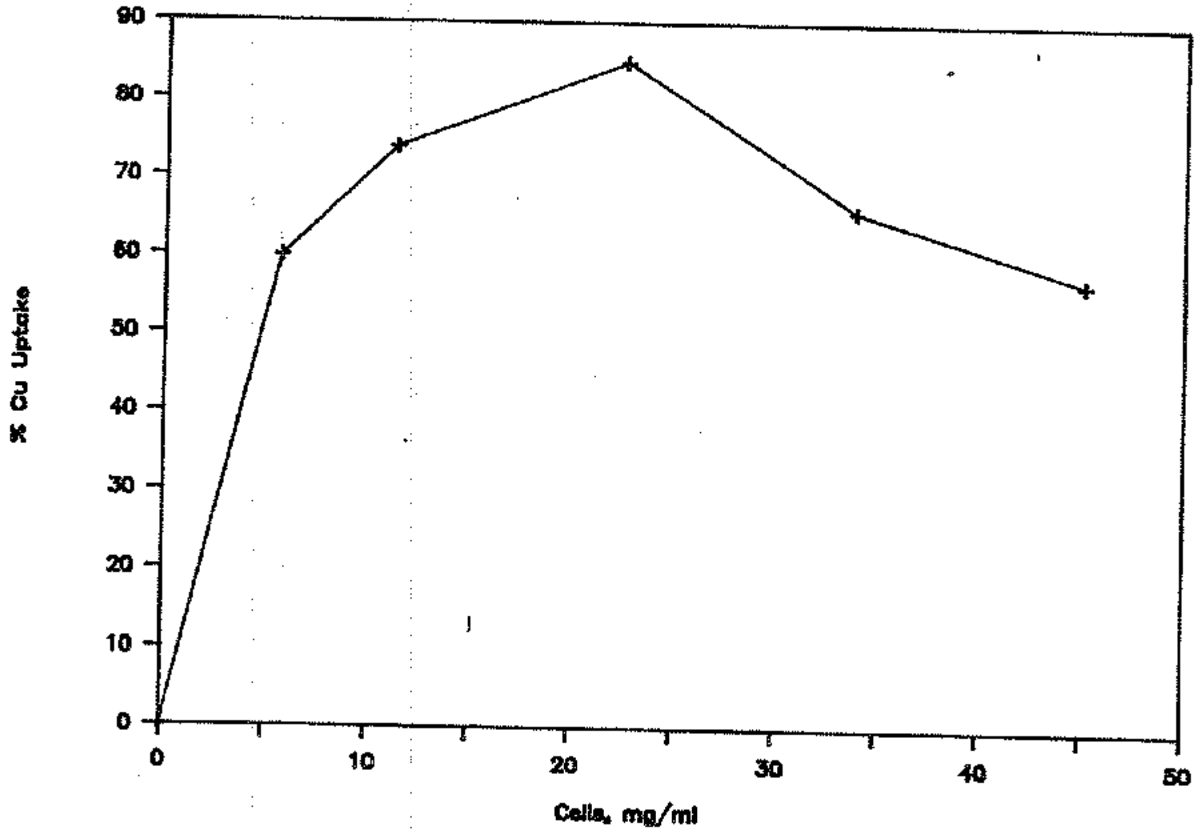
15.2 mg/ml cells; ◆Pb, ▲Cu, □Zn, +Ni

Figure 7. Percentage Cu uptake by Pseudomonas PxR in dilute mineral medium with glucose as the energy source



14.8 mg/ml of cells

Figure 8. Percentage of Cu uptake by Pseudomonas PxR in distilled water plus yeast extract



14.8 mg/ml of cells

experiment maximum uptake (50 %) was obtained with the highest cell mass, and there was a different relationship between cell mass and percentage metal uptake. A similar experiment experiment performed in distilled water (Figure 8), does not show an increased metal uptake at cell masses above 22.6 mg/ml, which was optimal for Cu removal (85%). These experiments confirm earlier observations that metal removal from aqueous solution are inhibited to some extent in more complex media and media with even modest quantities of other inorganic salts.

Solanellas and Bordons (1988) used Pipes Buffer (piperazine-N,N'-bis (2-ethanesulphonic acid) in their copper uptake studies because of it negligible metal-chelate properties. We compared Cu uptake by Pseudomonas Pxr in Pipes and our distilled water-yeast extract system with 21 mg/ml of cell suspension. In the 3 hour experiment 83% of the Cu was cell bound in water versus 90% in Pipes. A test with Flavobacterium sp. at 14.8 mg/ml in Pipes, removed 71% of the added Cd.

Objective 3.

Early studies indicated that saturation of the cell mass with metal occurred at a metal:cell dry weight in the range of 1:1.4 to 1:2.8 mg metal:mg cell dry weight. From this data we had a guide to the amount of cell mass needed to clear a waste water. It is now apparent that the value for cell saturation varied depending upon the organism used in the experiments.

Objective 4.

We know that glucose used as a energy source (1%) enhances metal removal from a water solution but is not as effective as small quantities of yeast extract (0.01%). Using a mixture of glucose and yeast extract offers no advantage over yeast extract alone. A recent study by Brynhildsen, et. al. (1988) demonstrated that glucose concentration had a significant effect on the sensitivity-resistance of a Klebsiella sp. to Cd, Cu, Hg, and Zn.

Table 2. Effect of Nutrient Supplements on Clearing of Cu, Cr, Ag and Pb From Water

	Glucose 1%		Yeast Ex .01%		Yeast Ex .1%		PO4 0.1M	
Metal	1	2	1	2	1	6	1	2
Cu	4.09	.41	4.43	.26	4.58	.27	.18	4.36
Cr	4.67	.17	4.67	.21	4.58	.27	4.75	.03
Ag	2.4	.07	2.7	.1	3.3	.05	.4*	.1
Pb	4.3	1.5	2.0	3.2	1.3*	3.4	.4"	3.2

M:C	1:2.6	1:1.5	1:1.4	1:0.7

1= Water phase
2= Cells
* ppt before cells added
" ppt at end 4 hrs incubation

Phosphate would appear to enhance Cu and Pb cell association but lowers the association of Cr and cells. Phosphate also has a chemical reaction with Ag (apparently the formation of silver orthophosphate which is insoluble) which removes the silver from solution.

Yeast extract is a complex mixture of compounds which are to a large extent amino acids, peptides and vitamins. It is a very promising supplement for this project in that low concentration is required for enhanced activity and it is a relatively cheap product.

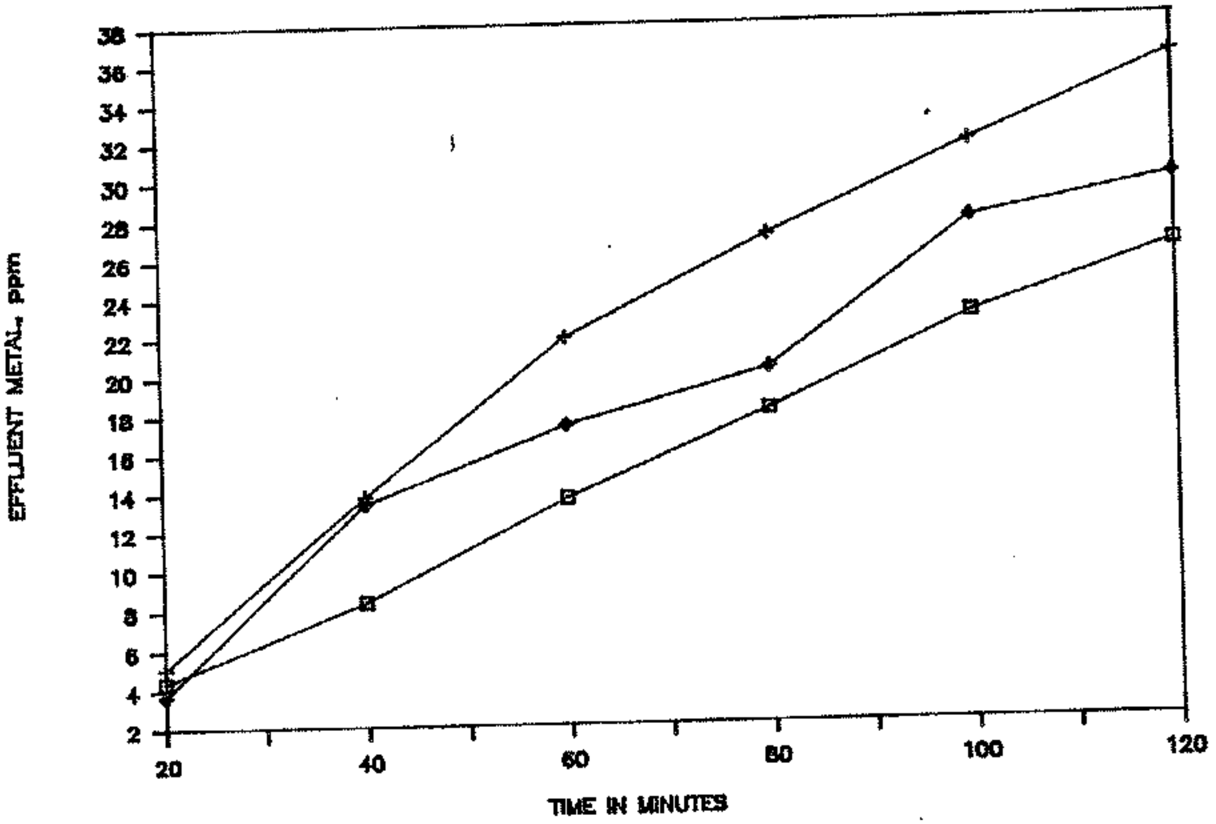
Objective 5.

Due to serious problems associated with the relocation of our research laboratory this phase of the project has been delayed since mid-January. One bioreactor test was run in early January with Arthrobacter HC824 at 10 mg/ml final cell dry weigh. The cells suspended in 300 ml of distilled water yeast extract were mixed with 400 ml of water containing 50 ppm each of Cu, Ni and Zn. This mixture was mixed for 20 minutes, then a feed of the same metal solution was fed to the bioreactor at 6 ml/minute. At the time the feed was started, the bioreactor was pumped at high speed across a membrane in tangential flow filter. The cell slurry retentate was returned to the bioreactor and the permeate (aqueous phase) went to discharge at a rate of 6 ml/minute. Thus, the bioreactor maintained a constant volume and constant cell mass. The results (Figure 9) showed a steady build-up in the metal content of the permeate over the 100 minutes of system operation. However, metal was still being removed from the aqueous phase as the permeate level never reached input metal concentrations of 50 ppm.

The experiment was repeated using four metals, Cu, Cr, Ni, Zn, and Ag, with a lower feed rate of the waste metal solution (3 ml/minute) and a cell mass of 8 mg/ml. The results in (Figure 10) demonstrated a good removal of Ag from the aqueous phase and poor but fairly constant removal of the other metals.

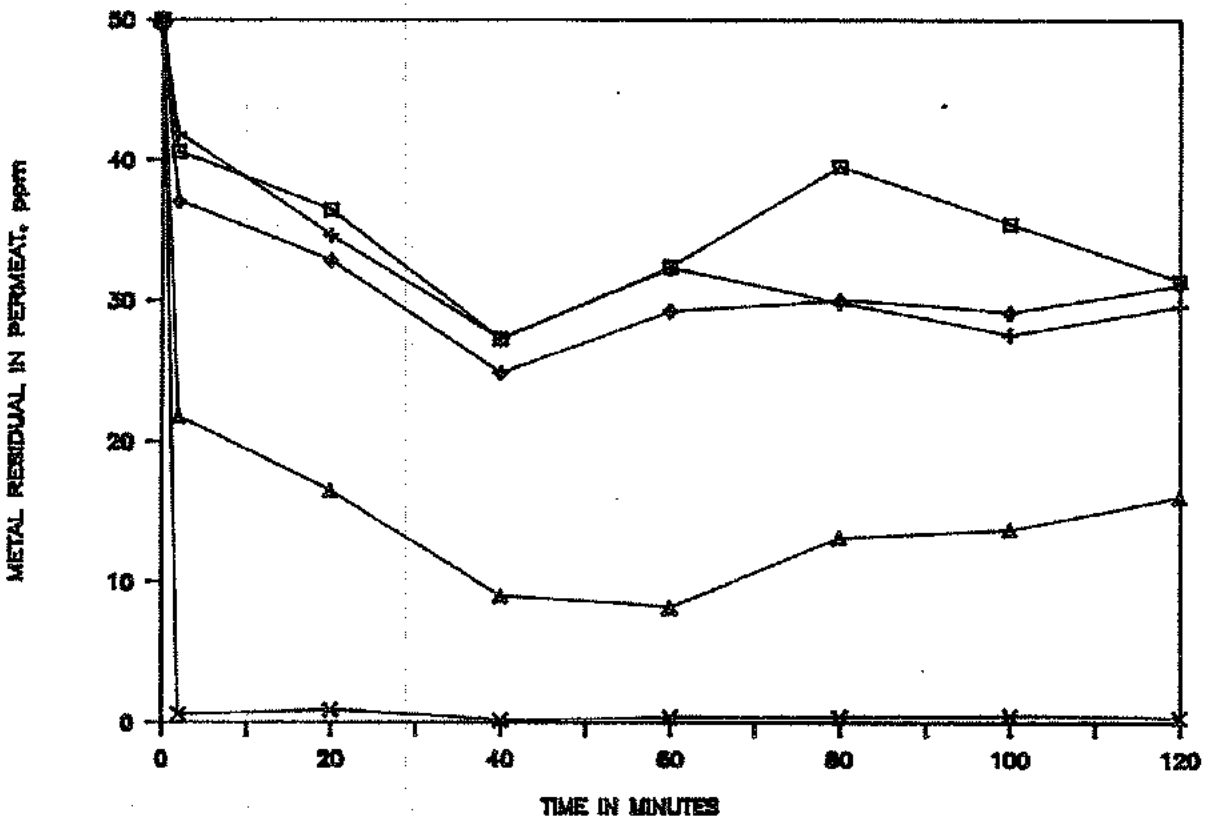
The data from other studies suggests that a much greater cell mass must be used in the bioreactors. Our objective in Phase II of this project will be the use of cell dry weights in the range of 20-30 mg/ml.

Figure 9. Bioreactor fed mixed metals Cu, Ni, and Zn



10 mg/ml Cell mass, feed rate 6 ml/min, feed atart 20 min.
□ Cu, ◈ Zn, + Ni

Figure 10. Bioreactor fed mixed metals, Cu, Cr, Ni, Zn, and Ag



8 mg/ml cells, 600 ml volume, fed at 3 ml/minute

Objective 6.

A variety of different digestion methods have been tried for the isolation of plasmid DNA from Arthrobacter HC824. All of these attempts have isolated only chromosomal DNA. In a recent test using a modification of the alkaline digestion method, there is evidence for a very high molecular weight plasmid near the chromosomal DNA region of the gel. Further tests during Phase II of this project will be done to confirm this observation.

At least one plasmid has been detected in the Pseudomonas PxR strain by the alkaline lysis method. The molecular weight of the plasmid is approximately 11 kb. It was cut by EcoRI into two fragments, 9kb and 2 kb, which demonstrated that the plasmid has a single EcoRI restriction site. In addition, the PxR gels show a high molecular weight band, which may indicate the presence of a large molecular weight plasmid. The alkaline lysis method has been used for a plasmid screen of clinical isolates of Pseudomonas aeruginosa and of Ps. fluorescens. These screens have not detected plasmids in these strains. Work will continue during Phase II of this project to isolate and restrict this potential plasmid from Ps. PxR.

In order to confirm the function of the plasmid(s) in the Ps. PxR strain, it is necessary to transform it into a suitable recipient strain and test for the retained function and plasmid presence in the recipient strain. Since antibiotic resistance is normally coded on the same plasmid as metal resistance, we have two markers to use in the transformation studies. We have screened metal and antibiotic resistance in three potential recipient organisms, Ps. aeruginosa, Ps. fluorescens and E. coli HB101. The results of the metal and antibiotic resistance screens are shown in Tables 3 and4. The two Pseudomonads are not good candidates as recipients as the patterns are similar to Ps. PxR. E. coli HB101 may be a good transformation recipient due to the Cd, Cr, Hg, ampicillin and chloramphenicol sensitive markers not present in the PxR strain.

Table 3. Metal resistance of strains

Agents and Concentration	E. coli HB101	Ps. PxR	Ps. fluorescens	Ps. aeruginosa
Control	R	R	R	R
Pb, 0.5 mM	R	R	R	R
Zn, 2 mM	R	R	R	R
Cd, 0.5 mM	S	R	S	R
Cr, 2 mM	S	S-R	S	S
Ni, 2 mM	R	R	R	R
Cu, 2 mM	R	R	R	R
Hg, 0.5 mM	S	R	S	S
Ag, 0.5 mM	S	S	S	S

Table 4. Antibiotic sensitivity pattern of strains

Agent	E. coli HB 101	Ps. PxR	Ps. fluorescens	Ps. aeruginosa
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Additional Observations

While not included as an initial objective of this project, it has become apparent that the metal binding organisms may produce and secrete into the metal compounds which function as metal chelate agents. *Ps.* HC824 was grown in Trypticase Soy Broth in the presence of 5 ppm of Cd, the cells removed and the supernatant collected for analyses. The protein content of the supernatant was estimated by the Warburg-Christen method by measuring the Absorbance at 260 and 280 nM and using their table to estimate protein. The supernatant was divided into aliquots to which were added varying (0-50 ppm) of the metals under study in this project. A UV-Vis scan of the native supernatant with and without added metals was performed. Comparison of the scans indicates the possible chelation of Cd, Cu, Pb, Cr, and Zn by extracellular products of the organism, but not the chelation of Ag, Ni or Hg. The spectral shifts in the presence of metal are metal specific and represent the formation of new peaks, magnification of peak shoulders, and changes in Absorbance maxima.
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LITERATURE CITED

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D. Conclusions

The studies with PS. HC824 demonstrate that it is possible to enhance the metal resistance pattern of an environmental isolate with limited resistance to a series of heavy metals, to an organism with high resistance to the metals. It is found that environmental isolates obtained by enrichment isolation from heavily polluted sediments readily yield bacteria which carry multiple metal resistance to the metal pollutants of the area.

We are surprised at the rapid metal uptake by metal resistant bacteria. The kinetics of uptake vary with different isolates and with different metals, but the bulk of the metal which becomes cell associated occurs within a few minutes after addition of the organism. Of the metals studied Pb, Cu, Zn and Ni are the easily removed, whereas Cr is the most difficult.

Initially it was thought that the metal-cell saturation levels were constant. However, it is now apparent that this is a somewhat more variable and complex relationship. It is apparent that actively growing cells will accumulate or bind metal, but that resting cells with a minimum of nutrient supplement give superior results in metal removal. The non-chelating buffer, Pipes, seems to be a an ideal system with Pseudomonads for the removal of metal.

The bioreactor visualized for this system shows promise but will require additional study, particularly using reactor cell mass in the range of 20 mg/ml or greater. The results with clearing of Ag from solution are very good even in the preliminary experiments.

It is becoming apparent that the strains we are using for this study probably carry plasmids which carry the genetic information for specific metal resistances. This may allow us to optimize the system by carrying genetic information from more than one strain into a common organism to clear the various metals from solution

RHODE ISLAND
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COMPLETION REPORT FY-1987 PROGRAM

A MICROBIAL METHOD FOR REMOVAL OF METALS, CUTTING OILS AND CYANIDE FROM POLLUTED WATER—PHASE I

by

R.W. Traxler, T.C. Lee, D.R. Nelson

COMPLETION REPORT

Title: A Microbial Method for Removal of Metals, Cutting Oils and Cyanide From Polluted Water - Phase I.

Duration: June 1987 to May 1988

Principal Investigators: Dr. Richard W. Traxler
Dr. Tung-Ching Lee
Dr. David R. Nelson

Date: August 1, 1987

INTRODUCTION

Regulations limiting the discharge of toxic metals and cyanide into public sewers have been in effect for three years but the majority of affected platers and finishers are not in compliance with these regulations. Many of the larger firms meet discharge standards or are expected to do so in the near future.

The magnitude of the problem is seen by the amount of heavy metal entering the Narragansett Bay Commission sewer system in recent years. The peak was in 1981 with 956,099 pounds release with a drop in 1985 to 409,657 pounds. The interim goal is to reduce this volume to about 200,000 pounds within a year. The existing technology for solution of this problem by chemical means is expensive. One of the larger companies was forced to spend $500,000 for a pretreatment system. This type of a solution to the problem is beyond the capability of the smaller operator who does not have the capital resources for even a 5th of this type of investment. The ultimate result is that without a less expensive system these small companies will be forced out of business. This project is aimed at the small operation to provide to these companies a relatively simple, inexpensive but effective means of pollution control. The project while of extreme potential value to Rhode Island can also be applied to the same problem in other states.

A. The FY 1987 Objectives Phase I Metal Removal:

1. Expand resistance spectrum in one isolate, if possible, to include resistance to Cu, Pb, Ag, Cr, Zn, Cd, Ni and Hg.
2. Determine the kinetics of metal removal.
3. Determine the saturation level of cell mass.
4. Determine the effect of nutrients on metal removal.
5. Perform bioreactor studies with simulated and real waste for metal removal.
6. Determine the presence or absence of plasmid DNA which is linked to the objectives of Phase II.

B. Phase I Results and Discussion

Objective 1.

Using a serial enrichment-adaptation procedure we have been able to expand the resistance spectrum of Arthrobacter HC823 to a combined mixture of eight metals, each at a concentration of 50 ppm. The eight metals are: Cu, Pb, Ag, Cr, Zn, Cd, Ni, and Hg. This is a combined total metal ion load of 400 ppm of metal ion in the test system. We are delighted to be able to achieve this resistance pattern in one isolate.

In addition, we have determined the metal resistance of a natural isolate identified as a <u>Flavobacterium</u> sp. and a member of the genus <u>Pseudomonas</u> labeled strain PxR824, isolated from heavily metal polluted sediment. Tests have not been run to enhance the resistance of these isolates. Those metal listed as R (resistant) were resistant to 50 ppm of the metal while those listed as S (sensitive) would not grow in the presence of 1 ppm of the metal (Table 1.).

On isolation, the <u>Flavobacterium</u> sp. required 1 ppm of zinc for growth in solid or liquid medium. After sub-culture the organism no longer shows a Zn requirement for growth.

Table 1. Resistance spectrum of two environmental isolates.

Cation	Flavobacterium sp	Pseudomonas HC824
Pb	R	R
Zn	R	R
Cd	R	R
Cr	R	S
Cu	R	R
Ni	R	R
Ag	R	S
Hg	S	S

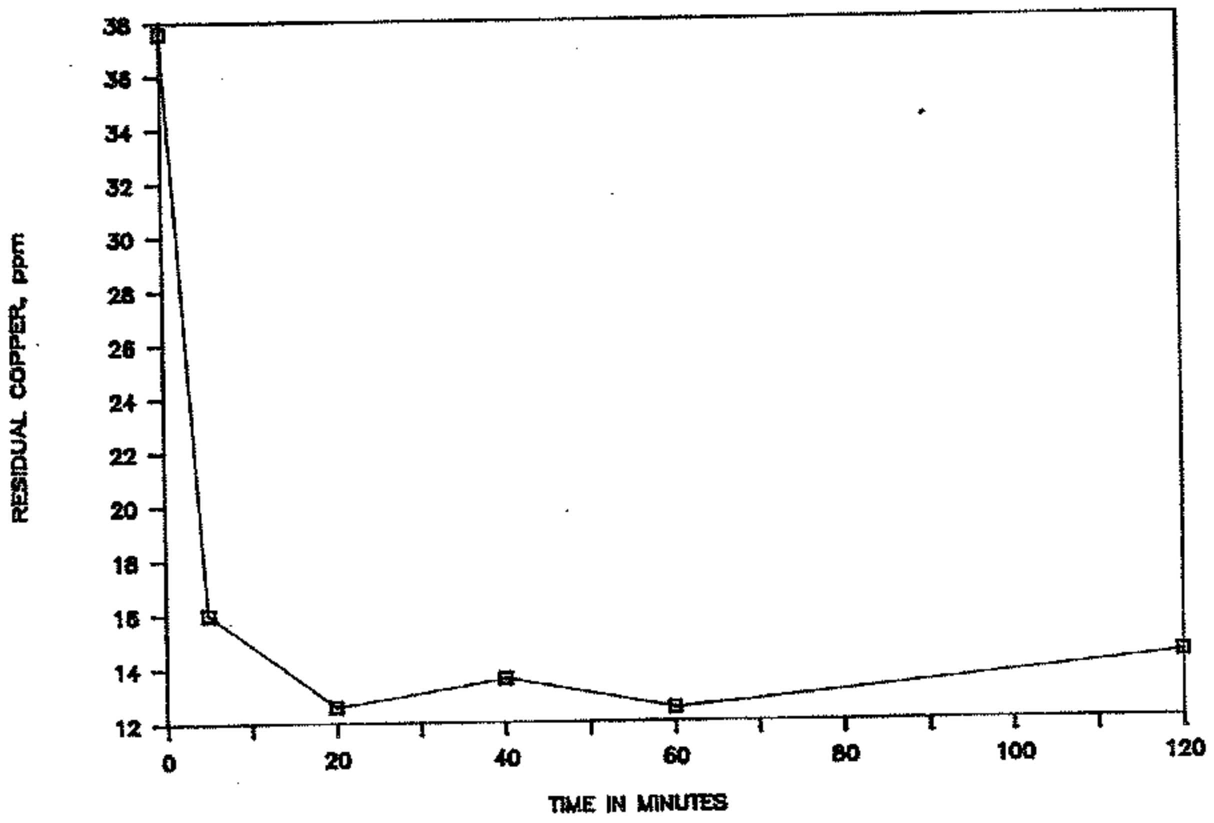
<u>Objective 2.</u>

Kinetic studies were initiated in November using Cu as the first metal in non-nutrient supplemented experiments. The first experiments indicate a much more rapid removal of the metal from a microbial suspension in distilled water than anticipated. We find the same rapid uptake by <u>Arthrobacter</u> HC824 with Pb, Zn, Ni, and Cr (Figures 1-5). Uptake of Ni and Cr are initially rapid for the first 5 minutes then the uptake rate is reduced. These differences in kinetics suggest different mechanisms associated with cell binding. Also, it is seen from these data that binding or uptake is highly efficient with Pb and Zn, less so with Cu and Ni, and poor with Cr.

<u>Arthrobacter</u> HC824 was tested in a mixture of Pb, Cu, Zn, and Ni suspended in distilled water plus yeast extract (Figure 6), and the metal content of the aqueous phase determined as an index of metal removal from solution. Lead was rapidly cleared from the aqueous phase. The efficiency of metal removal was less for Cu, Zn and Ni.

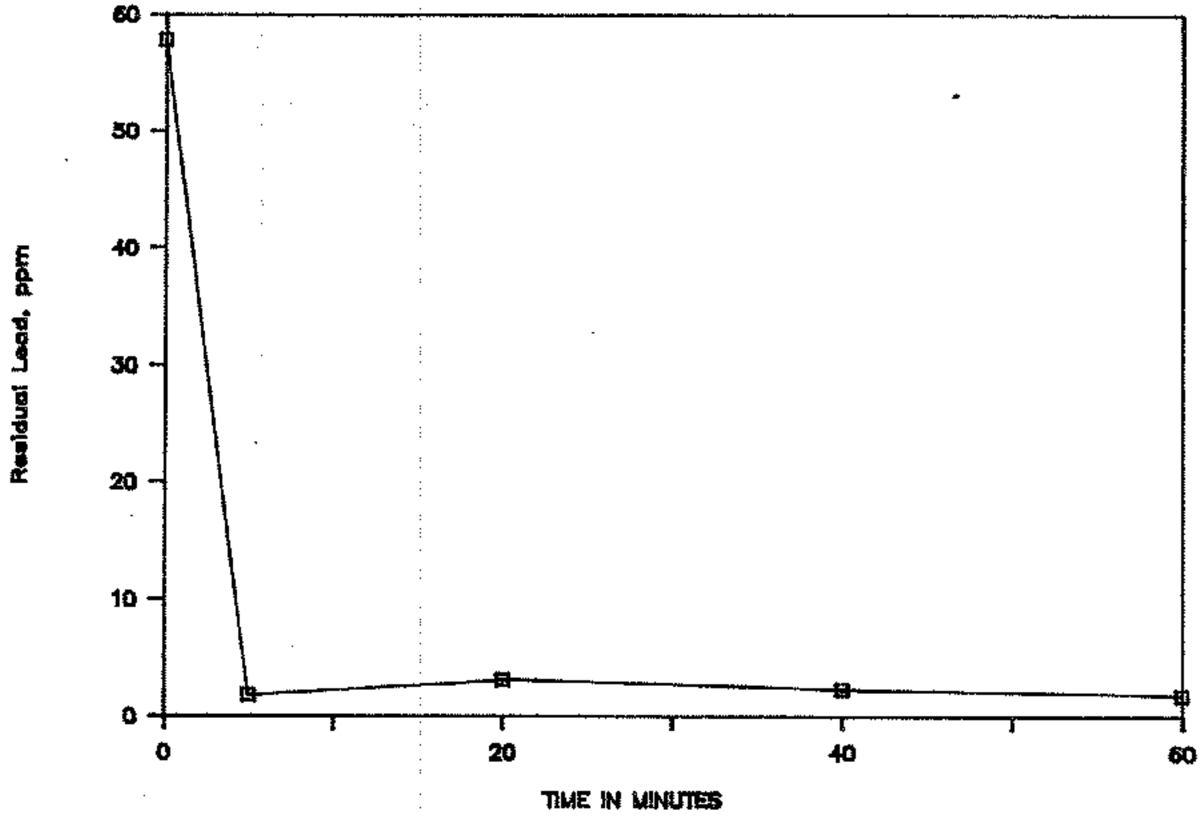
The first experiment with <u>Pseudomonas</u> PxR was conducted in a dilute mineral medium with glucose as the carbon source, and amended with Cu at 50 ppm. The cell mass (mg/ml dry weigh basis) was varied from 12-48 mg/ml (Figure 7). In this 3 hour

Figure 1. Kinetics of Cu uptake By Arthrobacter HC824



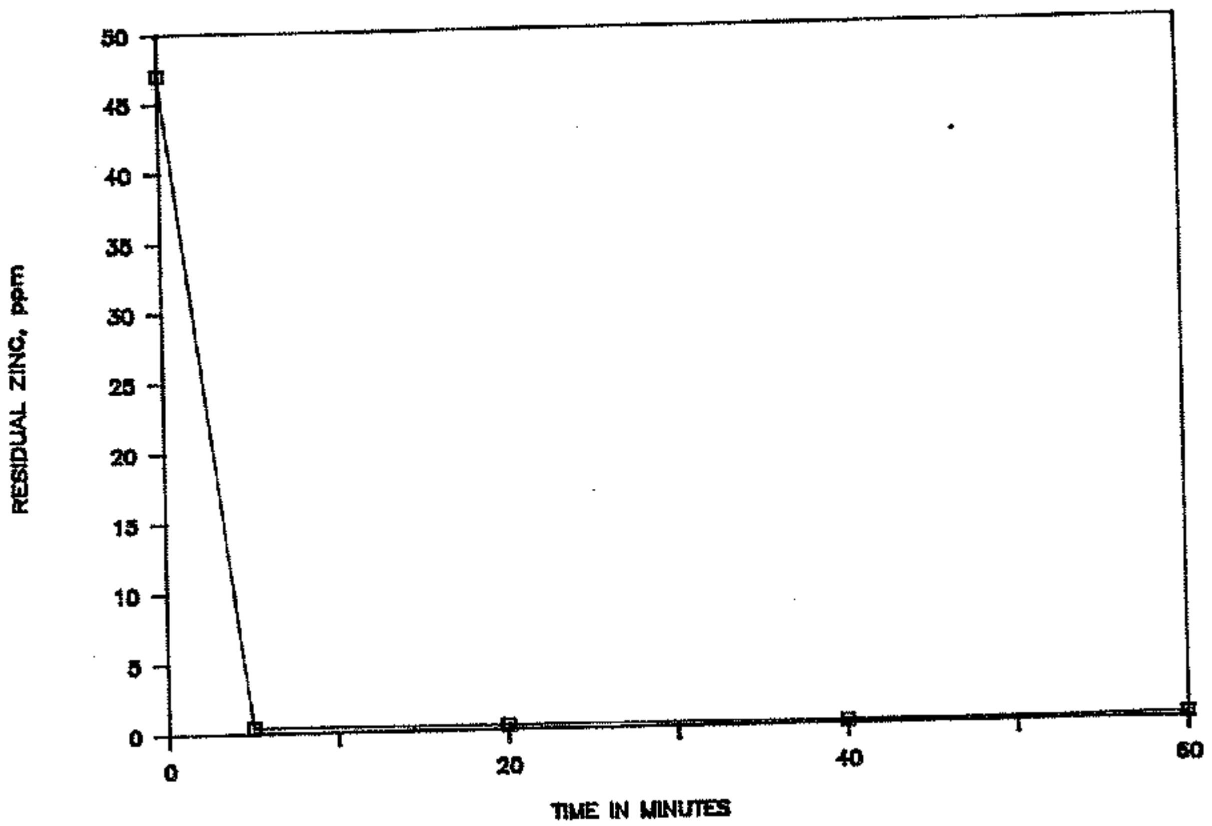
9.2 mg/ml of cells in distilled water + 0.01% yeast extract

Figure 2. Kinetics of Pb uptake by Arthrobacter HC824



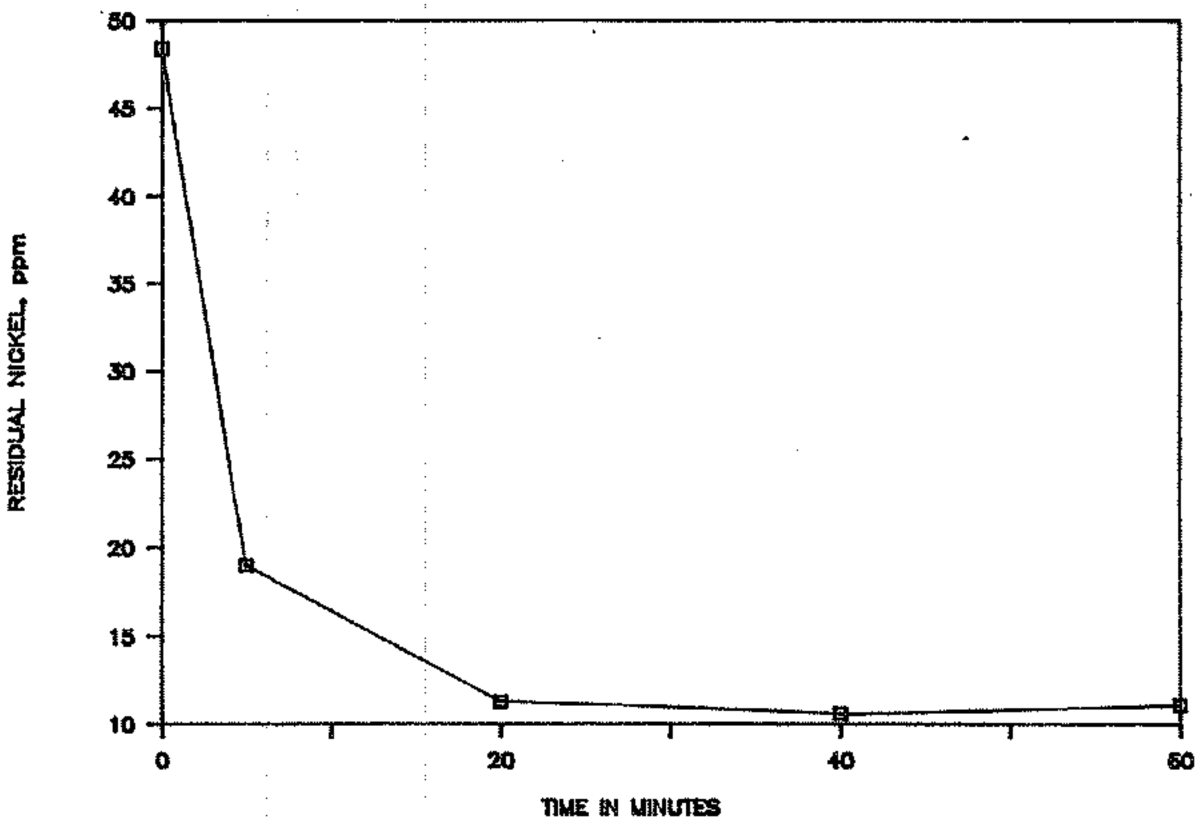
7.5 mg/ml of cells in distilled water + 0.01% yeast extract

Figure 3. Kinetics of Zn uptake by Arthrobacter HC824



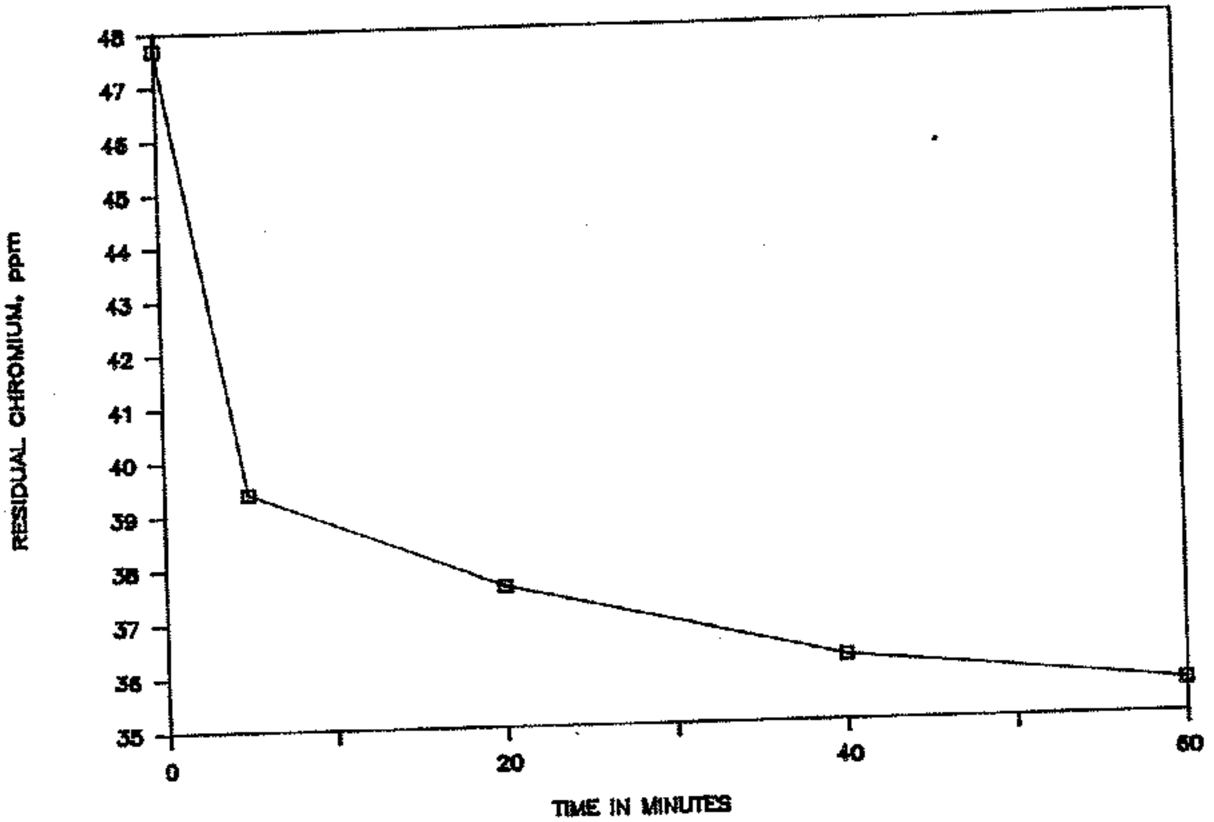
6 mg/ml of cells in distilled water +0.01% yeast extract

Figure 4. Kinetics of Ni uptake by Arthrobacter HC824



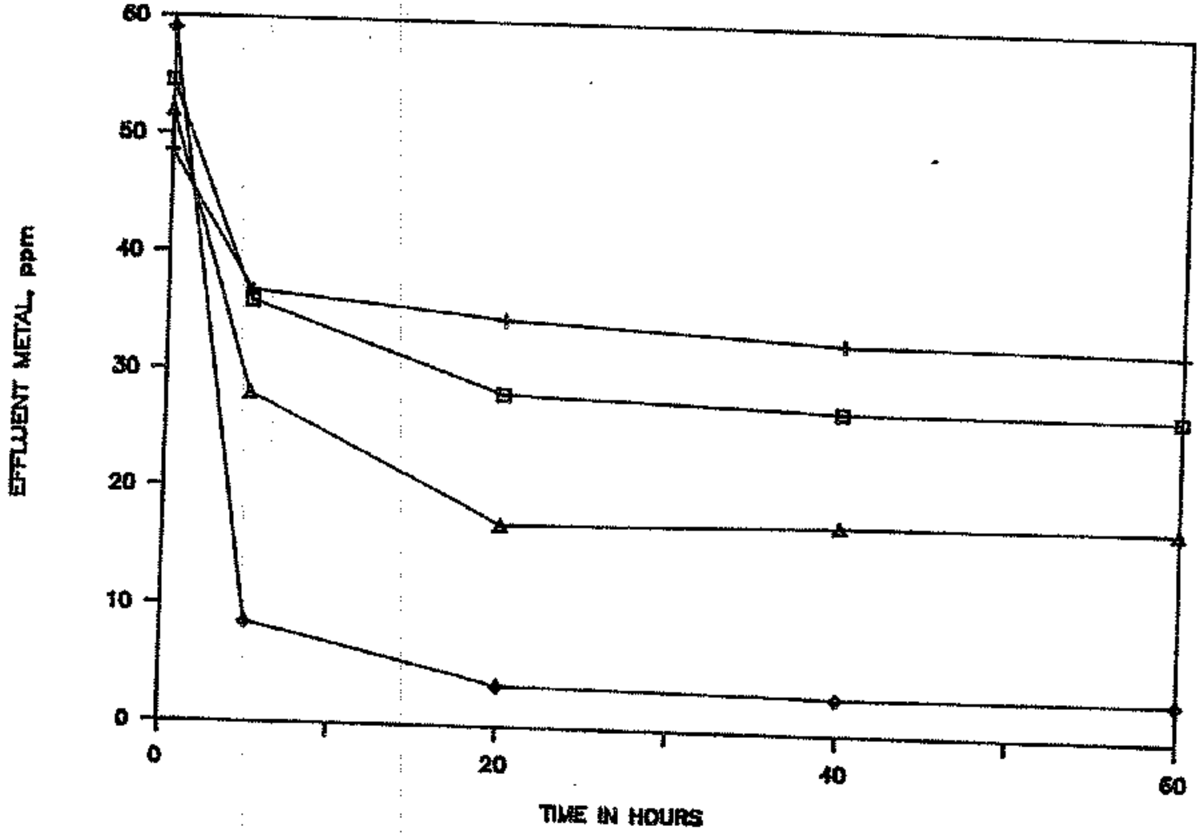
6.5 mg/ml of cells in distilled water + 0.01% yeast extract

Figure 5. Kinetics of Cr upatke by Arthrobacter HC824



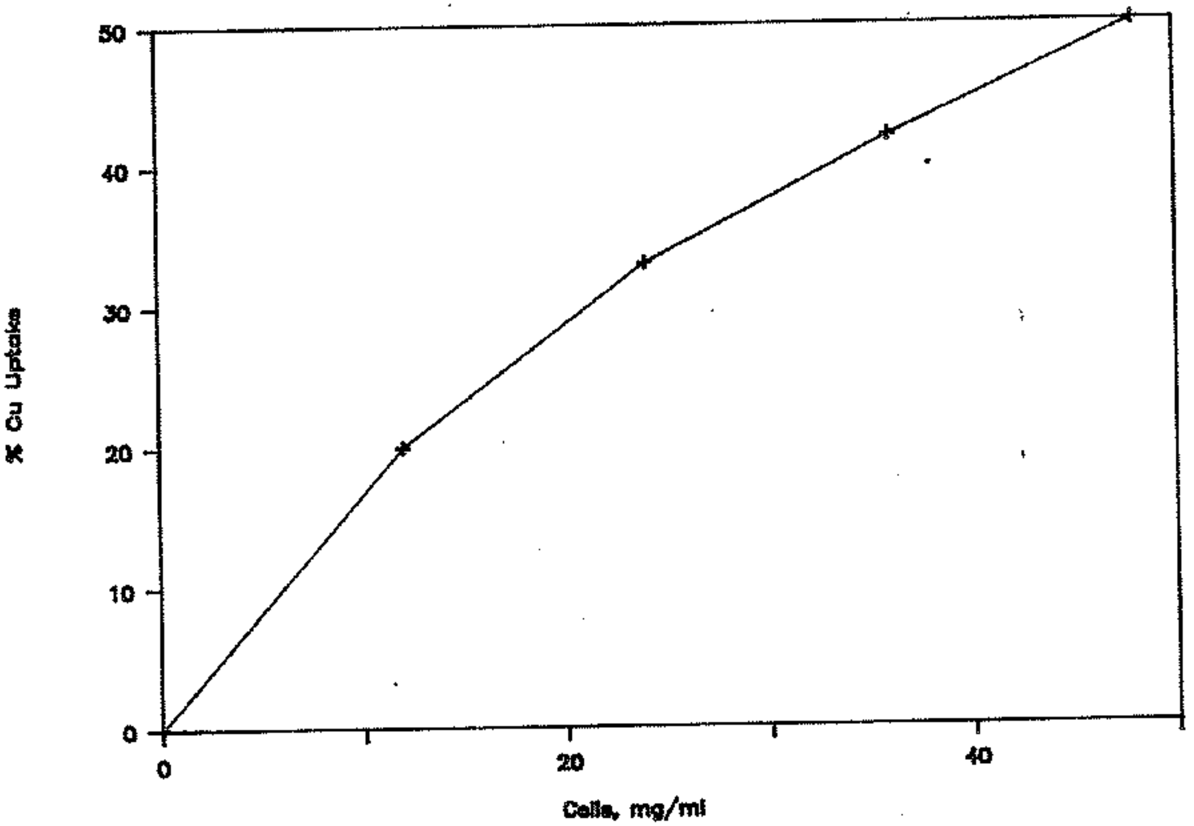
6.5 mg/ml of cells in distilled water + yeast extract

Figure 6. Kinetics of uptake of a metal mixture by Arthrobacter HC824 in distilled water plus yeast extract



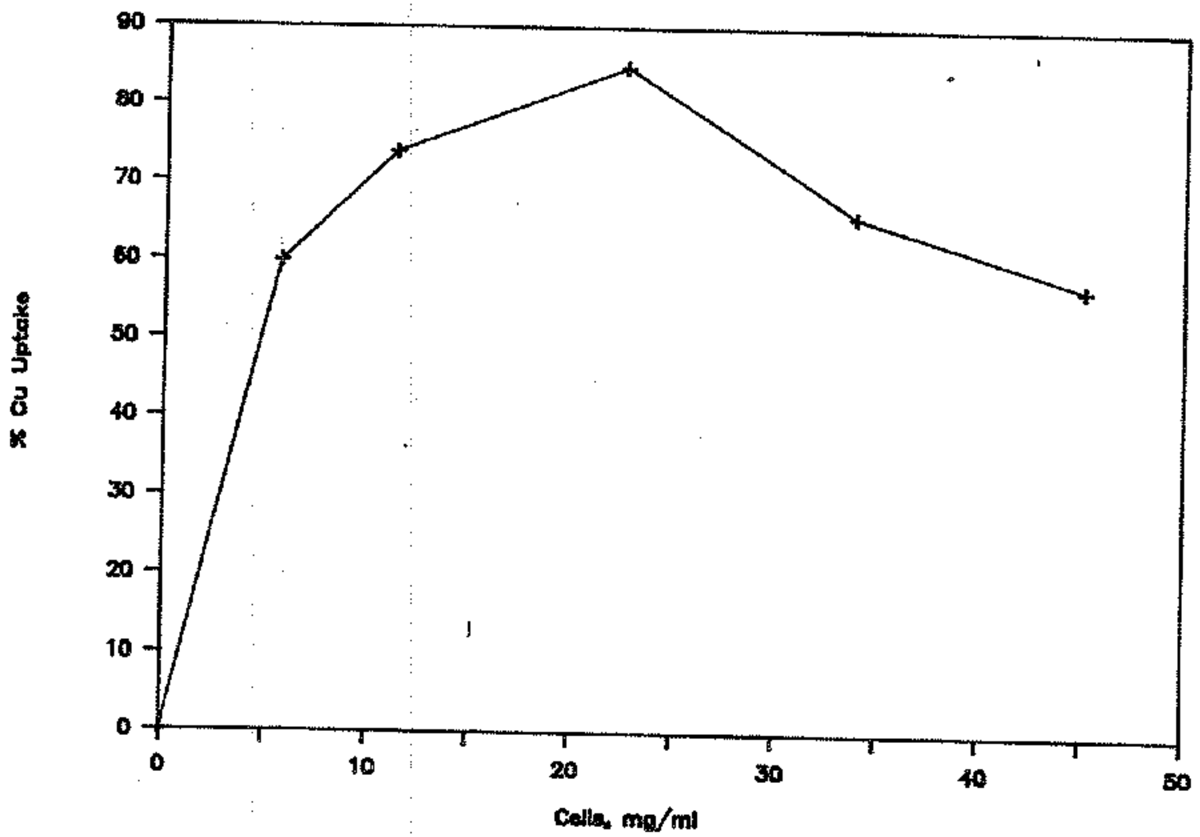
15.2 mg/ml cells; ◆Pb, ▲Cu, □Zn, +Ni

Figure 7. Percentage Cu uptake by Pseudomonas PxR in dilute mineral medium with glucose as the energy source



14.8 mg/ml of cells

Figure 8. Percentage of Cu uptake by Pseudomonas PxR in distilled water plus yeast extract



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experiment maximum uptake (50 %) was obtained with the highest cell mass, and there was a different relationship between cell mass and percentage metal uptake. A similar experiment experiment performed in distilled water (Figure 8), does not show an increased metal uptake at cell masses above 22.6 mg/ml, which was optimal for Cu removal (85%). These experiments confirm earlier observations that metal removal from aqueous solution are inhibited to some extent in more complex media and media with even modest quantities of other inorganic salts.

Solanellas and Bordons (1988) used Pipes Buffer (piperazine-N,N'-bis (2-ethanesulphonic acid) in their copper uptake studies because of it negligible metal-chelate properties. We compared Cu uptake by Pseudomonas Pxr in Pipes and our distilled water-yeast extract system with 21 mg/ml of cell suspension. In the 3 hour experiment 83% of the Cu was cell bound in water versus 90% in Pipes. A test with Flavobacterium sp. at 14.8 mg/ml in Pipes, removed 71% of the added Cd.

Objective 3.

Early studies indicated that saturation of the cell mass with metal occurred at a metal:cell dry weight in the range of 1:1.4 to 1:2.8 mg metal:mg cell dry weight. From this data we had a guide to the amount of cell mass needed to clear a waste water. It is now apparent that the value for cell saturation varied depending upon the organism used in the experiments.

Objective 4.

We know that glucose used as a energy source (1%) enhances metal removal from a water solution but is not as effective as small quantities of yeast extract (0.01%). Using a mixture of glucose and yeast extract offers no advantage over yeast extract alone. A recent study by Brynhildsen, et. al. (1988) demonstrated that glucose concentration had a significant effect on the sensitivity-resistance of a Klebsiella sp. to Cd, Cu, Hg, and Zn.

Table 2. Effect of Nutrient Supplements on Clearing of Cu, Cr, Ag and Pb From Water

	Glucose 1%		Yeast Ex .01%		Yeast Ex .1%		PO4 0.1M	
Metal	1	2	1	2	1	6	1	2
Cu	4.09	.41	4.43	.26	4.58	.27	.18	4.36
Cr	4.67	.17	4.67	.21	4.58	.27	4.75	.03
Ag	2.4	.07	2.7	.1	3.3	.05	.4*	.1
Pb	4.3	1.5	2.0	3.2	1.3*	3.4	.4"	3.2

M:C	1:2.6	1:1.5	1:1.4	1:0.7

1= Water phase
2= Cells
* ppt before cells added
" ppt at end 4 hrs incubation

Phosphate would appear to enhance Cu and Pb cell association but lowers the association of Cr and cells. Phosphate also has a chemical reaction with Ag (apparently the formation of silver orthophosphate which is insoluble) which removes the silver from solution.

Yeast extract is a complex mixture of compounds which are to a large extent amino acids, peptides and vitamins. It is a very promising supplement for this project in that low concentration is required for enhanced activity and it is a relatively cheap product.

Objective 5.

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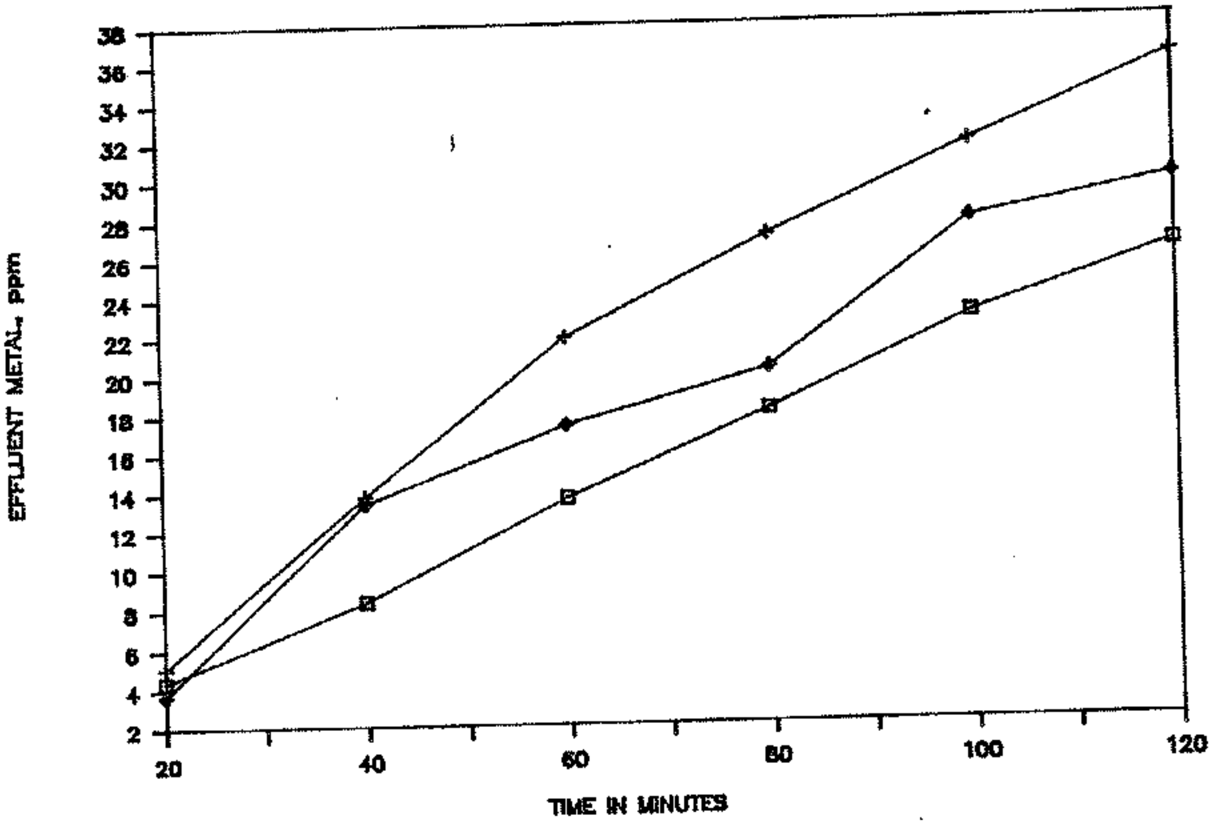

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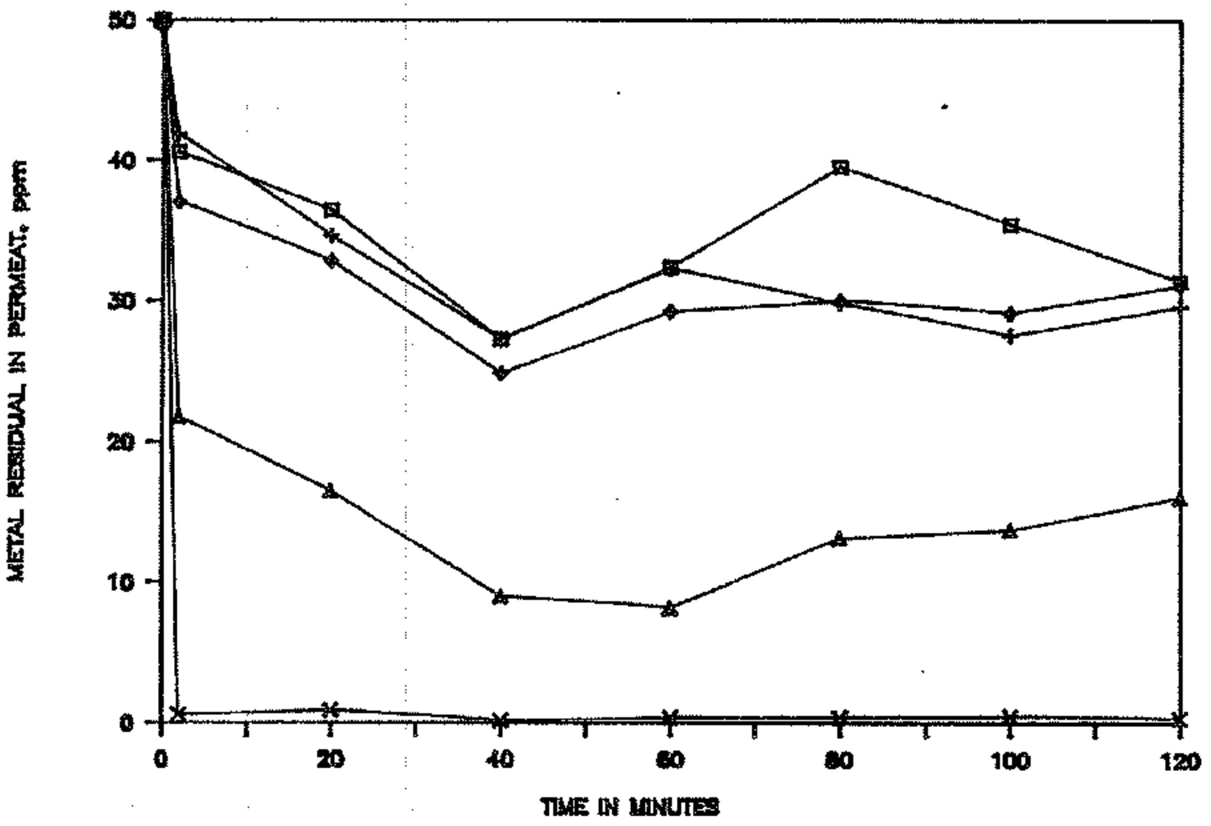

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We are surprised at the rapid metal uptake by metal resistant bacteria. The kinetics of uptake vary with different isolates and with different metals, but the bulk of the metal which becomes cell associated occurs within a few minutes after addition of the organism. Of the metals studied Pb, Cu, Zn and Ni are the easily removed, whereas Cr is the most difficult.

Initially it was thought that the metal-cell saturation levels were constant. However, it is now apparent that this is a somewhat more variable and complex relationship. It is apparent that actively growing cells will accumulate or bind metal, but that resting cells with a minimum of nutrient supplement give superior results in metal removal. The non-chelating buffer, Pipes, seems to be a an ideal system with Pseudomonads for the removal of metal.

The bioreactor visualized for this system shows promise but will require additional study, particularly using reactor cell mass in the range of 20 mg/ml or greater. The results with clearing of Ag from solution are very good even in the preliminary experiments.

It is becoming apparent that the strains we are using for this study probably carry plasmids which carry the genetic information for specific metal resistances. This may allow us to optimize the system by carrying genetic information from more than one strain into a common organism to clear the various metals from solution

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COMPLETION REPORT FY-1987 PROGRAM

A MICROBIAL METHOD FOR REMOVAL OF METALS, CUTTING OILS AND CYANIDE FROM POLLUTED WATER—PHASE I

by

R.W. Traxler, T.C. Lee, D.R. Nelson

COMPLETION REPORT

Title: A Microbial Method for Removal of Metals, Cutting Oils and Cyanide From Polluted Water - Phase I.

Duration: June 1987 to May 1988

Principal Investigators: Dr. Richard W. Traxler
Dr. Tung-Ching Lee
Dr. David R. Nelson

Date: August 1, 1987

INTRODUCTION

Regulations limiting the discharge of toxic metals and cyanide into public sewers have been in effect for three years but the majority of affected platers and finishers are not in compliance with these regulations. Many of the larger firms meet discharge standards or are expected to do so in the near future.

The magnitude of the problem is seen by the amount of heavy metal entering the Narragansett Bay Commission sewer system in recent years. The peak was in 1981 with 956,099 pounds release with a drop in 1985 to 409,657 pounds. The interim goal is to reduce this volume to about 200,000 pounds within a year. The existing technology for solution of this problem by chemical means is expensive. One of the larger companies was forced to spend $500,000 for a pretreatment system. This type of a solution to the problem is beyond the capability of the smaller operator who does not have the capital resources for even a 5th of this type of investment. The ultimate result is that without a less expensive system these small companies will be forced out of business. This project is aimed at the small operation to provide to these companies a relatively simple, inexpensive but effective means of pollution control. The project while of extreme potential value to Rhode Island can also be applied to the same problem in other states.

A. The FY 1987 Objectives Phase I Metal Removal:

1. Expand resistance spectrum in one isolate, if possible, to include resistance to Cu, Pb, Ag, Cr, Zn, Cd, Ni and Hg.
2. Determine the kinetics of metal removal.
3. Determine the saturation level of cell mass.
4. Determine the effect of nutrients on metal removal.
5. Perform bioreactor studies with simulated and real waste for metal removal.
6. Determine the presence or absence of plasmid DNA which is linked to the objectives of Phase II.

B. Phase I Results and Discussion

Objective 1.

Using a serial enrichment-adaptation procedure we have been able to expand the resistance spectrum of *Arthrobacter* HC823 to a combined mixture of eight metals, each at a concentration of 50 ppm. The eight metals are: Cu, Pb, Ag, Cr, Zn, Cd, Ni, and Hg. This is a combined total metal ion load of 400 ppm of metal ion in the test system. We are delighted to be able to achieve this resistance pattern in one isolate.

In addition, we have determined the metal resistance of a natural isolate identified as a Flavobacterium sp. and a member of the genus Pseudomonas labeled strain PxR824, isolated from heavily metal polluted sediment. Tests have not been run to enhance the resistance of these isolates. Those metal listed as R (resistant) were resistant to 50 ppm of the metal while those listed as S (sensitive) would not grow in the presence of 1 ppm of the metal (Table 1.).

On isolation, the Flavobacterium sp. required 1 ppm of zinc for growth in solid or liquid medium. After sub-culture the organism no longer shows a Zn requirement for growth.

Table 1. Resistance spectrum of two environmental isolates.

Cation	Flavobacterium sp	Pseudomonas HC824
Pb	R	R
Zn	R	R
Cd	R	R
Cr	R	S
Cu	R	R
Ni	R	R
Ag	R	S
Hg	S	S

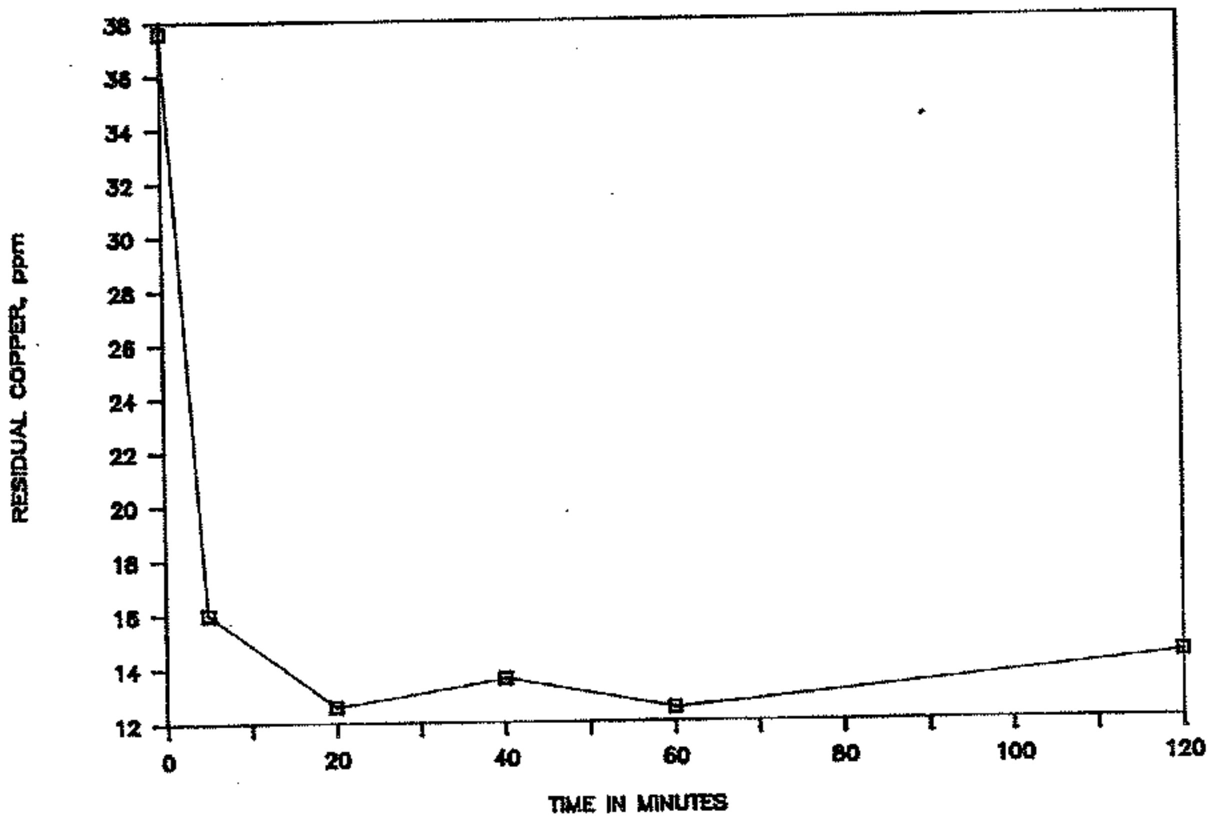
Objective 2.

Kinetic studies were initiated in November using Cu as the first metal in non-nutrient supplemented experiments. The first experiments indicate a much more rapid removal of the metal from a microbial suspension in distilled water than anticipated. We find the same rapid uptake by Arthrobacter HC824 with Pb, Zn, Ni, and Cr (Figures 1-5). Uptake of Ni and Cr are initially rapid for the first 5 minutes then the uptake rate is reduced. These differences in kinetics suggest different mechanisms associated with cell binding. Also, it is seen from these data that binding or uptake is highly efficient with Pb and Zn, less so with Cu and Ni, and poor with Cr.

Arthrobacter HC824 was tested in a mixture of Pb, Cu, Zn, and Ni suspended in distilled water plus yeast extract (Figure 6), and the metal content of the aqueous phase determined as an index of metal removal from solution. Lead was rapidly cleared from the aqueous phase. The efficiency of metal removal was less for Cu, Zn and Ni.

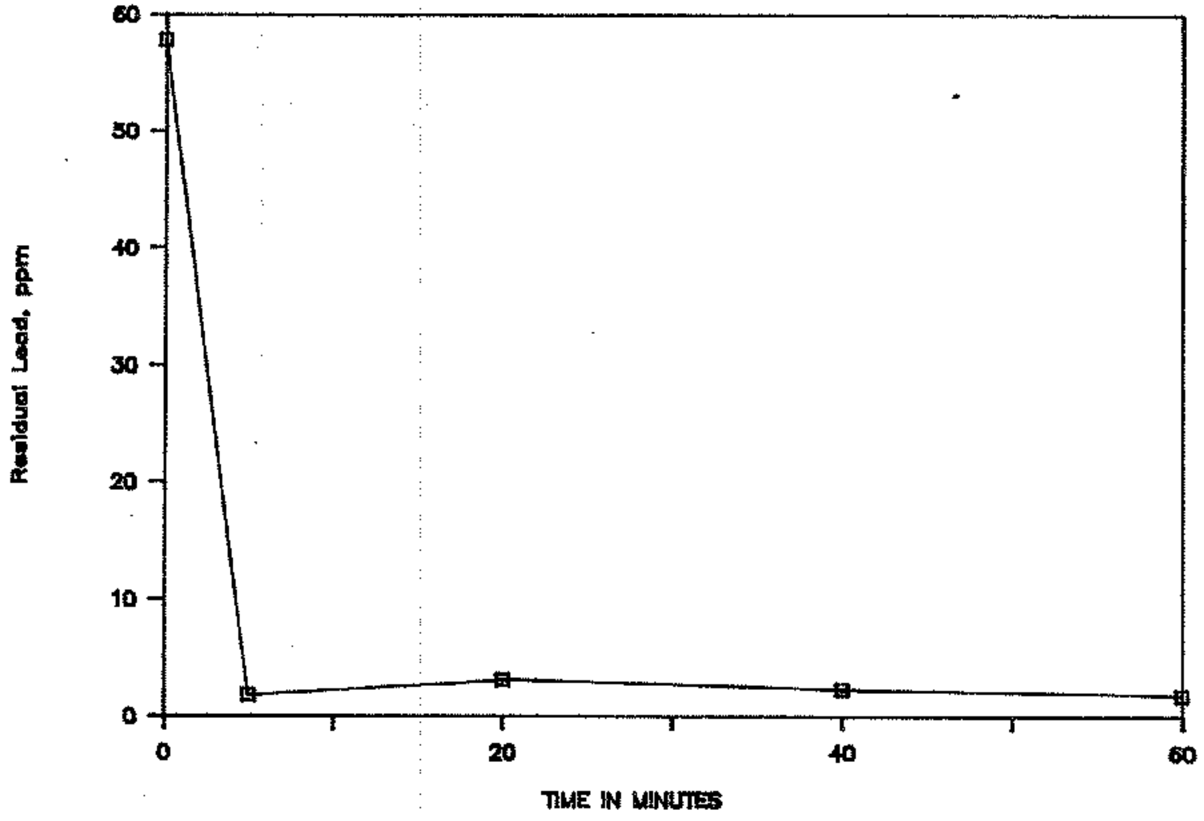
The first experiment with Pseudomonas PxR was conducted in a dilute mineral medium with glucose as the carbon source, and amended with Cu at 50 ppm. The cell mass (mg/ml dry weigh basis) was varied from 12-48 mg/ml (Figure 7). In this 3 hour

Figure 1. Kinetics of Cu uptake By Arthrobacter HC824



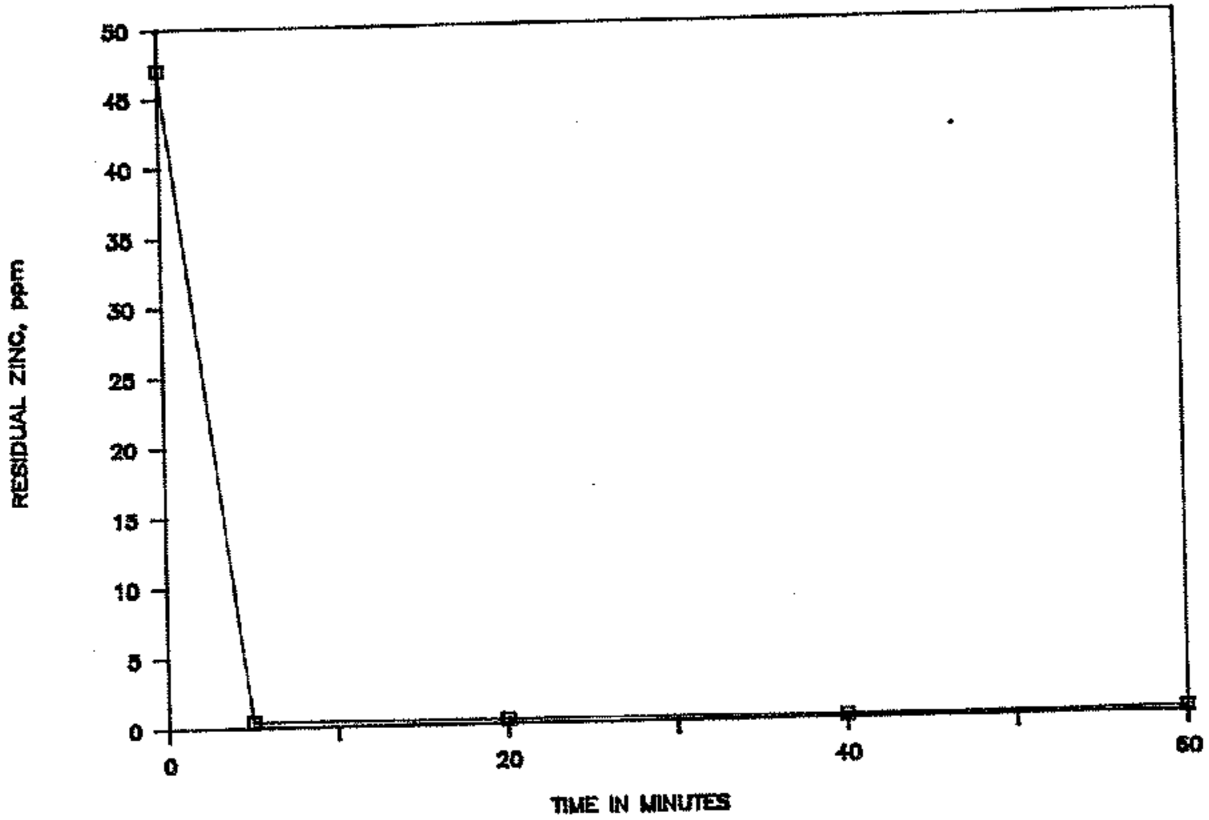
9.2 mg/ml of cells in distilled water + 0.01% yeast extract

Figure 2. Kinetics of Pb uptake by Arthrobacter HC824



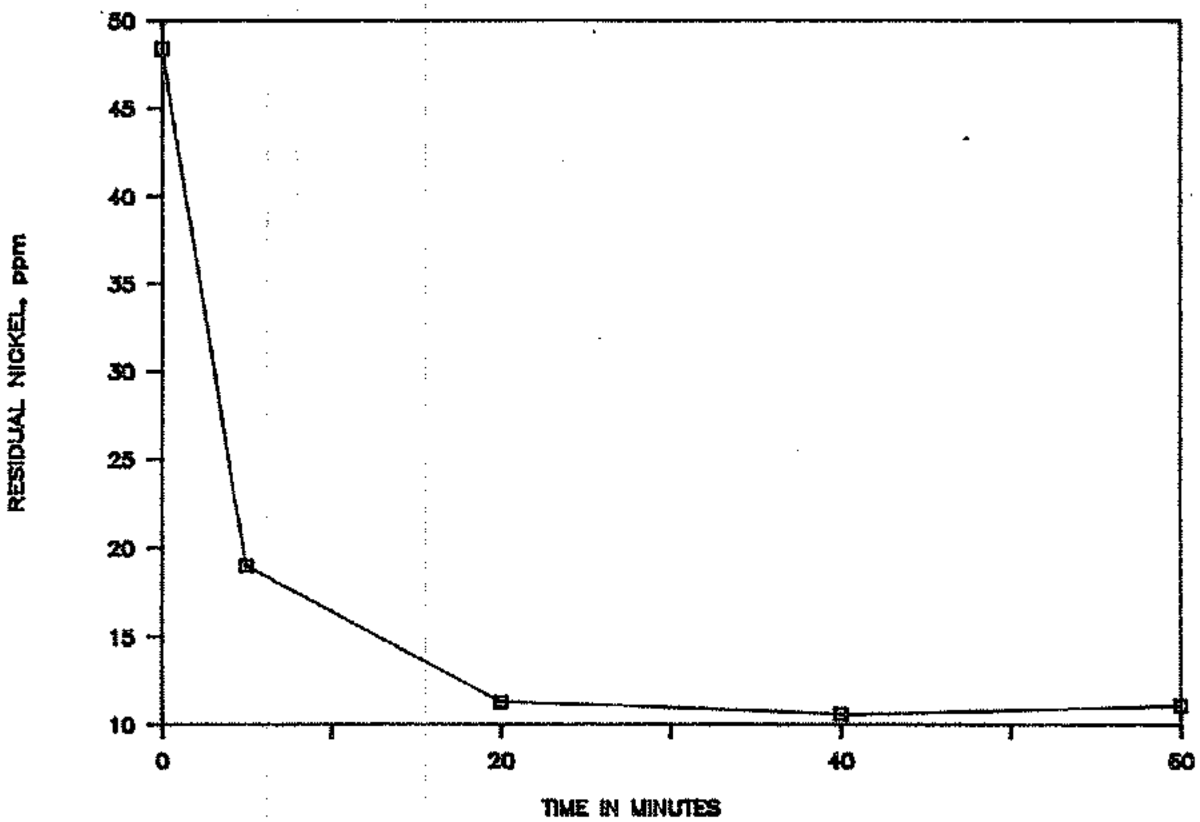
7.5 mg/ml of cells in distilled water + 0.01% yeast extract

Figure 3. Kinetics of Zn uptake by Arthrobacter HC824



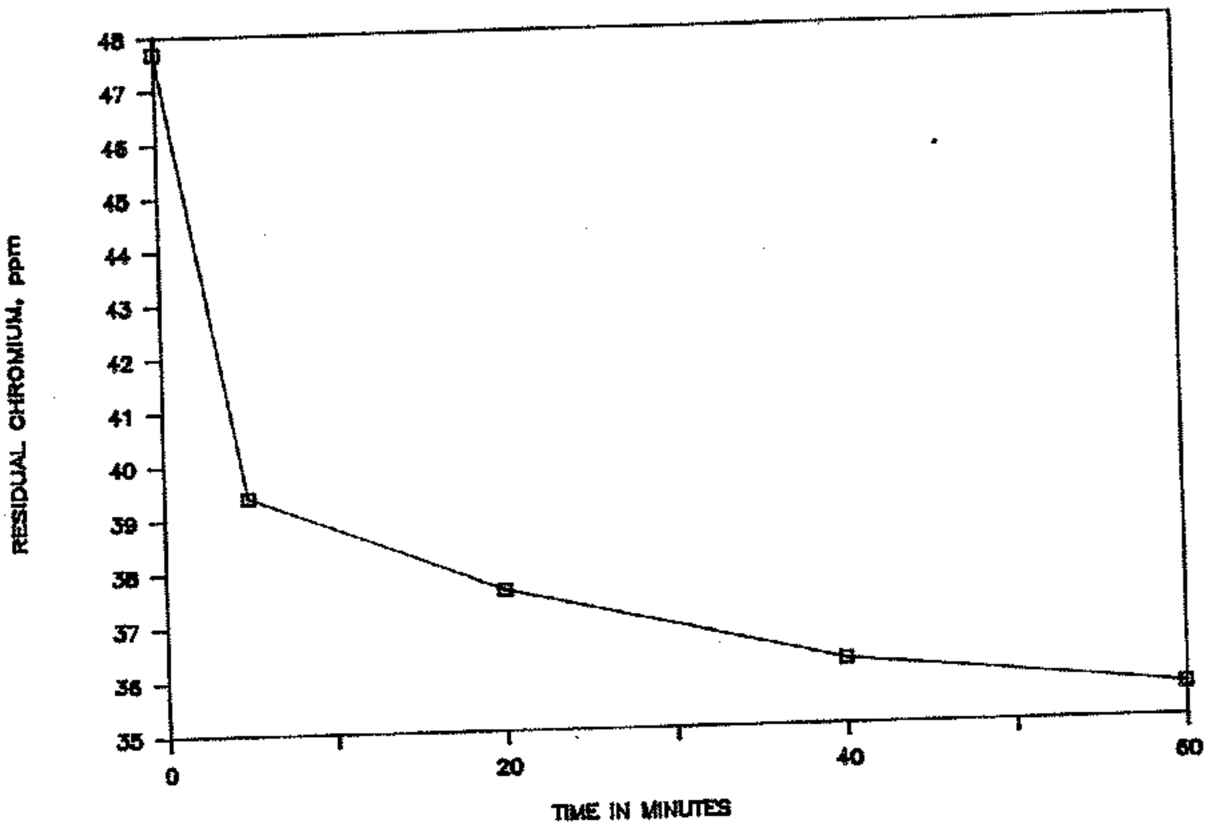
6 mg/ml of cells in distilled water +0.01% yeast extract

Figure 4. Kinetics of Ni uptake by Arthrobacter HC824



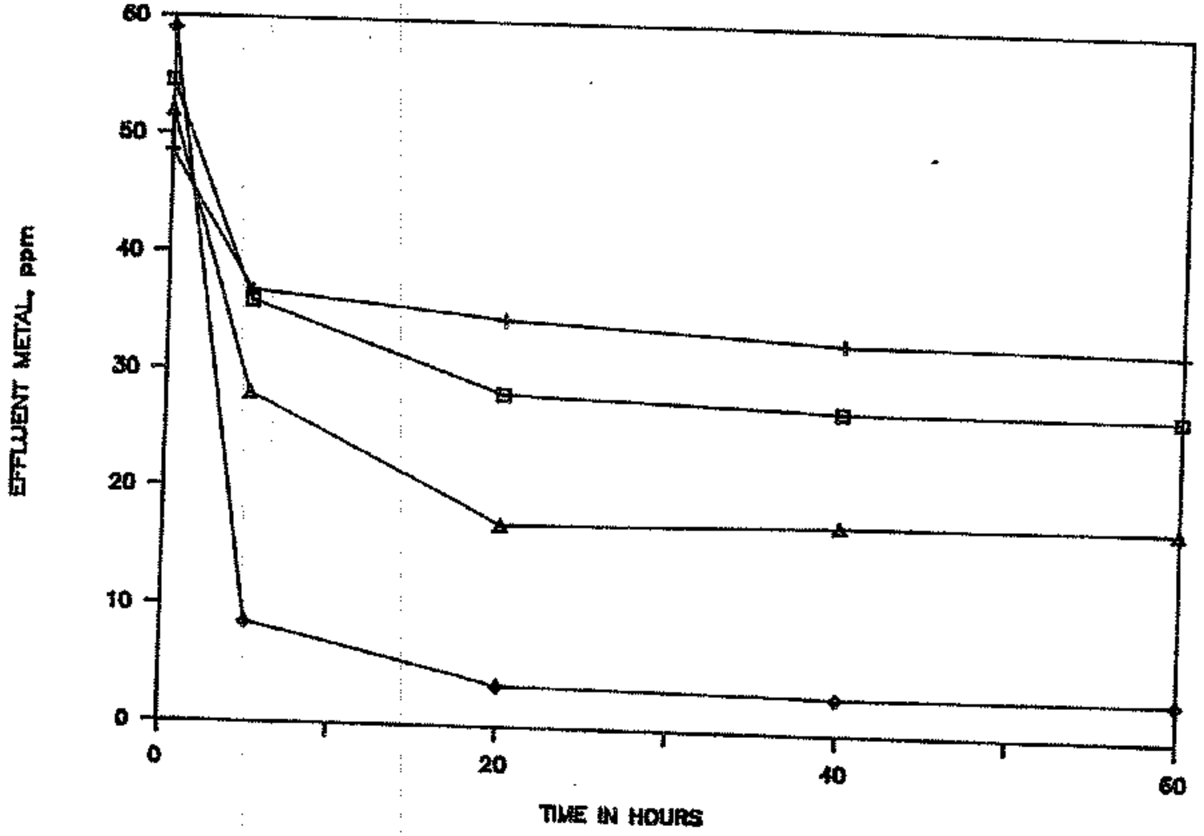
6.5 mg/ml of cells in distilled water + 0.01% yeast extract

Figure 5. Kinetics of Cr upatke by Arthrobacter HC824



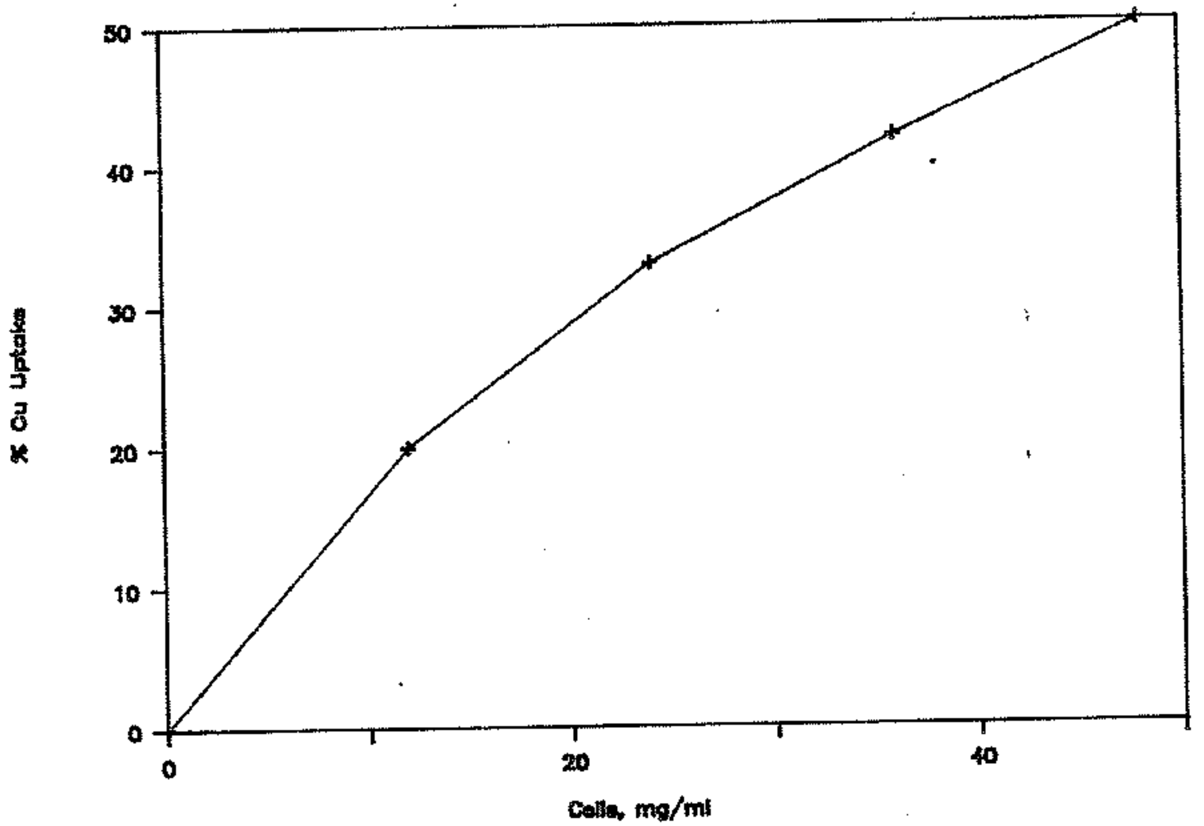
6.5 mg/ml of cells in distilled water + yeast extract

Figure 6. Kinetics of uptake of a metal mixture by Arthrobacter HC824 in distilled water plus yeast extract



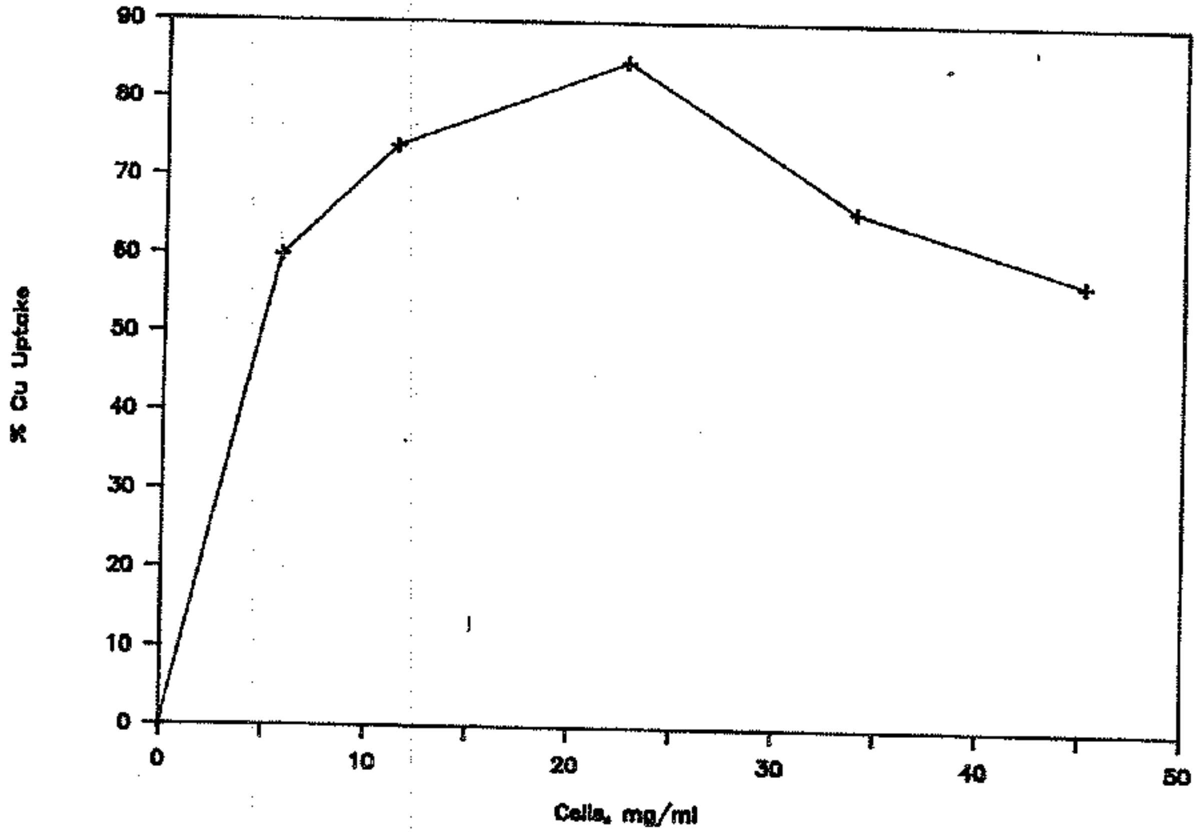
15.2 mg/ml cells; ◆Pb, ▲Cu, □Zn, +Ni

Figure 7. Percentage Cu uptake by Pseudomonas PxR in dilute mineral medium with glucose as the energy source



14.8 mg/ml of cells

Figure 8. Percentage of Cu uptake by Pseudomonas PxR in distilled water plus yeast extract



14.8 mg/ml of cells

experiment maximum uptake (50 %) was obtained with the highest cell mass, and there was a different relationship between cell mass and percentage metal uptake. A similar experiment experiment performed in distilled water (Figure 8), does not show an increased metal uptake at cell masses above 22.6 mg/ml, which was optimal for Cu removal (85%). These experiments confirm earlier observations that metal removal from aqueous solution are inhibited to some extent in more complex media and media with even modest quantities of other inorganic salts.

Solanellas and Bordons (1988) used Pipes Buffer (piperazine-N,N'-bis (2-ethanesulphonic acid) in their copper uptake studies because of it negligible metal-chelate properties. We compared Cu uptake by Pseudomonas Pxr in Pipes and our distilled water-yeast extract system with 21 mg/ml of cell suspension. In the 3 hour experiment 83% of the Cu was cell bound in water versus 90% in Pipes. A test with Flavobacterium sp. at 14.8 mg/ml in Pipes, removed 71% of the added Cd.

Objective 3.

Early studies indicated that saturation of the cell mass with metal occurred at a metal:cell dry weight in the range of 1:1.4 to 1:2.8 mg metal:mg cell dry weight. From this data we had a guide to the amount of cell mass needed to clear a waste water. It is now apparent that the value for cell saturation varied depending upon the organism used in the experiments.

Objective 4.

We know that glucose used as a energy source (1%) enhances metal removal from a water solution but is not as effective as small quantities of yeast extract (0.01%). Using a mixture of glucose and yeast extract offers no advantage over yeast extract alone. A recent study by Brynhildsen, et. al. (1988) demonstrated that glucose concentration had a significant effect on the sensitivity-resistance of a Klebsiella sp. to Cd, Cu, Hg, and Zn.

Table 2. Effect of Nutrient Supplements on Clearing of Cu, Cr, Ag and Pb From Water

Metal	Glucose 1%		Yeast Ex .01%		Yeast Ex .1%		PO4 0.1M	
	1	2	1	2	1	6	1	2
Cu	4.09	.41	4.43	.26	4.58	.27	.18	4.36
Cr	4.67	.17	4.67	.21	4.58	.27	4.75	.03
Ag	2.4	.07	2.7	.1	3.3	.05	.4*	.1
Pb	4.3	1.5	2.0	3.2	1.3*	3.4	.4"	3.2

M:C	1:2.6	1:1.5	1:1.4	1:0.7

1= Water phase
2= Cells
* ppt before cells added
" ppt at end 4 hrs incubation

Phosphate would appear to enhance Cu and Pb cell association but lowers the association of Cr and cells. Phosphate also has a chemical reaction with Ag (apparently the formation of silver orthophosphate which is insoluble) which removes the silver from solution.

Yeast extract is a complex mixture of compounds which are to a large extent amino acids, peptides and vitamins. It is a very promising supplement for this project in that low concentration is required for enhanced activity and it is a relatively cheap product.

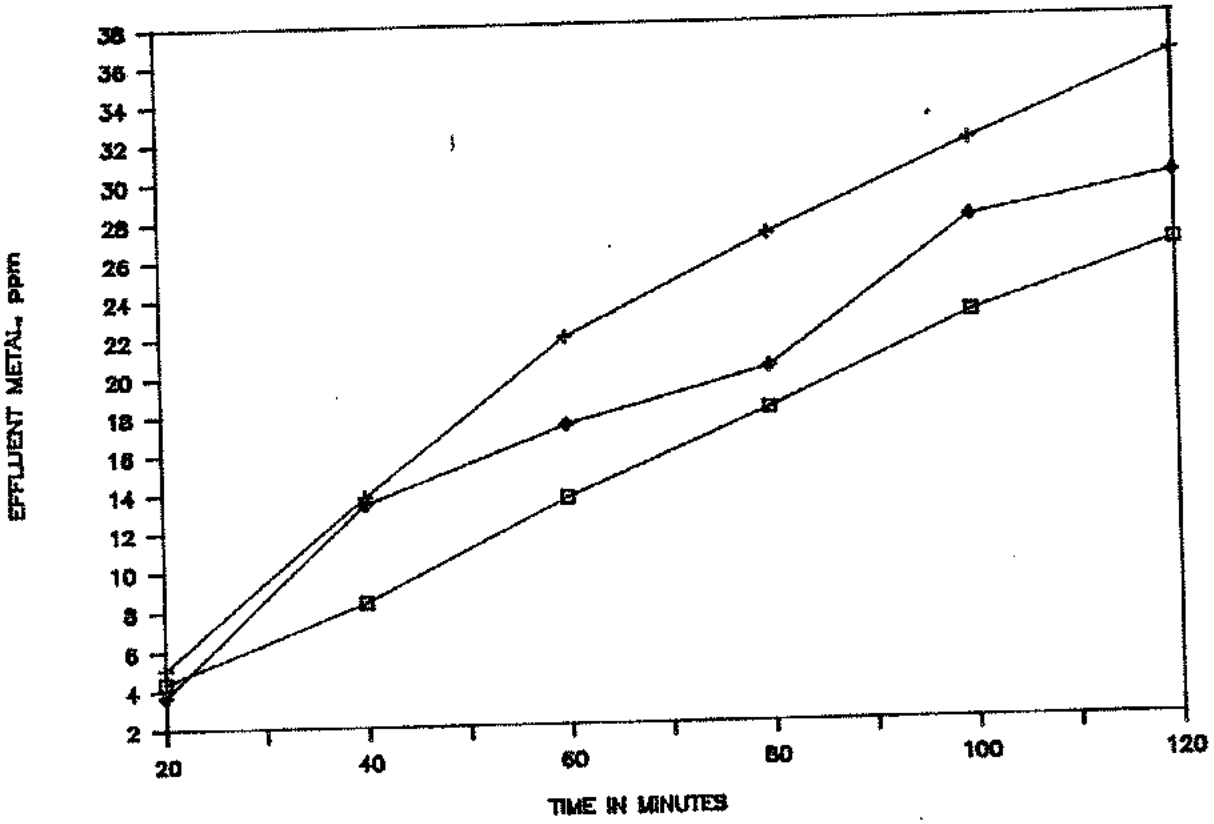
Objective 5.

Due to serious problems associated with the relocation of our research laboratory this phase of the project has been delayed since mid-January. One bioreactor test was run in early January with Arthrobacter HC824 at 10 mg/ml final cell dry weigh. The cells suspended in 300 ml of distilled water yeast extract were mixed with 400 ml of water containing 50 ppm each of Cu, Ni and Zn. This mixture was mixed for 20 minutes, then a feed of the same metal solution was fed to the bioreactor at 6 ml/minute. At the time the feed was started, the bioreactor was pumped at high speed across a membrane in tangential flow filter. The cell slurry retentate was returned to the bioreactor and the permeate (aqueous phase) went to discharge at a rate of 6 ml/minute. Thus, the bioreactor maintained a constant volume and constant cell mass. The results (Figure 9) showed a steady build-up in the metal content of the permeate over the 100 minutes of system operation. However, metal was still being removed from the aqueous phase as the permeate level never reached input metal concentrations of 50 ppm.

The experiment was repeated using four metals, Cu, Cr, Ni, Zn, and Ag, with a lower feed rate of the waste metal solution (3 ml/minute) and a cell mass of 8 mg/ml. The results in (Figure 10) demonstrated a good removal of Ag from the aqueous phase and poor but fairly constant removal of the other metals.

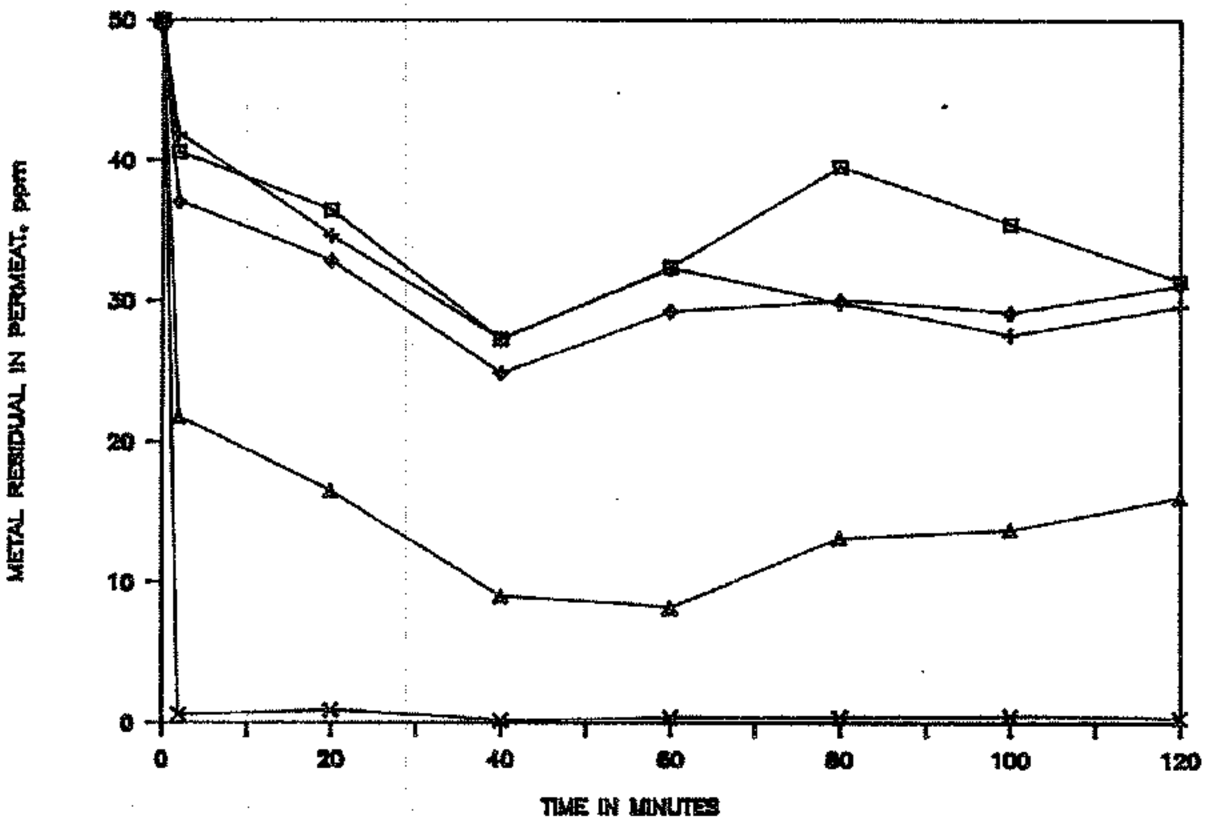
The data from other studies suggests that a much greater cell mass must be used in the bioreactors. Our objective in Phase II of this project will be the use of cell dry weights in the range of 20-30 mg/ml.

Figure 9. Bioreactor fed mixed metals Cu, Ni, and Zn



10 mg/ml Cell mass, feed rate 6 ml/min, feed atart 20 min.
□ Cu, ◆ Zn, + Ni

Figure 10. Bioreactor fed mixed metals, Cu, Cr, Ni, Zn, and Ag



8 mg/ml cells, 600 ml volume, fed at 3 ml/minute

Objective 6.

A variety of different digestion methods have been tried for the isolation of plasmid DNA from Arthrobacter HC824. All of these attempts have isolated only chromosomal DNA. In a recent test using a modification of the alkaline digestion method, there is evidence for a very high molecular weight plasmid near the chromosomal DNA region of the gel. Further tests during Phase II of this project will be done to confirm this observation.

At least one plasmid has been detected in the Pseudomonas PxR strain by the alkaline lysis method. The molecular weight of the plasmid is approximately 11 kb. It was cut by EcoRI into two fragments, 9kb and 2 kb, which demonstrated that the plasmid has a single EcoRI restriction site. In addition, the PxR gels show a high molecular weight band, which may indicate the presence of a large molecular weight plasmid. The alkaline lysis method has been used for a plasmid screen of clinical isolates of Pseudomonas aeruginosa and of Ps. fluorescens. These screens have not detected plasmids in these strains. Work will continue during Phase II of this project to isolate and restrict this potential plasmid from Ps. PxR.

In order to confirm the function of the plasmid(s) in the Ps. PxR strain, it is necessary to transform it into a suitable recipient strain and test for the retained function and plasmid presence in the recipient strain. Since antibiotic resistance is normally coded on the same plasmid as metal resistance, we have two markers to use in the transformation studies. We have screened metal and antibiotic resistance in three potential recipient organisms, Ps. aeruginosa, Ps. fluorescens and E. coli HB101. The results of the metal and antibiotic resistance screens are shown in Tables 3 and4. The two Pseudomonads are not good candidates as recipients as the patterns are similar to Ps. PxR. E. coli HB101 may be a good transformation recipient due to the Cd, Cr, Hg, ampicillin and chloramphenicol sensitive markers not present in the PxR strain.

Table 3. Metal resistance of strains

Agents and Concentration	E. coli HB101	Ps. PxR	Ps. fluorescens	Ps. aeruginosa
Control	R	R	R	R
Pb, 0.5 mM	R	R	R	R
Zn, 2 mM	R	R	R	R
Cd, 0.5 mM	S	R	S	R
Cr, 2 mM	S	S-R	S	S
Ni, 2 mM	R	R	R	R
Cu, 2 mM	R	R	R	R
Hg, 0.5 mM	S	R	S	S
Ag, 0.5 mM	S	S	S	S

Table 4. Antibiotic sensitivity pattern of strains

Agent	E. coli HB 101	Ps. PxR	Ps. fluorescens	Ps. aeruginosa
Control	R	R	R	R
LB+Amp 50 ug/ml	S	R	R	R
LB+Kan 50 ug/ml	S	S	S	S
LB+Tet 10 ug/ml	S	S	S	R
LB+Chl 30 ug/ml	S	R	R	R

Additional Observations

While not included as an initial objective of this project, it has become apparent that the metal binding organisms may produce and secrete into the metal compounds which function as metal chelate agents. Ps. HC824 was grown in Trypticase Soy Broth in the presence of 5 ppm of Cd, the cells removed and the supernatant collected for analyses. The protein content of the supernatant was estimated by the Warburg-Christen method by measuring the Absorbance at 260 and 280 nM and using their table to estimate protein. The supernatant was divided into aliquots to which were added varying (0-50 ppm) of the metals under study in this project. A UV-Vis scan of the native supernatant with and without added metals was performed. Comparison of the scans indicates the possible chelation of Cd, Cu, Pb, Cr, and Zn by extracellular products of the organism, but not the chelation of Ag, Ni or Hg. The spectral shifts in the presence of metal are metal specific and represent the formation of new peaks, magnification of peak shoulders, and changes in Absorbance maxima.
It is too early to equate these findings with metal removal from aqueous solution but it suggests that events other than metal uptake are associated with the clearing of metals from aqueous solutions,

C. New Literature Summary and References

Erardi, et. al. (1987) used a copper tolerant strain of Mycobacterium scrofulaceum to remove copper from culture medium by sulfate-dependent precipitation as copper sulfide. A derivative of this strain which lacked a 173-kilobase plasmid did not precipitate copper. The plasmid-carrying strain had a sulfate-independent copper resistance mechanism.

Chlorella stigmatophora grown in artificial seawater produced cell wall polysaccharides which dissolved in the growth

medium (Kaplan, et. al., 1987). This polysaccharide had a varying complexing capacity for Zn, Cd, Pb, and Cu.

Brynhildsen, et. al. (1988) found that the nutritional state of an organism has a profound effect on its sensitivity to metals. Metals taken up by an energy-driven transport system may be less toxic under conditions of carbon starvation. The toxicity of Cu, Cd, and Zn to a Klebsiella sp was affected considerably by the carbon concentration, whereas the toxicity of Hg is independent of carbon concentration.

Solanellas and Bordons (1988) surveyed copper accumulation by resting cells of copper-resistant bacteria isolated from sewage sludge. Their best strain for accumulation was a Bacillus which retained copper at up to 3.8% of its cell dry weight, in the absence of glucose.

Belliveau, et. al. (1987) reviewed metal resistance and accumulation in bacteria, and in this paper summarize most of the current data and concepts of metal transport, resistance and accumulation.

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D. Conclusions

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COMPLETION REPORT FY-1988 PROGRAM

URANIUM CONCENTRATION IN BEDROCK: PRIMARY SOURCES OF RADON IN RHODE ISLAND AQUIFERS

by

O.D. Hermes, Nancy Nevins

COMPLETION REPORT SUBMITTED TO:
RHODE ISLAND WATER RESOURCES BOARD

URANIUM CONCENTRATION IN BEDROCK: PRIMARY SOURCES OF RADON IN RHODE ISLAND AQUIFERS

Project No. G1612-02

PRINCIPAL INVESTIGATOR:

O.DON HERMES
GEOLOGY DEPARTMENT
UNIVERSITY OF RHODE ISLAND
KINGSTON, RI

COLLABORATOR:

NANCY NEVINS
GEOLOGY DEPARTMENT
UNIVERSITY OF RHODE ISLAND
KINGSTON, RI

JULY 31, 1989

RESEARCH OBJECTIVES:

The occurrence of elevated levels of radon gas in indoor air has, in recent years, become recognized as a leading cause of lung cancer. The Environmental Protection Agency (EPA) now estimates that up to 20,000 lung cancer deaths per year in the United States may be attributed to long term exposure to radon and it's decay products (US EPA, 1986). Radon-222 (^{222}Rn), the isotope which poses the health risk, is the only gas in a long series of decays originating with the decay of ^{238}U:

$$^{238}\mathrm{U} - {}^{234}\mathrm{Th} - {}^{234}\mathrm{Pa} - {}^{234}\mathrm{U} - {}^{230}\mathrm{Th} - {}^{226}\mathrm{Ra} - {}^{222}\mathrm{Rn}$$

Primary ^{238}U comprises more than ninety-nine percent of the naturally occurring uranium isotopes ^{222}Rn decays with a half life of 3.8 days, undergoing several rapid disintegrations leading to ^{210}Pb, which has a half life of 22 years. The ^{210}Pb ultimately decays to the stable lead isotope ^{206}Pb.

Radon is an inert, water soluble gas which occurs naturally in air, soil and water. The primary geologic sources of uranium, and hence radon, are igneous rocks, especially alkali-enriched granitic rocks, and sedimentary and metamorphic rocks subsequently derived from these igneous protoliths. Uranium tends to concentrate in highly differentiated rock types, thus igneous rocks of granitic composition are strongly enriched in U compared to rocks of basaltic or ultramafic composition. The U-bearing bedrock releases the radioactive gas into groundwater traveling through fractures. Because it is a noble gas, radon is more free to migrate than any of it's parents. Radon's occurrence in groundwater or indoor air is controlled by physical variables such as pressure, temperature, emissivity of radon from rocks, as well as the geochemistry of parent isotopes. Previous studies (Hess and others, 1980; King and others, 1982; Hess and others, 1985; Hall and others, 1987; Wanty and Gundersen, 1987) have shown that high Rn levels in groundwater exhibit a positive correlation with uranium and radium levels in the geologic materials that comprise aquifers.

A major source of radon in indoor air is soil gas, which may enter a dwelling by diffusion through foundations or cracks. Radon accumulates in the soil gas as a result of a direct flux from the underlying geologic substrate. An equally important contributor to indoor levels of radon is Rn-rich potable water. The health risk of radon-rich waters in domestic wells is two-fold. Ingestion of the contaminated water has been associated with increased risk of stomach cancer (Suomela and Kahlos, 1972; Cross and others, 1985). Of greater concern is the inhalation of the radioactive gas partitioned into the air from the water supply (Gesell and Prichard, 1978; Hess and others, 1980). Alpha-decay of this inhaled ^{222}Rn results in lung tissue damage and increased risk of lung cancer.

Known petrologic and geochemical characteristics of geological materials in Rhode Island suggest anomalously high concentrations of radioactive parent nuclide uranium-238. The primary objective of this project has been to quantitatively determine uranium concentrations in the states's crystalline bedrock, metasedimentary rocks of the Narragansett Basin, and surficial glacial deposits, in an attempt to identify and delineate geographic areas which are potental sinks for the daughter product radon in both groundwater aquifers and indoor air.

Although uranium is present in nearly all geological materials, levels are usually so low that trace level analytical methods are necessary to determine it's concentration. The determination of U contents has required the establishment of an analytical technique not previosly available to the URI community. The method chosen for this study is a modification of traditional neutron activation analysis known as <u>epithermal neutron activation analysis</u>. As a result of the work accomplished in this project, such analyses may now be routinely performed at the Rhode Island Nŭclear Science Center. The set up of this method entails the development of a suitable procedure based on trial irradiations, experimentation, and on reviews of recent related literature, with the aim of minimizing analytical error and optimizing detection limits. Thus, the establishment of this technique constituted a major early effort of this project and is a valuable by-product of our work.

In addition to measuring the uranium in geologic material, secondary goals of this project have been to determine the specific siting, or location, of the U within representitive rocks and to measure Rn content in selected domestic wells. Uranium may be sited interstially (outside of mineral phases), or within the crystal lattice of accessory minerals such as zircon, sphene and monazite. Wathen (1986) has shown that U located in the intersitial areas of rocks is held relatively loosely and may potentially release it's decay product, radon, to air and groundwater more easily. Uranium siting is determined using radiographic methods (Bowie, 1977).

The approach to groundwater sources of ^{222}Rn has not been to randomly sample water, but to first locate and characterize aquifers of potentially high radon based on geologic rationale, and then to test for geologic correlations. The well data, in addition to results of the radiographic analyses, will not be included in the present report as they are ongoing and presently being evaluated. A full report may be expected as a Master's Thesis by Nancy Nevins in late fall, 1989.

RELATED RESEARCH:

The threat posed by radon gas accumulations in indoor air became nationally known with the discovery of extremely high levels of Rn in domestic dwellings located within the Reading Prong province, which includes part of New Jersey, Pennsylvania and New York (Gundersen, L.C., 1986; Smith and others, 1987). This discovery has prompted numerous studies throughout the United States with the aim of understanding sources of Rn, as well as factors controlling it's solubility, mobility and transport pathways. In the New England region, radon-related research has been conducted over the past 25 years in Maine and New Hampshire; states with abundant granitic bedrock similar to Rhode Island. Previous studies in these states have been particularly successful in correlating high levels of radon in groundwater with certain rock types.

In New Hampshire it is clear that the highest levels of radon in groundwater are associated with two-mica granites. Campisano and Hall (1986) measured Rn in groundwater from wells drilled in a two-mica granite and found that concentrations ranging from 50,000 - 100,000 pCi/L were fairly common. Radon levels ranged from 3000 pCi/L in a dug well, to 1.3 x 10^6 pCi/L in a drilled well, the highest reported value in New Hampshire to date. For comparison, the national average concentration for ^{222}Rn in public water supplies serving populations of more than 1000 people is estimated at 780 pCi/L (Horton, 1986).

Wathen (1986) has investigated the effect of U siting in two-mica granites on U concentrations and Rn activities in groundwater. Results of these investigations in New Hampshire and Maine indicate that the location of the U within the rock is along grain boundaries, where it is generally adsorbed on ferric oxides. Elevated levels of Rn associated with these granites are thought to be due to the greater leaching potential of U, as nearly all the U is labile when situated outside of mineral grains. Alternately, when U is locked up in resistate accessory minerals, such as zircon, allanite, or monazite, neither it, nor it's daughter product Rn, is readily available for transport to groundwater or overlying soil. Thus, U siting plays an important role in the mobility and subsequent release of the radon from the source rock into pore spaces filled with air or groundwater.

Work in Maine has established that U concentrations in rocks can be directly correlated with metamorphic grade (Hess and others, 1980; Brutsaert and others, 1981). Radon measurements from domestic wells show a direct correlation with metamorphic grade and range from an average level of 1100 pCi/L in chlorite grade rocks, to an average of 13,600 pCi/L in sillimanite grade rocks. Wells in the granitic terrain were found to have the highest concentrations of Rn ranging from 5,000 to 100,000 pCi/L with an average of 22,100 pCi/L.

METHODOLOGY:

EPITHERMAL NEUTRON ACTIVATION ANALYSIS

The basic principle of neutron activation analysis is that a stable isotope, when bombarded by neutrons (generated in a nuclear reactor), undergoes a nuclear transformation producing a radioactive nuclide (Lyon, 1964). The emanations from this formed radionuclide (gamma-rays) are measured using radiation detection instruments, such as scintillation counters, thus allowing quantitative determination of the elemental composition of the sample before irradiation. A special method of neutron irradiation, called epithermal irradiation, has been shown to yield improved results over instrumental neutron activation analysis when measuring U in geological material (Steinnes and Brune, 1969; Meyer, 1971), and is the chosen method for this project.

The neutron energy distribution in the nuclear reactor core is divided into three neutron flux components. A fast neutron component comprises those neutrons above about 0.1 MeV; an epithermal neutron component ranging from 0.2 ev to 0.1 MeV; and a thermal neutron component consisting of neutrons with energy below 0.2 ev. In most cases irradiation with the whole of the reactor's spectrum is performed, where the vast majority of the neutrons fall in the thermal energy range. Most nuclides capture thermal neutrons with a relatively high probability (cross sections), and epithermal and fast neutrons with a very low probability. Thus traditional activation analysis is used successfully and routinely in the quantification of a large number of elements in a geologic matrix, but this method is much less effective in detecting concentration levels of elements such as U and Th.

A variation of traditional neutron activation, epithermal neutron activation, is necessary when determining concentrations of U in geologic materials for two reasons. First, the ratio of these trace elements to the matrix elements (ie. Al, Na, Fe) present in geologic material is extremely small. Second, as previously stated, a nuclide must capture an incoming neutron in order to undergo a nuclear transformation. Uranium-238, unlike the majority of nuclides in geological material, has a relatively low probability of capturing thermal neutrons, and has a greater preference for the epithermal component of the flux. It is essential to optimize the number of collisions, as the signal generated by the newly formed nuclide, and subsequently measured, is directly proportional to the number of atoms that react with the incoming neutrons.

Epithermal neutron activation analysis allows the activation rate of nuclides with high epithermal cross sections to be enhanced relative to other nuclides by shielding the rock sample from the component of thermal neutrons. The selective penetration of epithermal neutrons is accomplished by placing a cadmium shield between the incoming neutrons and the rock sample. Cadmium metal has an extremely high absorption cross-section in the thermal neutron region, and, as such, is well suited in preventing their transmition. When a sample is irradiated behind a cadmium cover, virtually all the thermal neutrons are excluded (absorbed by the cadmiun) and only those neutrons with energies greater than 0.4 ev pass through to contribute to the activation process (Steinnes and Brune, 1969). For U, and additional elements which include Th, Ta, and Hf, this sheilding process enhances the fraction of activations by epithermal neutrons over that due to thermal neutron capture. Therefore, for complex matrices such as geologic samples, the activity level of the abundant light matrix radionuclides such as ^{24}Na (half-life=15h) and ^{56}Mn (half-life=2.58h) decreases to a much greater extent than the activities of U (Meyer, 1971; Parry, 1982). As a result, the radioactivity level of the U is enhanced permitting detection to approximately 0.1 ppm levels.

PROCEDURE

A broad spectrum of volcanic and plutonic rocks, representative of the major rock groups in Rhode Island, have been analyzed for U and Th content. Knowledge of Th concentrations permits calculation of a Th/U ratio which can offer insight into initial redox conditions of the magma body, or suggest secondary enrichment or depletion of U in a rock. Therefore Th was also measured using the epithermal enhancement method (as with U, it has a high probability of capturing epithermal neutrons).

After field collection, the rocks samples are ground and prepared for analysis using rock grinding and powdering equipment in the Geology Department. Routine major and trace chemisty analysis are done, as needed, on a Kevex ED-XRF system that is fully operational in the geology department. Splits of each powdered sample are analyzed for U and Th by epithermal neutron activation techniques at the Rhode Island Nuclear Science Center. In preparation for each irradiation, approximately 300 mg of powdered rock sample is weighed into 2/5 dram polyethylene capsules and heat sealed to avoid post-irradiation spillage of the radioactive sample. A flux monitor is necessary for each sample and consists of a 5 cm length of iron wire. The wire serves to record the neutron flux on each sample, as this flux is not uniform among all samples. Each cleaned and weighed iron wire is wrapped and taped around the sealed sample capsule.

The samples, with their respective flux wires, are then placed in one of two cadmium vials designed to hold nine samples each. Each Cd vial measures 7.75 cm in height and 2.92 cm in diameter. These two Cd vials were inturn placed in a rabbit and irradiated at a flux of 4×10^{12} n/cm^2-sec for three hours. Irradiations are done in the late afternoon on any given day to ensure that the rabbit remains in the reactor overnight following shutdown. This necessary precaution allows the Cd isotopes produced sufficient decay time before being released to the rabbit station the following day.

After removal from the rabbit, the samples are separated from the encapsulating cadmium, thus immediately lowering exposure levels, and are then stored in an appropriate facility in the reactor. The samples and standards are measured for their gamma-ray spectra on a lithium drifted germanium detector (Ge(Li) with an energy resolution of 0.5 KeV/channel and an efficiency of 21%. Counting of each of the 18 samples is done seven days after irradiation in order to obtain the gamma-spectra indicative of ^{238}U. The samples are counted a second time 18 days following irradiation for the spectra resulting from the ^{234}Th in the sample. In both cases the 18 samples are placed in an automatic sample changer and counted for 2 hours each. Each of the spectra are recorded and appropriate data stored on magnetic tape.

The gamma-ray spectra are then evaluated using the total peak area method. A peak height analysis program is run which identifies and labels the energy (in KeV units) of each peak and the corresponding intensity (counts/second) for each of the spectra. The data from the peak height analysis program are then entered into the spreadsheet program QUATTRO™. A macro has been written specifically to convert peak intensities corresponding to U and Th in the sample to final concentrations (ppm).

RESULTS:

A major early effort of our work has been to develop and perfect the above analytical technique to quantitatively determine U and Th concentrations in geological material. Compared to several alternative analytical techniques for U and Th analysis, the chosen method requires a simpler set-up, less preparation per sample, and has been proven quantitatively accurate and statistically reproducible. This method is now of potential use to other researchers and constitutes a valuable by-product of our work.

A broad range of bedrock samples from Rhode Island and adjacent Connecticut and Massachusetts have been evaluated for U and Th content (Tables 1, 2, and 3). A generalized bedrock map of southeastern New England (Fig. 1) shows the prominent rock units in Rhode Island. The bedrock in the state is separable into two distinct assemblages with different late Precambrian and Paleozoic components. The boundary between these two terranes is a zone of ductile deformation termed the Hope Valley Shear Zone (O'Hara and Gromet, 1985). The western Hope Valley terrane is dominated by pervasively deformed Precambrian gneisses of granitic composition whereas the eastern Esmond-Dedham terrane consists of crystalline rock of varying compositions, as well a metasedimentary rocks of the Narragansett basin. Previous work in Rhode Island has emphasized the characterization of the petrology and geochemistry of the crystalline rocks of this terrane, thus allowing division into two broad suites; calcalkaline and alkaline complexes, with further subdivisions based on age.

Trace element data from plutonic and volcanic rocks clearly discriminate the two mentioned suites (Hermes and Murray, in press). Alkalic suites are generally enriched in high field strength elements such as Zr, Nb, Ta, Y and Zn, and are thought to represent within plate, anorogenic plutons (Whalen and others, 1987). Commonly, granitic rocks enriched in these high field strength elements also show high concentrations of U (Harris and Marriner, 1980). In Rhode Island, the Scituate Granite and Quincy Granite (Fig. 1) are potassium feldspar, alkali-rich granites containing anomalously high levels of Zr, Nb, Y, and Zn (Hermes and others, 1981; Hermes and Zartman, 1985). The Devonian Scituate Granite and related rocks comprise a significant portion of the state, encompassing an area greater than 700 km^2. This suite of rocks is divided into a hypersolvus one feldspar peralkaline granite to the east and northeast and a less-alkalic subsolvus two feldspar granite to the west. Volcanic counterparts are the Spencer Hill volcanics.

Calcalkaline rocks, associated with island arc processes and typical of compressional plate margins, are chemically distinct from rocks of alkalic affinity. The calcalkaline plutonic and volcanic rocks of the Esmond-Dedham terrane have Precambrian and Paleozoic representitives. The Precambrian rocks include the Esmond Granite and related plutonic rocks, as well as quartz-rich granitic gneissic rocks. In addition, there are minor associated volcanic rocks. The granites of calcalkaline affinity differ from alkalic granites in that they typically have lower concentrations of the high field strength elements, but higher Ba and Sr levels. As levels of the selected trace elements Nb, Y, Zr, and Zn are lower in these calcalkaline rocks, it is suspected that U concentrations may also be low.

The youngest calcalkaline suite is the Narragansett Pier Granite , a large Permian batholith located along Rhode Island's southern coast (Fig.1). The Narragansett Pier Granite is a peraluminous, two-mica granite associated with abundant pegmatites and distinct from the more meta-aluminous Precambrian calcalkaline lithologies. This granite is a suspected potental radon source rock as two-mica granites elsewhere have been identified as a lithology with potential for yielding elevated concentrations of ^{222}Rn in groundwater. Two-mica granites tend to be enriched in U and are associated with some of the highest reported groundwater radon values (Lanctot and others, 1985; Campisano and others, 1986; Thomas, 1986; Wathen, 1986). This granite locally intrudes Carboniferous metasedimentary rocks of the Narragansett Basin. These basin rocks are interpreted as non-marine, primarily braided stream deposits.

Results of U and Th from representative plutonic and volcanic rocks in Rhode Island and adjacent Connecticut and Massachusetts are presented in Tables 1 and 2, respectively. U and Th values from selected samples of metasedimentary rocks of the Narragansett Basin are shown in

Table 3. While the final results exhibit a considerable range in U and Th levels, the lower concentrations are consistently found in the Precambrian rocks of calcalkaline affinity and the Hope Valley gneissic rocks. Among the plutonic suites, U levels range from 1.4-4 ppm and Th from 5.0-21.3 ppm (Table 1). Associated volcanic rocks overlap these concentrations ranging from 2.0-3.2 ppm U and 9.3-12.0 ppm Th, excluding the Hunting Hill Greenstone which is basaltic and expected to contain significantly less U and Th as compared to the more felsic rocks (Table 2).

The Permian aged Narragansett Pier Granite consists of two distinct and mappable facies recognized on the basis of textural and color variations. A pink facies comprises the bulk of the pluton while a white or leucocratic facies exists in the eastern corner of the granite body. The distribution of U and Th in these rocks tends to be bimodal (Table 1). Six of the seven pink facies rocks sampled yielded low to moderate U and ranged from 2.7 to 5.7 ppm. The same samples were generally found to be enriched in Th with levels from 22.0 to 103.2 ppm, the highest concentration found in this study to date. The three leucocratic samples are more enriched in U relative to the pink facies (7.6-13.1 ppm), yet contain significantly less Th. The bimodal distribution of U and Th suggests that the U may have been mobilized and reprecipitated in rocks of the white facies and is possibly related to the reduced nature of the adjacent sedimentary rocks of the Narragansett Basin which are locally rich in carbonaceous material.

Clearly concentrations of both U and Th are higher among the alkalic rocks sampled. The plutonic rocks range from 2.2 to 22.8 ppm with the highest U consistently found in the peralkaline Rhode Island Quincy Granite and one-feldspar hypersolvus Scituate Granite. The elevated U and Th values are consistent with previous geochemical and petrological work in this region. The alkalic rocks of southeastern New England are known to be higher in trace elements Rb, Zr, Nb, and Zn, and lower in Sr and Ba compared to the Precambrian calcalkaline unite (Hermes and Zartman, 1985; Hermes and Murray, in press). Commonly, granitic rocks enriched in these high field strength elements also show high concentrations of U and Th (Harris and Marriner, 1980), an observation also supported by the data of this study.

The clastic sediments of the Narragansett Basin yielded low to moderate U and Th values (Table 3). The samples analyzed were from the Rhode Island Formation, the most extensive formation, comprising more than eighty percent of the basin. Sedimentary samples were collected from two of the most populated areas in the state, Cranston and North Providence.

DISCUSSION AND CONCLUSIONS:

Approximately 70% of RI is underlain by rock of granitic composition, with the remaining 30% consisting of sedimentary strata. Of importance is the widespread occurrence of alkali-rich granitic rocks and the two-mica granite, rock types which elsewhere have been shown to be amongst the most enriched in primary U (Harris and Marriner, 1980; Campisano and others, 1986; Thomas, 1986; Wathen, 1986). Characterization of uranium in bedrock permits identification of areas where geologic conditions may be favorable for potential radon problems. This is not to say that a predictive model can be based soley on U "hot spots", but rocks enriched in U are first order concerns with regard to indoor air and groundwater accumulations of Rn.

Aeroradioactivity maps delineate patterns of radioactivity, which may reflect the gross pattern of bedrock lithologies. Goldsmith and others (1977) examined radioactivity patterns of Popenoe (1966) in southeat Connecticut and adjacent areas of Rhode Island. They concluded that the Narragansett Pier and Westerly Granites define a field of high radioactivity, with nodes of more than 1,000 cps centered over dikes of Westerly Granite. In addition, they suggest that material derived fron these rocks is apparently responsible for a relatively high level of radioactivity in the glacially formed Charlestown Moraine immediately to the south of the outcrop area. The aeroradioactivity study was predominantly limited to correlations between bedrock and aeroradioactivity in Southeastern Connecticut, but overlapping areas in Rhode Island show correlations as well. Regions of extreme high aeroradioactivity do correlate with bedrock. For example, the Scituate Granite, the major alkalic pluton in the state, as well as the Quincy Granite, both show elevated levels in the aeroradioactivity data, which is consistent with the high U and Th data collected in this project. Thus, these analyses serve to compliment and expand upon observations of the aeroradioactivity studies.

It remains unclear if radon levels might directly relate to such diverse distributions of U in bedrock as observed in this study. It is clear, however, that knowledge of U levels in bedrock and the distribution geographically of U is crucial to the understanding of radon occurrence and mobility in the groundwater environment.

PUBLICATIONS AND PROFESSIONAL PRESENTATIONS:

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* oral presentation was given at meeting

M.S. THESIS: Nancy Nevins, expected completion fall 1989

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Table 1. Results from range of plutonic lithologies (NPG=Narragansett Pier Granite)

SAMPLE ID	ROCK UNIT	LITHOLOGY	U (ppm)	Th(ppm)
<u>SUBALKALIC</u>				
PRECAMBRIAN				
RI-HV85-105	HOPE VALLEY	GNEISS	2.2	5.2
RI-CAR85-114	HOPE VALLEY	GNEISS	1.7	16.0
RI-CAR85-115	HOPE VALLEY	GNEISS	2.9	13.4
PEC-710	HOPE VALLEY	GNEISS	3.2	12.2
CT-VO-3	HOPE VALLEY	GNEISS	4.3	17.9
CT-VO-1	HOPE VALLEY	GNEISS	3.4	25.9
G2386-706	HOPE VALLEY	GNEISS	4.0	26.8
DH61781-1A	HOPE VALLEY	GNEISS	5.8	31.5
<u>CALC-ALKALIC</u>				
PRECAMBRIAN				
BLHdgd2	DEDHAM	GRANODIORITE	1.4	5.6
AM118853	DEDHAM	GRANODIORITE	3.5	11.9
AM109851	ESMOND	GRANODIORITE	2.5	16.2
AM911852	ESMOND	GRANITE	2.1	12.2
DH71586-3A	ESMOND	GRANITE	2.8	11.9
DH1010-85-5	ESMOND	GRANITE	1.7	12.3
DH72580-1	ESMOND	FINE GR GRAN	2.6	13.4
DH71580-1	ESMOND	GRANITE	0.9	12.1
DH71580-2	ESMOND	TONALITE	1.7	5.0
DH100386-2B	ESMOND	TONALITE	1.5	8.5
DH71580-3	ESMOND	GRANODIORITE	1.5	11.1
G2835-C723	POTTERHILL(CONN)	GR. GNEISS	1.8	13.9
TRG-1	TEN ROD	GR. GNEISS	2.3	10.9
DH61385-1B	TEN ROD	GR. GNEISS	2.8	12.4
NORWG15	WESTWOOD(MASS)	GRANITE	4.0	21.3
PERMIAN				
DH10785-6	NPG-Pink	GRANITE	3.5	59.8
SC-C	NPG-Pink	GRANITE	3.6	51.7
NT-D	NPG-Pink	GRANITE	4.1	40.0
AM92851	NPG-Pink	GRANITE	5.3	80.6
AM1029851	NPG-Pink	GRANITE	14.9	22.0
N-SHN-1	NPG-Pink	GRANITE	5.7	103.2
N-BF-1	NPG-Pink	GRANITE	2.7	65.7
WC-E-1	NPG-White	GRANITE	7.6	68.3
AM111851	NPG-White	GRANITE	11.0	6.6
NA-F	NPG-White	GRANITE	13.1	12.2
AM820851	WESTERLY	GRANITE	4.0	64.4
<u>ALKALIC</u>				
ORDOVICIAN				
AM118-85-1	QUINCY(MASS)	1 FELD.GRAN.	4.6	14.6
DEVONIAN				
NH88485	SCITUATE	2 FELD.GRAN.	2.8	24.5
NH38385	SCITUATE	2 FELD.GRAN.	2.4	17.3
AM92852	SCITUATE	2 FELD.GRAN.	2.9	16.3
RI-HV-85-101	SCITUATE	2 FELD.GRAN.	3.8	23.6
RI-HV-85-103	SCITUATE	2 FELD.GRAN.	8.2	46.0
RI-CAR85-104	SCITUATE	2 FELD.GRAN.	13.2	58.1
RI-OH-10	SCITUATE	2 FELD.GRAN.	3.1	18.2
RI-83-1	SCITUATE	2 FELD.GRAN.	3.4	17.3
RI-83-2	SCITUATE	2 FELD.GRAN.	5.1	23.8
DH102381-5	SCITUATE	2 FELD.GRAN.	6.3	20.6
DH102486-4	SCITUATE	2 FELD.GRAN.	2.7	12.5
DH102381-4	SCITUATE	2 FELD.GRAN.	2.9	15.4
DH72580-3	SCITUATE	1 FELD.GRAN.	9.5	28.9
DH40489-1	SCITUATE	1 FELD.GRAN.	7.0	21.1
CP-A	SCITUATE	1 FELD.GRAN.	9.9	35.1
CP-B	SCITUATE	1 FELD.GRAN.	3.9	19.7
AM911851	SCITUATE	1 FELD.GRAN.	5.8	22.5
AM1028851	SCITUATE	1 FELD.GRAN.	11.2	33.8
PCG-1	SCITUATE	1 FELD.GRAN.	22.8	68.7
DH72180-1	SCITUATE	1 FELD.GRAN.	8.7	27.4
DH72280-3	SCITUATE	1 FELD.GRAN.	2.3	18.3
NH11102685	SCITUATE	1 FELD.GRAN.	2.2	17.3
CARBONIFEROUS				
DH72580-2	RI QUINCY	1 FELD.GRAN.	10.9	20.0
AM81685-1	RI QUINCY	1 FELD.GRAN.	18.8	63.8

Table 2. Results from a range of volcanic lithologies

SAMPLE ID	ROCK UNIT	LITHOLOGY	U (ppm)	Th (ppm)
CALC-ALKALINE				
PRECAMBRIAN				
42985-3A	LYNN	FELSIC	3.2	12.0
ODHMT-5	MATTAPAN	WELDED TUFF	2.3	9.3
DH111886-1	HUNTING HILL	GREENSTONE	0.3	0.4
DH111886-4	HUNTING HILL	GREENSTONE	0.7	2.3
DH111886-2	HUNTING HILL	GREENSTONE	0.1	0.4
F-7-2	DIAMOND HILL	FELSITE	2.0	10.5
F-8-N	DIAMOND HILL	FELSITE	2.1	9.3
ALKALIC				
ORDOVICIAN ?				
BLHMV15	?	FELSITE	6.5	22.2
101085-4	?	FELSITE	8.0	25.2
DEVONIAN				
80586-1C	SPENCER HILL	FELSITE	8.0	33.5
72386-4B	SPENCER HILL	PORPHRY	2.4	24.3
80586-1F	SPENCER HILL	FELSITE	9.3	25.3
80586-5B	SPENCER HILL	FELSITE	9.8	35.2
CARBONIFEROUS				
51485-3	WAMSUTTA	FELSITE	2.6	12.8
100786-4	WAMSUTTA	FELSITE	3.0	13.4
100786-9B	WAMSUTTA	BASALT	0.6	1.6

Table 3. U and Th results from sedimentary rocks of RI Formation, Narragansett Basin

SAMPLE ID	LITHOLOGY	U (ppm)	Th (ppm)
NN01889-1A	BLACK SHALE	5.1	14.2
NN01889-2B	BLACK SHALE	4.9	16.5
CORE	BLACK SHALE	3.2	17.1
NN01889-2C	SILTSTONE	7.0	12.3
NN01889-1B	SANDSTONE	0.7	13.1
NN01889-2A	SANDSTONE	3.2	9.7

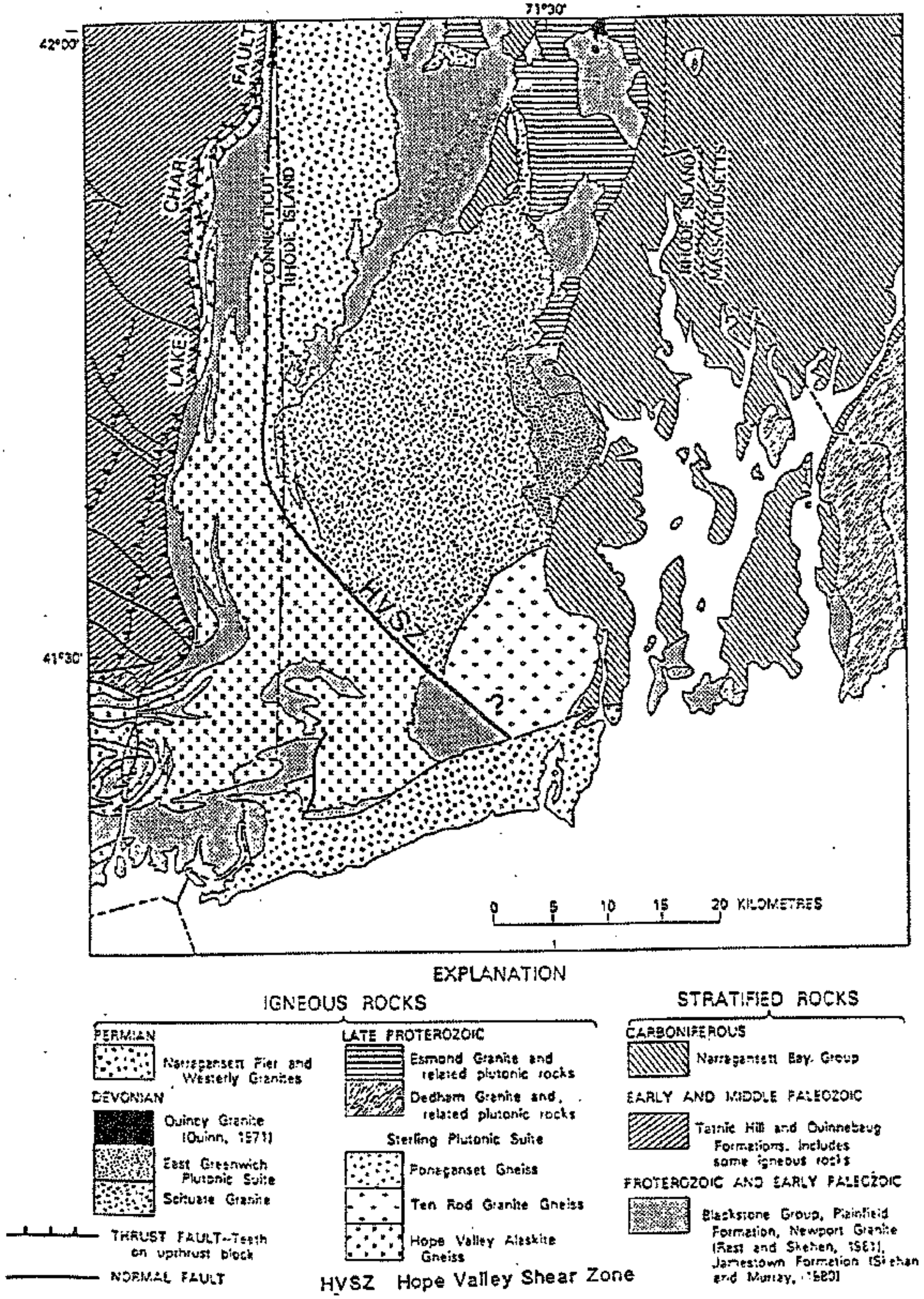

Figure 1. Generalized geologic map of southeastern New England emphasizing the volcanic and plutonic rocks referred to in this report. Geology after Quinn (1971), Zen (1983), Hermes and Zartman (1985), and O'Hara and Gromet (1985).

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MICROBIAL PROCESSES CONTROLLING THE FATE OF NITROGEN IN VEGETATIVE BUFFER STRIPS

by

P.M. Groffman, W.M. Sullivan J.L. Lemunyon

FINAL REPORT

RHODE ISLAND WATER RESOURCES CENTER

MICROBIAL PROCESSES CONTROLLING THE FATE OF NITROGEN IN VEGETATIVE BUFFER STRIPS

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PRINCIPAL INVESTIGATOR:

Peter M. Groffman
Department of Natural Resources Science

CO-PRINCIPAL INVESTIGATORS:

W. Michael Sullivan
Department of Plant Sciences

Jerrell L. Lemunyon
Department of Plant Sciences

UNIVERSITY OF RHODE ISLAND

KINGSTON, RHODE ISLAND

INTRODUCTION

The nature of non-point source pollution

The movement of pollutants from terrestrial environments into water bodies is a critical threat to water quality in many areas, including Narragansett Bay. Terrestrial land uses can deliver substantial loads of sediments, nutrients and toxic compounds into water bodies, leading to eutrophication, sedimentation, and biological decline. Understanding the terrestrial sources of pollutants, and the biological, chemical and physical factors affecting their fate and transport in terrestrial environments is essential to the maintenance of water quality for drinking supplies, navigation, fisheries and recreational uses.

Extensive basic and applied research has addressed specific "point source" pollutants over the last 20 years, and many advancements have been made towards their control. Non-point source (NPS) pollutants have proven more difficult to study and control however. These pollutants have multiple, diffuse sources and are affected by a wide range of chemical, physical and biological factors as they travel across the landscape. Small, diffuse non-point sources can multiply and interact to cause significant degradation of ground and surface water bodies however, and these pollutants have become proportionately more significant as point source controls have increased. The diverse origins of NPS pollutants greatly complicate their control because a wide range of control strategies are required, and these controls must be applied in a total landscape or watershed context. Many of these controls are expensive and difficult to justify at a local scale, given the diffuse and often poorly defined nature of NPS pollutants. Furthermore, landscape and watershed scale approaches to control are seldom attempted in scientific studies and are difficult to implement in a legislative context. Control of NPS pollution thus provides significant challenges to scientists and policy makers.

NPS pollutants can be classified based on their source, their chemical nature or their mode of transport across the landscape. In a heterogeneous landscape, NPS pollutants from agriculture, industrial areas, highways and suburban development often become highly mixed, making it difficult to pinpoint original sources. Chemically, NPS pollutants can be conveniently classified as nutrients, metals or organics. These pollutants can either be transported primarily by water flowing across the surface of the land (surface runoff), or by subsurface flow (groundwater). Different chemical types of pollutants with different modes of transport are affected by different physical, chemical and biological processes as they move across the landscape and thus pose distinct challenges for control.

Control of NPS pollution requires a mixture of engineering approaches with maintenance and augmentation of pollutant mitigation processes inherent in the environment. Surface runoff is frequently controlled by engineered drainage systems and detention basis that reduce the erosive power of runoff and allow for settling and stabilization of pollutants contained therein. Runoff control systems are often dependent on and/or are designed to augment natural infiltration and biological degradation processes present in soil. Groundwater borne pollutants are more difficult to control since subsurface flow is difficult to isolate and treat. Biological and chemical pollutant degradation mechanisms in the subsurface are poorly understood and are not readily amenable to engineering solutions.

Vegetated buffer strips

Vegetated buffer strips (VBS) are an example of a NPS pollutant control mechanism that relies heavily on pollutant degradation mechanisms inherent in the environment. VBS are defined as "small strips of grass or other vegetation that are used to trap pollutants moving from land areas before they enter water bodies (SCS 1989)". VBS potentially can serve to intercept pollutants moving in both surface runoff and subsurface flow, and can facilitate a variety of biological and chemical pollutant attenuation mechanisms. The maintenance of riparian VBS was adopted as a "best management practice" (BMP) by the USDA SCS (Dillaha et al. 1988) and VBS are recommended for use as a complement to structural stormwater control devices in Rhode Island (Scott 1988).

Despite the emerging widespread use of VBS, there are several unresolved scientific issues relating to their effectiveness for controlling both surface runoff and groundwater pollutants (Hayes et al. 1988). Understanding of the physical processes that intercept pollutants, and of the chemical and biological processes that degrade pollutants in VBS are incomplete. Generating this understanding is essential for evaluation of the effectiveness of VBS in different situations and for developing management strategies to enhance their performance.

The concept of buffer strips originated from research that found that strips of riparian forest vegetation were important in maintaining stream water quality in areas of intensive agriculture (Karr and Schlosser 1978, Lowrance et al. 1984, Jacobs and Gilliam 1985). Riparian strips were found to effectively impede surface runoff moving out of agricultural fields, reducing sediment delivery to water bodies and increasing infiltration of surface flow. Soluble pollutants in both surface and subsurface flow moving through riparian zones were found to be subject to plant uptake, microbial degradation and chemical immobilization by soil particles. Major unresolved questions relating to the effectiveness of riparian filters center around the long term fate of pollutants trapped in sediments, soil and vegetation in the zones and to the effects of pollutants on biological resources in the buffer. The latter question has increased in importance as interest (and legislation) in wetland preservation has increased in recent years (riparian zones are often dominated by wetland ecosystems).

Research on the use of grass VBS to trap sediment and nutrients moving from agricultural operations began in the 1980's (Magette et al. 1987). Most studies have focused on removal of sediment in surface runoff by grass VBS (Young et al. 1980, Magette et al. 1987, Dillaha et al. 1988, Lee et al. 1989). The long term effectiveness of these strips, and their ability to remove soluble pollutants from surface and subsurface flow are not well established (Doyle et al 1977, Thompson et al. 1978, Young et al. 1980). The performance of either grass or forested VBS in non-agricultural zones is largely untested.

Factors controlling the effectiveness of VBS

For VBS to be effective NPS pollutant control mechanisms they must physically intercept pollutants and then either chemically or biologically remove or degrade them. Physical interception of surface runoff is complicated by the strong tendency of water to move in discrete channels. Such channelization can completely eliminate pollutant attenuation by VBS as water and pollutants can rapidly flow through the channels into either receiving water or wetlands. Once begun, channelization tends to increase in severity. Some type of engineered control system is necessary to insure that the erosive, channelizing force of runoff is dissipated before runoff enters the VBS. If uniform, "sheet flow" is achieved, sediments will be deposited and soluble pollutants will be subject to biological and chemical attenuation.

The ability of VBS to physically impede groundwater flow is low. Indeed, the major control mechanism for surface runoff in VBS is to increase infiltration of surface flow into soil, stimulating movement of soluble pollutants into groundwater. The ability of VBS to affect groundwater pollutants is dependent on the ability of plant roots, microorganisms and chemical binding processes to be active in the saturated zone through which groundwater flows. In upland areas, groundwater is usually well below the area of highest tree root and microorganism density.

Chemical mechanisms of pollutant attenuation that operate in VBS arise from the ability of soil mineral and organic components to absorb certain chemical species. Clay and organic matter surfaces contain negative charges that can absorb cations and many polar organic compounds. Most toxic metals are cations as is ammonium (NH_4^+), a major inorganic form of soil nitrogen (N). Cation absorption by soil is a dynamic process however, and any cations absorbed on a soil particle can be displaced and released to the soil solution. Furthermore, the cation absorbing capacity (cation exchange capacity, CEC) of soil is finite, and is controlled by the amount of clay and organic matter present. Clay and organic matter are in short supply in Rhode Island soils in general, and in subsurface soils in particular.

Biological pollutant attenuation mechanisms in VBS include plant uptake of nutrients and microbial processing of nutrients, metals and organics. Plant uptake of nutrients is dependent on the ability of plants to intercept and remove nutrients from either surface or subsurface flow. Plants differ greatly in their selectivity for particular nutrient forms and in the rate at which they take up nutrients. More importantly, nutrients trapped in plant tissues can later be released back into the soil solution as these tissues decompose. Storage of nutrients in structural tissues of trees (Ehrenfeld 1987), or in grass tissues that are later harvested (Brown and Thomas 1978) represent effective pollutant removal mechanisms. Clearly, some form of plant community management is necessary to maintain an effective plant uptake sink for nutrients in VBS.

Microorganisms have the ability to degrade organic compounds as food resources and to absorb (immobilize) nutrients and metals into their tissues to support growth. Microbial immobilization is reversible; nutrients that are absorbed can later be released, or mineralized, depending on the amount of nutrient available in soil. Nitrate (NO_3^-), the most mobile form of N, can be converted to N_2 gas by certain microorganisms that respire NO_3^- in the absence of oxygen. Wet (oxygen poor), organic rich wetland soils are thought to be excellent sites for this process (denitrification), but its significance in wetland soils may be greatly overestimated (Bowden 1987, Neely and Baker 1989). Microbial processes in subsurface soils are poorly understood but are likely strongly inhibited by a lack of organic carbon to support growth. Research is needed to establish if microbial processes can significantly contribute to pollutant attenuation in VBS and if strategies can be devised to favorably manage these processes in the environment.

Landscape aspects of VBS

While most research on NPS pollutants has focused on field scale dynamics of specific pollutants and control mechanisms, a larger scale approach is needed when considering the cumulative impacts of land use changes on large water bodies such as Narragansett Bay. The use of VBS must be considered in relation to upstream and downstream sources of pollutants and biological resources. VBS and other NPS control mechanisms must be considered in the context of total watershed management since receiving water quality is the product of integrated, watershed scale factors.

A major landscape scale issue concerns the role of upland VBS as buffers for wetlands versus the role of wetlands as buffers for streams, lakes and coastal water bodies. Protection of wetlands is explicitly mandated by both federal and state legislation, yet the role of wetlands as landscape scale pollutant attenuation mechanisms has been extensively studied (Lowrance et al. 1984, Neely and Baker 1989) and is frequently cited. Wetlands are effective as buffers because pollutants in both surface and subsurface flow come into contact with surface soil and vegetation, maximizing the potential for biological and chemical attenuation of pollutants. Given that it is difficult to obtain this type of contact in upland areas (especially for subsurface flow), the development of VBS for wetland protection is problematic. Roman and Good (1985) presented a comprehensive approach for establishing upland buffers for wetlands in the New Jersey pinelands but they stressed that the mechanisms operating in upland buffers were not well characterized, and that much further research was required. The ability of upland areas to act as buffers is a critical question. We must determine if we will need to implement stronger controls on upland pollutant sources to protect wetlands, or if we will rely on wetlands to buffer receiving water bodies from upland land uses (with the potential for wetland degradation).

Landscape analysis of VBS must also consider aesthetic and wildlife habitat values of buffer areas. The maintenance of open space and wildlife (including rare and/or endangered species) can be advanced by the use of VBS for water quality maintenance, and can provide additional justification for their implementation as part of watershed management plans (Brown et al. 1987). Quantitative evaluation of aesthetic values is problematic however since it is based on subjective factors, and there are no generally accepted criteria or models currently available. The wildlife value of buffers is difficult to assess since wildlife habitat suitability is affected by many factors that vary widely in different types of VBS. Food, nesting and roosting resources, and buffer width and edge, will control wildlife abundances and densities in VBS. Research in existing VBS is required to assess their value as wildlife habitat.

Objectives of this research

This research addressed the microbial processes that control the fate of N in VBS. Our objective was to measure the potential of grass and forested VBS to immobilize and denitrify NO_3^-, and to determine the factors controlling these processes in the field. The research was part of a larger effort directed towards comprehensive evaluation of VBS as NPS pollutant control and wildlife maintenance techniques. Other components of this effort (some of which are presented in this report), addressed the ability of different grass species to remove NO_3^- from surface runoff (funded by the Soil Conservation

Service), the attenuation of NO_3^- and metals in groundwater moving through forested buffers (funded by the Narragansett Bay Project) and the wildlife habitat values of forested VBS (also funded by the Narragansett Bay Project).

MATERIALS AND METHODS

Field plots

This experiment was conducted at the University of Rhode Island's Peckham Farm, in Kingston, Rhode Island. Experimental VBS were established as part of an ongoing USDA SCS study on soil classified as a Typic Dystrochrept. This soil contained 0.92% organic carbon, 2.53% organic matter, and a pH of 5.89. The full scope of the buffer strip study consisted of 10 different species of grasses, each replicated three times, making a total of 30 plots (Table 1). Each plot measured 3 m x 5 m in size, with a 0.70 m alleyway between alternate plots. The switchgrass and big bluestem were both propagated in a greenhouse and when they had grown to a height of approximately four inches, were then transplanted into their respective plots. The remainder of the grasses were grown from seed in the field. Situated above the grass plots was a 25 m x 100 m oat field which was graded to a 2% slope to provide runoff onto the grass plots.

On April 20, 1988, the grass plots, along with the oat field, were treated with 33 kg N/ha in the form of urea. Additional treatments with urea were confined to the grass plots. On July 22, 1988, 96 kg N/ha was added as a top dressing, and on September 30, 1988 another 48 kg N/ha was added to boost root and rhizome production for the winter. The plots were sprayed on June 8, 1988 with 0.28 kg/ha of Buctril and .07 kg/ha of Banvel, both of which are for broadleaved weed control. Additional spot treatment for Agropyron repens, was accomplished using a 2% glyphosate solution. The plots were mowed four times to a height of three inches to suppress weeds, allow the grasses to fill the plots, and to prevent the grasses from going to seed.

Ceramic lysimeter plates were installed below each grass plot to collect water percolating below the root zone as part of the ongoing SCS study. The plates were installed in triplicate below each of the ten species at an average depth of 70 cm. Leachate samples were collected for selected events in late 1988 and have been collected for every percolation event since March 10, 1989 as part of the SCS study. Nitrate in leachate samples was quantified using an ion chromatograph.

For microbial process studies, only two of the grass treatments, common reeds canarygrass (Phalaris arundinacea) and tribute tall fescue (Festuca arundinacea) were used. The reeds canarygrass was chosen because it is well adapted to a moist environment (such as riparian areas) and has the ability to uptake large quantities of nutrients. The tall fescue was chosen because it is a common plant used in many other studies. We also located microbial process study plots in well and poorly drained riparian forest sites adjacent to the grass VBS study area. The poorly drained site was situated in a soil that was classified as an Aquic Dystrochrept, with a depth to mottles of 25 cm. This soil contained 8.5% organic carbon, 0.32% total N, and a pH of 3.52. In the well drained site, the soil was classified as a Typic Dystrochrept, with a 66 cm. depth to mottles. This soil contained 5.1% organic carbon, 0.25% total N, and a pH of 4.23. Sub-plots of the forest sites were treated with lime (20 lbs/ft^2 in the poorly drained, 10 lbs/ft^2 in the well drained) to test for pH limitation of microbial N processes.

TABLE 1

Grass species and plot numbers in vegetative buffer strip experiment. Plots established as part of USDA SCS funded research.

Grass species	Plot numbers
Big bluestem	10, 15, 27
Bromegrass	4, 11, 24
Garrison creeping foxtail	2, 19, 30
Kentucky bluegrass	8, 16, 25
Orchardgrass	7, 20, 22
Perennial ryegrass	1, 13, 23
Reeds canarygrass	5, 17, 29
Sweet vernalgrass	9, 14, 26
Switchgrass	3, 12, 21
Tall fescue	6, 18, 28

Microbial process experiments

Denitrification was measured using soil core techniques described by Groffman and Tiedje (1989). Cores of 15 cm depth and 2 cm diameter were removed from soil, placed in plexiglass tubes and sealed with rubber serum stoppers. Cores were subjected to a variety of experiments.

Experiment 1. The first experiment began on July 6, 1988 and consisted of three parts carried out over a three day period.

Part 1:

The first part of the experiment measured *in situ* rates of denitrification and N_2O production in the different plots. Ten soil cores were sampled from each of the forest plots and each of the grass treatments. These cores were immediately capped and 5 ml of acetylene was added to every other core. Acetylene was added to inhibit the final step in the denitrification process, allowing us to quantify denitrification rates by measuring the accumulation of nitrous oxide (N_2O) in the sealed cores (Yoshinari and Knowles 1976). The remainder of the cores received 5 ml air. To ensure a proper diffusion of the acetylene throughout the core sample, the atmosphere in each core was mixed by pumping five times with a 60 cc syringe. These cores were then placed in the ground and left to incubate for a total of 6 hours. A 3 ml gas sample was taken from each of the cores after two and six hours of incubation. The samples were placed into 10.25 x 65 mm evacuated glass tubes and were returned to the laboratory. After taking the six hour sample, the caps were removed and the cores brought to the laboratory where they were stored at 4° C overnight.

Part 2:

In part 2 of the experiment, the cores were incubated under anaerobic conditions to test for oxygen limitation of denitrification. The following day, the cores were recapped using the rubber septum stoppers and were alternately evacuated, by means of a vacuum pump, and refilled using 99.999% pure nitrogen gas. All cores received 5 ml acetylene, were mixed and were incubated at 22° C for 6 hours, with gas samples taken at two and six hours. After the second sampling, the caps were once again removed from the cores, and the cores were stored at 4 C overnight.

Part 3:

In part 3, cores were amended with either NO_3^- or NO_3^- and glucose to test for NO_3^- and carbon limitation of denitrification. The following day, five cores from each of the plots were subjected to treatment with a 100 ppm NO_3^--N solution, while the other five cores from each of the plots were treated with a 100 ppm NO_3^--N and 1000 ppm glucose solution. Cores were sealed, made anaerobic and incubated and sampled as described above.

Experiment 2. The second experiment was conducted on the three days between July 25-27, 1988. The objective was to assess how much denitrification would occur following an addition of NO_3^-, thus simulating a runoff event. Ten cores were taken from each of the reeds canary grass, tall fescue, well drained forest, and poorly drained forest sites. Five cores from each of these sites were then treated with 10 ml of a 100 ppm NO_3^--N solution, and the other five cores were treated with 10 ml of a 100 ppm NO_3^--N and 1000 ppm glucose solution. The cores were capped, amended with acetylene and incubated and sampled as described above. After the six hour sample was taken, the cores were uncapped and stored at 4 C overnight. The cores were resealed, and incubated on the following two days to follow the response of the cores to the amendments over a three day period.

Experiment 3. This experiment was designed to determine if low pH limited denitrification in the forest plots. On August 9, 1988, two new 100 ft^2 forest plots were created, one located in the poorly drained section and the other located in the well drained section. These plots received 20 lbs/ft^2 and 10 lbs/ft^2 of lime, respectively.

Denitrification rates were measured in the well drained forest on September 6, 1988, and in the poorly drained forest on September 23, 1988. The experimental procedure consisted of taking 20 cores from each of the four forest plots, and returning these cores to the lab. Each set of 20 cores were then broken into 4 sets of 5, with each set receiving one of the following treatments; 10 ml distilled water, 10 ml of a 100 ppm NO_3^--N solution, 10 ml of a 100 ppm NO_3^--N and 1000 ppm glucose solution, and the forth set receiving no amendment. All cores were then capped, amended with acetylene and incubated and sampled as described above.

Before any of the cores from experiments 1, 2 and 3 were discarded, their weight and length were recorded. The head space of each core was then measured by calculating the difference between the pressure within the core, as measured with a pressure transducer, at atmospheric pressure and with 5 ml air added. Gas samples were analyzed for N_2O on a Tracor model 540 gas chromatograph equipped with two electron capture detectors and four 2 m columns packed with PorapakT.M. Q. The data were expressed on an areal basis using bulk density values determined on each core. Results were analyzed using the ANOVA procedure in the SAS statistical package. A duncans multiple range test and an LSD test of significance with a 0.05 confidence interval, were used to determine differences between treatments both within and between plots.

Experiment 4. In this experiment, denitrification was measured over an 8 day period in NO_3^- amended (4 μg/g soil) soils held in 946 ml mason jars in the laboratory. Levels of mineral N in soil were also measured to assay immobilization and re-mineralizataion of the added NO_3^-. Each jar contained 100 g soil, and denitrification and soil mineral N levels were measured 1 day before addition of NO_3^- and 1, 3 and 8 days following the addition. Denitrification was measured by sealing the jar with a lid containing a black rubber septum, adding 10 ml of acetylene, and taking gas samples at 2 and 6 hours following sealing. Acetylene was removed from the jars by evacuating and refilling the jar with air three times. The jars were left unsealed between denitrification measurements. Mineral N was extracted from 5 g subsamples with 2 N KCl and analyzed on an Alpkem RFA 300 continuous flow analyzer.

RESULTS

The average concentrations of NO_3^- in leachate from the 10 grass species ranged from 0.9 to 31.6 mg/L. Loading rates of NO_3^- to groundwater ranged from 2.2 to 106.1 kg/ha. The 10 grasses can be broken into four groups based on their loading rates (Table 2). All grasses received 177 kg N/ha as fertilizer. N removal efficiencies (calculated as N not leached/total fertilizer N input) for the grasses thus ranged from 40 to 99% of the N applied.

In experiment 1, aerobic, in situ rates of denitrification and N_2O flux were insignificant in all plots (Table 3). Anaerobic, unamended rates were also very low, but were somewhat higher in the poorly drained forest plot than

TABLE 2

Nitrate leaching losses (kg N/ha) and approximate N removal efficiencies for grasses in vegetative buffer strip experiment, Spring 1988 - Spring 1989. Data collected as part of USDA SCS funded research.

Grasses	Nitrate leaching losses	N removal efficiency
orchardgrass, sweet vernalgrass	2.0 to 10.0 kg/ha	94-99%
tall fescue, creeping foxtail	10.0 to 25.0 kg/ha	86-94%
perennial ryegrass, big bluestem	25.0 to 50.0 kg/ha	72-86%
kentucky bluegrass, reed canarygrass	> 50.0 kg/ha	<70%
bromegrass, switchgrass		

TABLE 3

Denitrification rate (g N ha^{-1} d^{-1}) in soil cores in response to amendments, 880706[1]

	Well drained forest	Poorly drained forest	Tall fescue	Reeds canary
Aerobic				
No amendment	-4.6^{c}	-8.7^{c}	-4.0^{b}	2.0^{b}
C_2H_2	-21.3^{c}	-16.3^{c}	-9.0^{b}	-2.0^{b}
Anaerobic with C_2H_2				
No amendment	1.1^{c}	13.1^{c}	1.0^{b}	1.0^{b}
NO_3^-	1306^{b}	1402^{b}	17208^{a}	15208^{a}
NO_3^- and glucose	2155^{a}	2951^{a}	21702^{a}	15819^{a}

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[1] Values followed by different supercripts within columns are significantly different at $p < 0.05$. The tall fescue and reeds canarygrass plots had significantly higher ($p < 0.05$) denitrification than the forest plots when all treatments were combined.

in the other plots (Table 3). Nitrate amended denitrification rates were higher ($p < 0.05$) than either aerobic or anaerobic unamended rates in all plots (Table 3). Nitrate and carbon amended rates were higher ($p < 0.05$) in all plots other than the reeds canary grass (Table 3).

In experiment 2, denitrification rates in NO_3^- and NO_3^- and carbon amended cores were in the order of: tall fescue > reeds canary grass > poorly drained forest > well drained forest (all differences $p < 0.05$, Table 4). Nitrate and carbon amended rates were higher than NO_3^- only amended rates in all plots, but the differences were significant in the poorly drained forest and reeds canary grass plots only (Table 4). The NO_3^- amendment in experiment 2 simulated a 31.8 kg N/ha addition. Denitrification N removal efficiencies for the different plots, (calculated as denitrification rate/total N addition), ranged from 1 to 50% per day (Table 4). Results from experiment 3 indicated that the lime amendment significantly increased soil pH in the forest plots, but denitrification did not increase accordingly (Table 5).

When NO_3^- was added to soils held in mason jars in the laboratory (experiment 4), soil from the reeds canarygrass plot showed the strongest denitrification response followed by the tall fescue and well drained forest plots (Figure 1). The poorly drained forest soil showed no denitrification response to added NO_3^- in this experiment. All soils other than the poorly drained forest were able to immediately absorb the added NO_3^- (Figure 2). However, levels of mineral N increased in all soils over the eight day incubation.

DISCUSSION

The results from the lysimeters suggest that the different grasses have dramatically different abilities to take up N. It is important to note that all grasses received 177 kg N/ha as fertilizer and therefore all grasses demonstrated a significant ability to take up N. However, N removal efficiencies (calculated as N not leached/total N fertilizer input), were rather low in many cases. These results were obtained during spring and summer, when N removal efficiencies should been highest due to high plant uptake of N and low leaching during this period. Results from a related SCS study conducted at the URI agronomy farm with VBS established and fertilized during winter found much lower N removal efficiencies by grass. In this study, tall fescue-perennial ryegrass VBS were established and fertilized with 33 kg N/ha in September. An average of 21 kg N/ha (64%) was leached overwinter. These results suggest that winter N removal efficiencies by VBS will be much lower than summer removal efficiencies. It is also important to note that the ability of grasses to take up N fertilizer does not necessarily predict their ability to remove N from runoff. We had hoped to directly measure removal of N from runoff during the summer of 1988, but technical difficulties hindered our efforts. These experiments will be done during 1989.

The ultimate fate of N taken up by vegetation in VBS is uncertain. N in plant tissues can be released during senescence and decomposition and can be re-mineralized and released into the soil solution. Some type of plant harvest is necessary to minimize this problem (Brown and Thomas 1978). Harvest of grasses is more straightforward than for trees since it is physically easier to accomplish and it stimulates regrowth of the grasses. Tree removal, or woodlot management, is more complex to accomplish and can involve considerable disturbance to soil in the VBS. Tree regrowth is often not immediate following harvest and thus tree removal can temporarily reduce VBS performance.

TABLE 4

Denitrification (g N ha^{-1} d^{-1}) response and N removal efficiencies for soil cores treated with simulated runoff containing either NO_3^- or NO_3^- and glucose, 880725[1]. Total NO_3^--N addition - 31,800 g N/ha.

Plot	NO_3^- amended		NO_3^- and glucose amended	N removal efficiency (% N denitrified/day) NO_3^- amended	 NO_3^- and glucose amended
Well drained[c] forest	311		408	1	1.3
Poorly drained[bc] forest	365	*	1439	1.2	4.5
Tall fescue[a]	7889		16186	25	51
Reeds canary[b] grass	4537	*	9139	14	29

[1] Plots followed by different supercripts showed significantly different denitrification activity over both to amendments at $p < 0.05$. *Indicates significant difference between NO_3^- and NO_3^- and glucose treatments at $p < 0.05$.

TABLE 5

Denitrification (g N ha^{-1} d^{-1}) in soil cores from limed and unlimed forest plots treated with simulated runoff, September 1988

Plot	pH	NO_3^- amended	NO_3^- and glucose amended
Poorly drained forest			
Limed	4.79	365	1102
Unlimed	3.52	336	1606
Well drained forest			
Limed	4.94	31	72
Unlimed	4.23	101	685

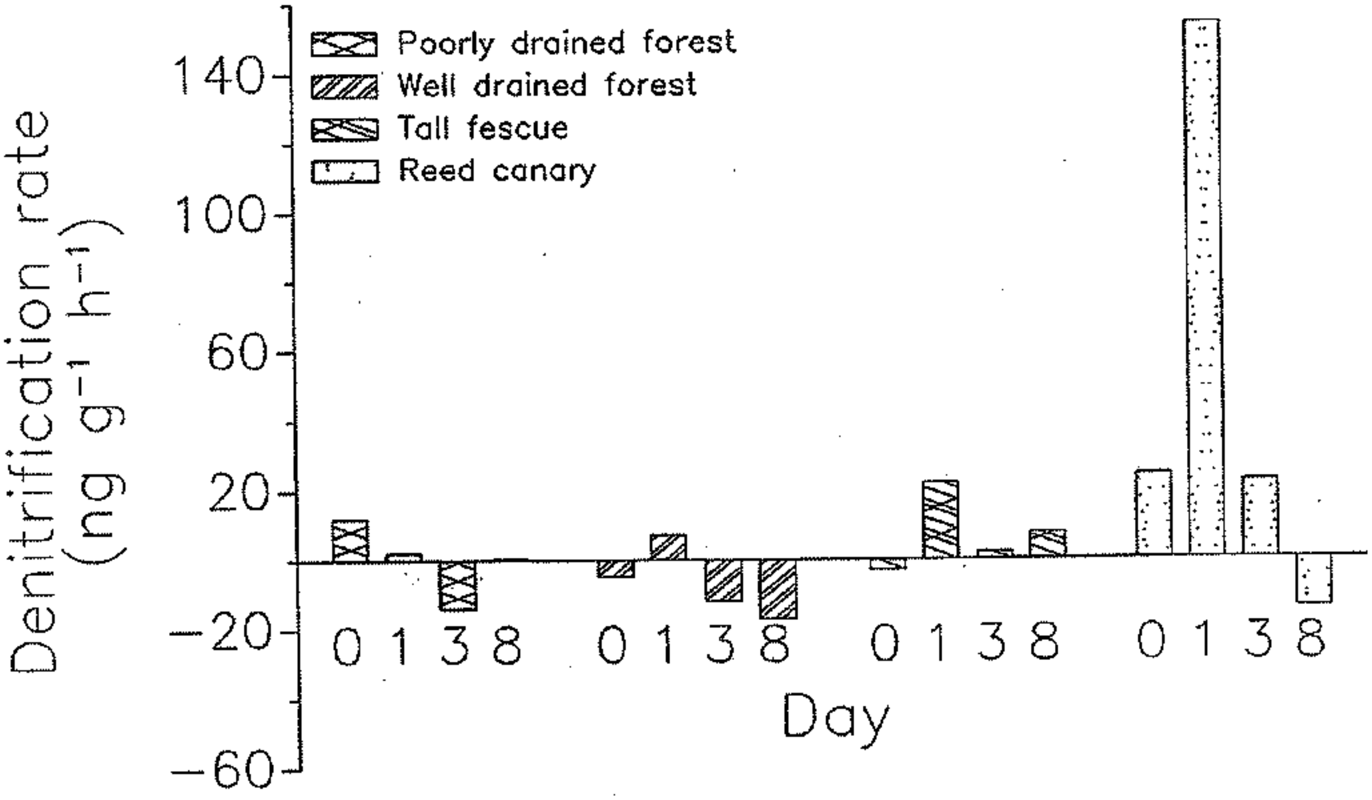

Figure 1 - Denitrification response to added NO_3^- (4 ug/g soil) over 8 days in soil held in mason jars.

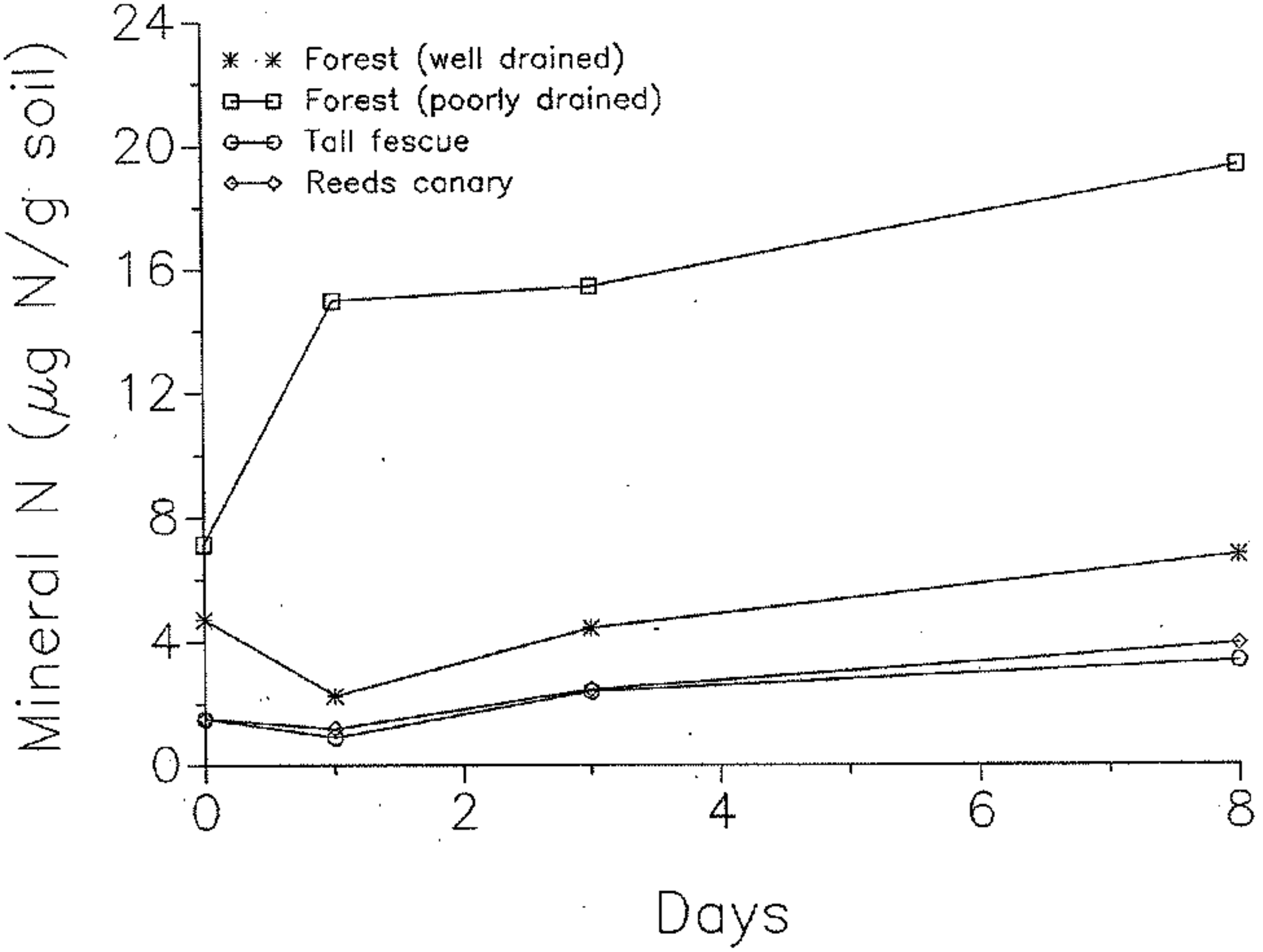

Figure 2 - Mineral N in soils held in mason jars that received 4 ug/g soil NO_3^--N immediately before day 1 sampling.

Data from experiment 1 found that in situ rates of denitrification in the plots were very low and were limited by the presence of oxygen and an absence of NO_3^- and/or glucose. Oxygen and NO_3^- control of denitrification have been reported in many studies (Tiedje 1988). However, the strong stimulation caused by glucose that was observed in the forest plots and not in the grass plots was surprising since the forest plots have high levels of organic matter relative to the grass plots. It is possible that tillage, fertilization and liming over time have increased substrate availability (both physical and biochemical) to microbes in the grass plots. Since the carbon amended incubations in experiment 1 were carried out under anaerobic conditions, the stimulation that we observed was due only to increasing the supply of substrates to denitrifiers and not to a reduction in soil oxygen levels caused by general stimulation of heterotrophic microbes as has been observed in other studies (Rice et al. 1988, Groffman and Tiedje 1988). The data suggest that carbon availability to denitrifiers may limit denitrification activity in forest soils more than has previously been thought.

We expected the forest plots to have a much higher potential for denitrification than the grass plots, since forest soils (especially poorly drained forests) generally have higher moisture and organic matter levels than upland agricultural soils. In contrast to our expectations, soils from the grass plots exhibited consistently higher denitrification activity than soils from the forest plots. In experiment 1, the grass plots had higher activity than the forest plots in anaerobic incubations of soil amended with either NO_3^- or NO_3^- and glucose. In experiments 2 and 4, the grass plots had higher activity than the forest plots in response to NO_3^- additions made to simulate runoff. These results suggest that carbon availability to microbes is higher in the grass plots than in the forest plots (discussed above), and that the population of denitrifiers is bigger and/or more active in the grass plots than in the forest plots.

Experiment 3 was done to test the hypothesis that low pH limited denitrification activity in the forest plots relative to the grass plots. Although we successfully raised the pH in the forest plots from 3.5 to 4.8 in the poorly drained plot and from 4.2 to 4.9 in the well drained plot (pH in the grass plots was 5.3), denitrification rates did not increase accordingly. Denitrification was actually lower in the limed plots than in the unlimed plots in most cases. This is likely due to the fact that microbes in soil are adapted to in situ physical and chemical conditions, and changing the pH thus reduced their activity (Koskinen and Keeney 1982). In the long term, raising soil pH should lead to the development of a different microbial community, with higher denitrification activity (Parkin et al. 1985). These results suggest that forested buffers in Rhode Island may not always be effective denitrification sinks for NO_3^-, and that managing these zones to increase denitrification is not simple and requires long-term study.

Denitrification N removal efficiencies calculated from experiment 2 (Table 4) were quite high in the grass plots, suggesting that up to 50% of a very large N addition (> 30 kg N/ha) could be denitrified per day. These results must be interpreted with great caution however, since they were obtained with soil cores and are not field measured fluxes. Adding amendments to confined soil cores does not allow for free drainage and thus stimulates the development of anaerobiosis in the cores and maximizes the accessibility of NO_3^- to denitrifiers. In experiment 4 (soil held in mason jars), simulated runoff was less confined and the denitrification response was less intense and was relatively brief. Measurements of denitrification in soil cores taken from field VBS that have received runoff are necessary to validate these results.

The simulated runoff experiments were useful in several regards however. First, the role of carbon in increasing N removal efficiency in all plots is clear. The carbon effect is likely due both to increasing substrate availability to denitrifiers (discussed above) as well as to depletion of soil oxygen levels resulting from a general stimulation of heterotrophic activity. These results suggest that runoff containing high levels of available carbon (feedlot or manured field runoff for example) may be more amenable to treatment in VBS than runoff that is low in available carbon. Second, the results suggest that if free drainage can be prevented, significant denitrification can occur in VBS. Flow of runoff through the VBS could be controlled either by surface contour engineering or subsurface drainage manipulation, creating a hybrid NPS pollutant control mechanism that utilizes aspects of VBS and common detention basins.

Results from the mason jar experiment suggest that immobilization of N by soil microbes is not a reliable N removal mechanism in VBS. All soils (other than the poorly drained forest) were able to absorb a spike of 4 ppm NO_3^-, but all soils showed net N mineralization over the next 8 days. These results suggest that N that is immobilized during runoff events, may later be released to the soil solution and may either leached to groundwater, or carried out of the VBS in the next runoff event. On the other hand, immobilization may be useful as a temporary sink for NO_3^-, allowing plant access to the N that is re-mineralized. This is especially important in light of the fact that N moving rapidly in runoff may not be particularly accessible to plant roots.

In summary, we demonstrated that there are major differences in the nature and extent of microbial processes in VBS of different types of grasses and soils. Our results suggest that low pH may limit the ability of forest soils to act as buffers, and that availability of carbon sources may ultimately limit denitrification in VBS. The study also suggests that N that is immobilized in VBS may be subject to re-mineralization and release. Management of VBS should focus on maximizing N removal by denitrification, perhaps by manipulation of flow through the VBS, and on maximizing N removal by plant harvest.

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RHODE ISLAND
WATER RESOURCES CENTER

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1892

COMPLETION REPORT FY-1988 PROGRAM

A MICROBIAL METHOD FOR REMOVAL OF METALS, CUTTING OILS & CYANIDE FROM POLLUTED WATER

by

R.W. Traxler, Tung-Ching Lee, D.R. Nelson

COMPLETION REPORT

A Microbial Method for Removal of Metals, Cutting Oils & Cyanide from Polluted Water

Submitted by

Richard W. Traxler, Principal Investigator
Food Science & Nutrition Department

Tung-Ching Lee, Co-investigator
Food Science & Nutrition Department

David R. Nelson, Co-investigator
Microbiology Department

Project No. G1612-04

to

U.S. Department of the Interior

FINAL REPORT

Project Number: 04

Start 6/1/87
End 5/31/89

Title: A Microbial Method For Removal Of Metals, Cutting Oils And Cyanide From Polluted Water

Investigators: Dr. R. W. Traxler, Univ. of Rhode Island
Dr. Tung-Ching Lee, Univ. of Rhode Island
Dr. D. R. Nelson, Univ. of Rhode Island

COWRR: 05D Waste Treatment Process

Descriptors: Bacteria, Biodegradation, Heavy Metals, Waste Disposal, Pollution Control

Problem & Research Objectives:

Rhode Island regulations limiting the discharge of toxic metals and cyanide into public sewers have been in effect for five years but the majority of affected platers and finishers are not in compliance with these regulations. Many of the larger firms meet discharge standards or are expected to do so in the near future, but the smaller companies have not had the resources to effectively meet these standards.

The magnitude of the problem is seen by the amount of heavy metal entering the Narragansett Bay Commission sewer system in recent years. The peak was in 1981 with 956,099 pounds release with a drop in 1985 to 409,657 pounds. The interim goal is to reduce this volume to about 200,000 pounds within a year. The existing technology for solution of this problem by chemical means is expensive. One of the larger companies was forced to spend $500,000 for a pre-treatment system. This type of a solution to the problem is beyond the capability of the smaller operator who does not have the capital resources for even a 5th of this type of investment. The ultimate result is that without a less expensive system these small companies will be forced out of business. This project is aimed at the small operation to provide to these companies a relatively simple, inexpensive but effective means of pollution control. The project, while of extreme potential value to Rhode Island, can also be applied to the same problem in other states.

A. The FY 1987 Objectives Phase I Metal Removal:

1. Expand resistance spectrum in one isolate, if possible, to include resistance to Cu, Pb, Ag, Cr, Zn, Cd, Ni and Hg.

2. Determine the kinetics of metal removal.

3. Determine the saturation level of cell mass.

4. Determine the effect of nutrients on metal removal.

5. Perform bioreactor studies with simulated and real waste for metal removal.

6. Determine the presence or absence of plasmid DNA which is linked to the objectives of Phase II.

B. Objectives for FY 1988, Phase II

1. Evaluate assays for metal resistance.

2. Develop a system to transfer genetic resistance of a metal from one bacterium to another.

3. Test a model system for metal bioaccumulation.

4. Investigate cyanide utilization.

C. Phase I Results and Discussion

Objective 1.

Using a serial enrichment-adaptation procedure we have been able to expand the resistance spectrum of Arthrobacter HC823 to a combined mixture of eight metals, each at a concentration of 50 ppm. The eight metals are: Cu, Pb, Ag, Cr, Zn, Cd, Ni, and Hg. This is a combined total metal ion load of 400 ppm of metal ion in the test system. We are delighted to be able to achieve this resistance pattern in one isolate.

In addition, we have determined the metal resistance of a natural isolate identified as a Flavobacterium sp. and a member of the genus Pseudomonas labeled strain PxR824, isolated from heavily metal polluted sediment. Tests have not been run to enhance the resistance of these isolates. Those metal listed as R (resistant) were resistant to 50 ppm of the metal while those listed as S (sensitive) would not grow in the presence of 1 ppm of the metal (Table 1.).

On isolation, the Flavobacterium sp. required 1 ppm of zinc for growth in solid or liquid medium. After sub-culture the organism no longer shows a Zn requirement for growth.

Table 1. Resistance spectrum of two environmental isolates.

Cation	Flavobacterium sp	Pseudomonas HC823
Pb	R	R
Zn	R	R
Cd	R	R
Cr	R	S
Cu	R	R
Ni	R	R
Ag	R	S
Hg	S	S

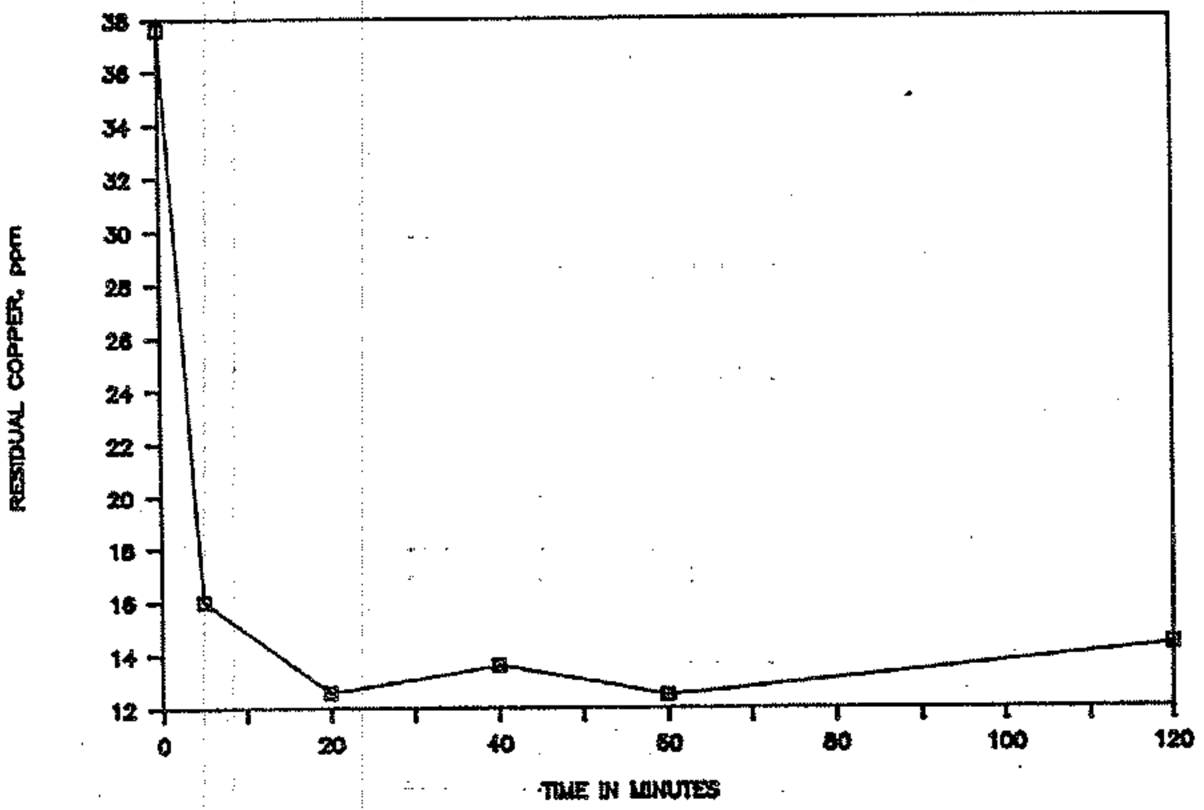
Objective 2.

Kinetic studies were initiated in November using Cu as the first metal in non-nutrient supplemented experiments. The first experiments indicate a much more rapid removal of the metal from a microbial suspension in distilled water than anticipated. We find the same rapid uptake by Arthrobacter HC824 with Pb, Zn, Ni, and Cr (Figures 1-5). Uptake of Ni and Cr are initially rapid for the first 5 minutes then the uptake rate is reduced. These differences in kinetics suggest different mechanisms associated with cell binding. Also, it is seen from these data that binding or uptake is highly efficient with Pb and Zn, less so with Cu and Ni, and poor with Cr.

Arthrobacter HC824 was tested in a mixture of Pb, Cu, Zn, and Ni suspended in distilled water plus yeast extract (Figure 6), and the metal content of the aqueous phase determined as an index of metal removal from solution. Lead was rapidly cleared from the aqueous phase. The efficiency of metal removal was less for Cu, Zn and Ni.

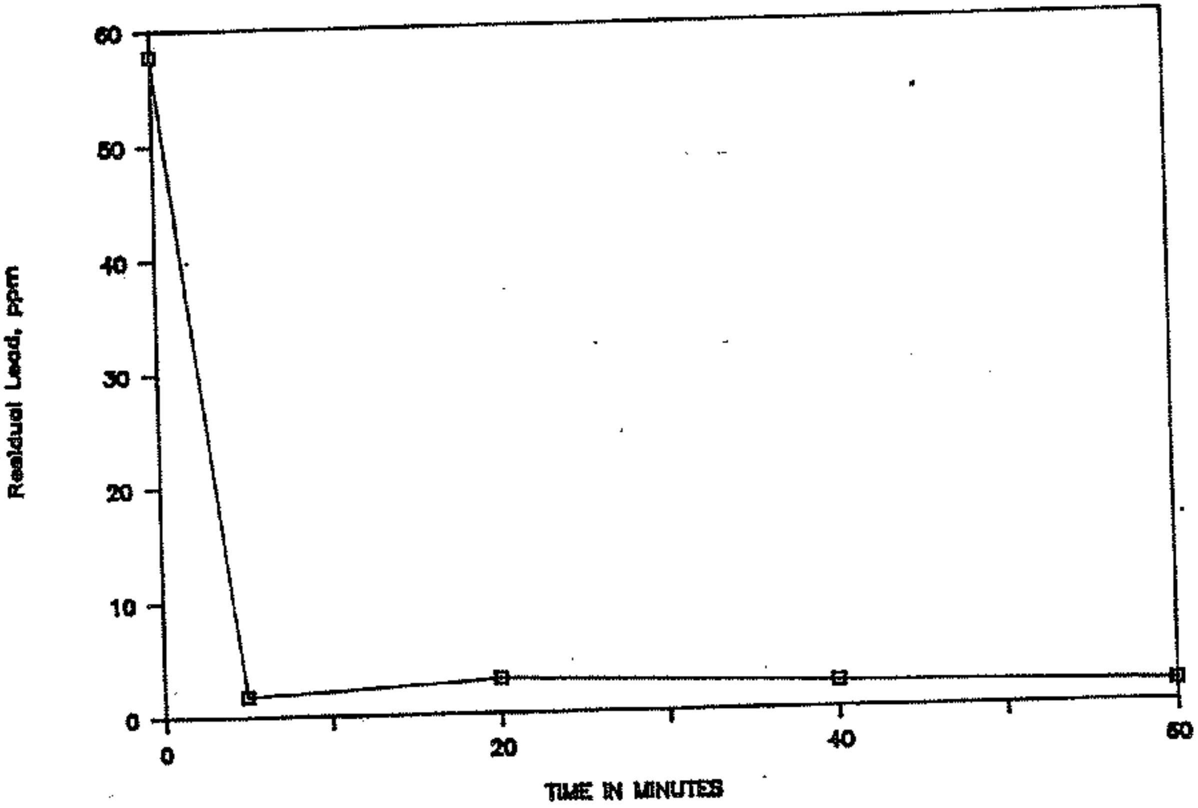
The first experiment with Pseudomonas PxR was conducted in a dilute mineral medium with glucose as the carbon source, and amended with Cu at 50 ppm. The cell mass (mg/ml dry weigh basis) was varied from 12-48 mg/ml (Figure 7). In this 3 hour experiment maximum uptake (50 %) was obtained with the highest cell mass, and there was a different relationship between cell mass and percentage metal uptake. A similar experiment performed in distilled water (Figure 8), does not show an increased metal uptake at cell masses above 22.6 mg/ml, which was optimal for Cu removal (85%). These experiments confirm earlier observations that metal removal from aqueous solution are inhibited to some extent in more complex media and media with even modest quantities of other inorganic salts.

Figure 1. Kinetics of Cu uptake By Arthrobacter HC824



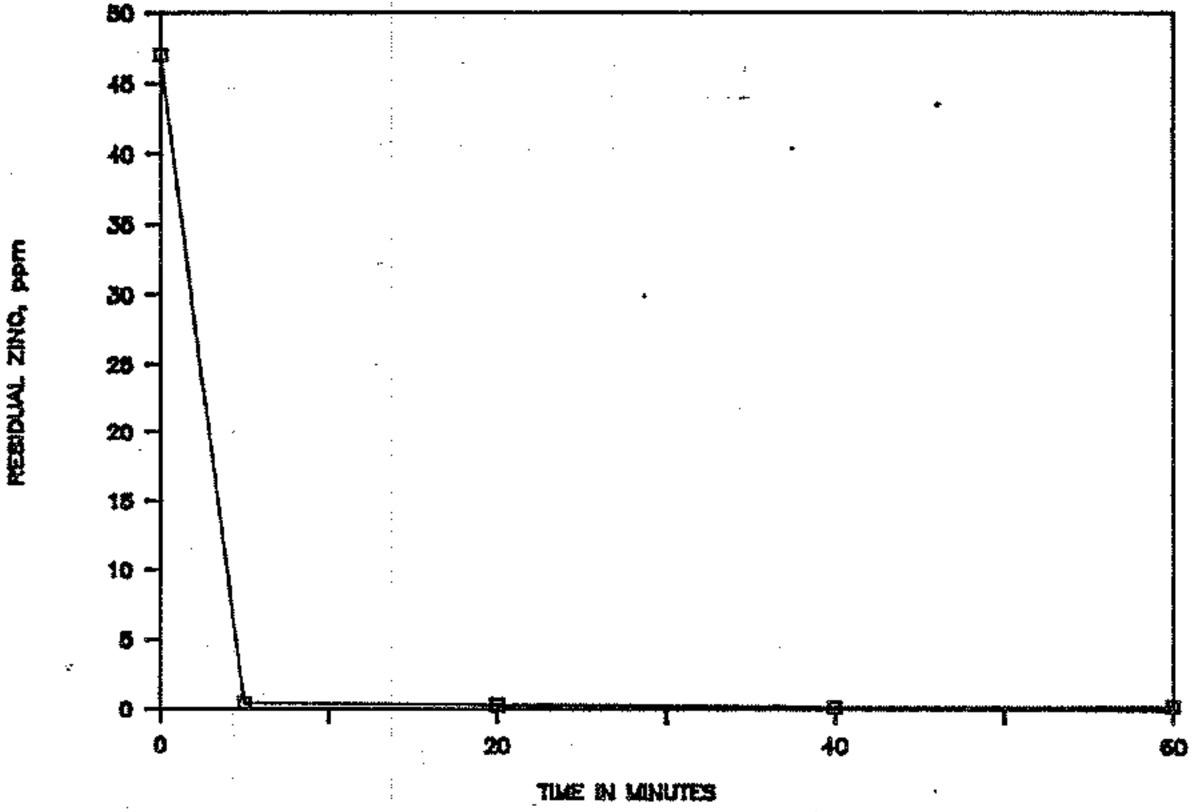
9.2 mg/ml of cells in distilled water + 0.01% yeast extract

Figure 2. Kinetics of Pb uptake by Arthrobacter HC824



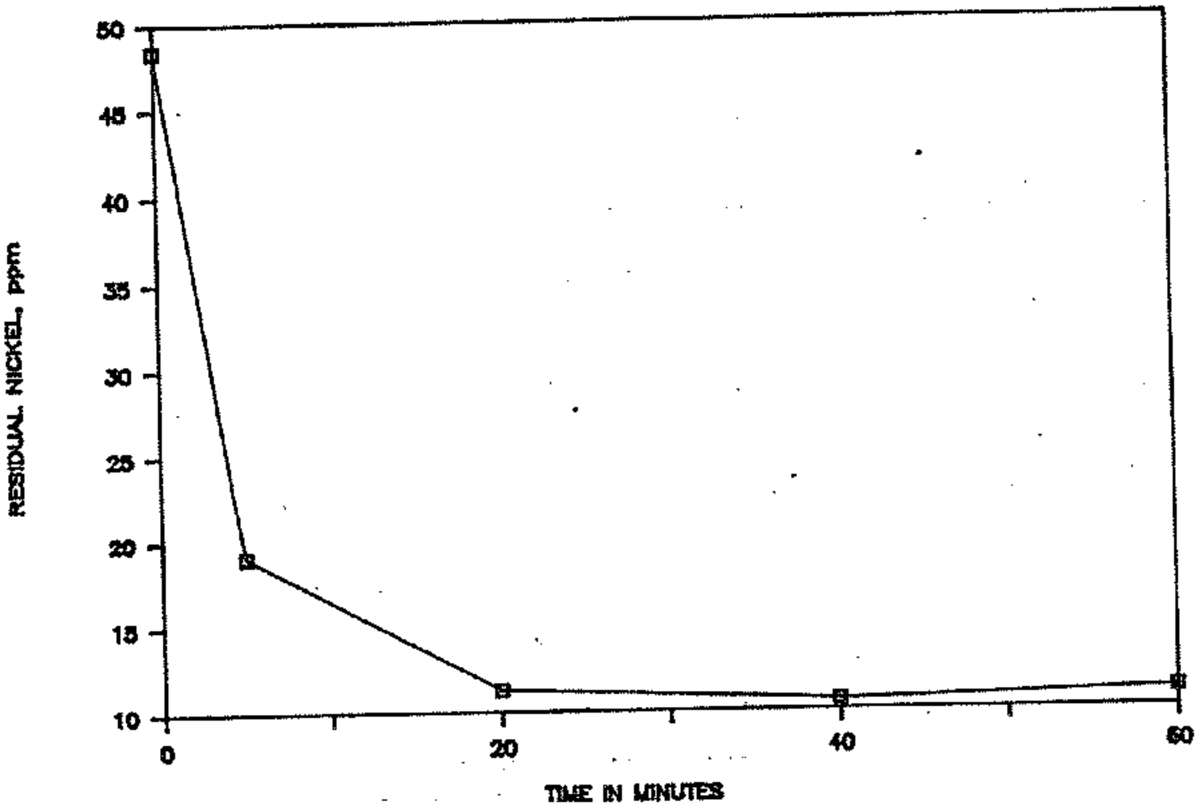
7.5 mg/ml of cells in distilled water + 0.01% yeast extract

Figure 3. Kinetics of Zn uptake by Arthrobacter HC824



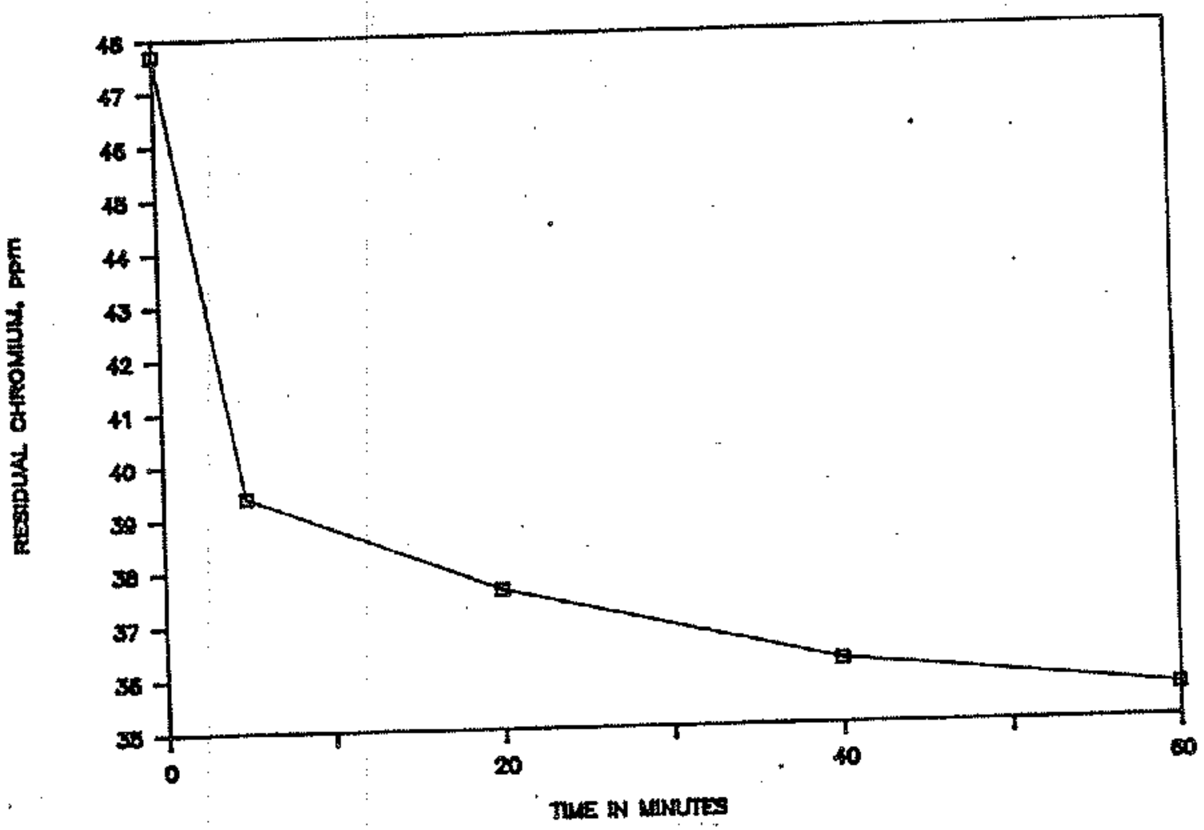
6 mg/ml of cells in distilled water +0.01% yeast extract

Figure 4. Kinetics of Ni uptake by Arthrobacter HC824



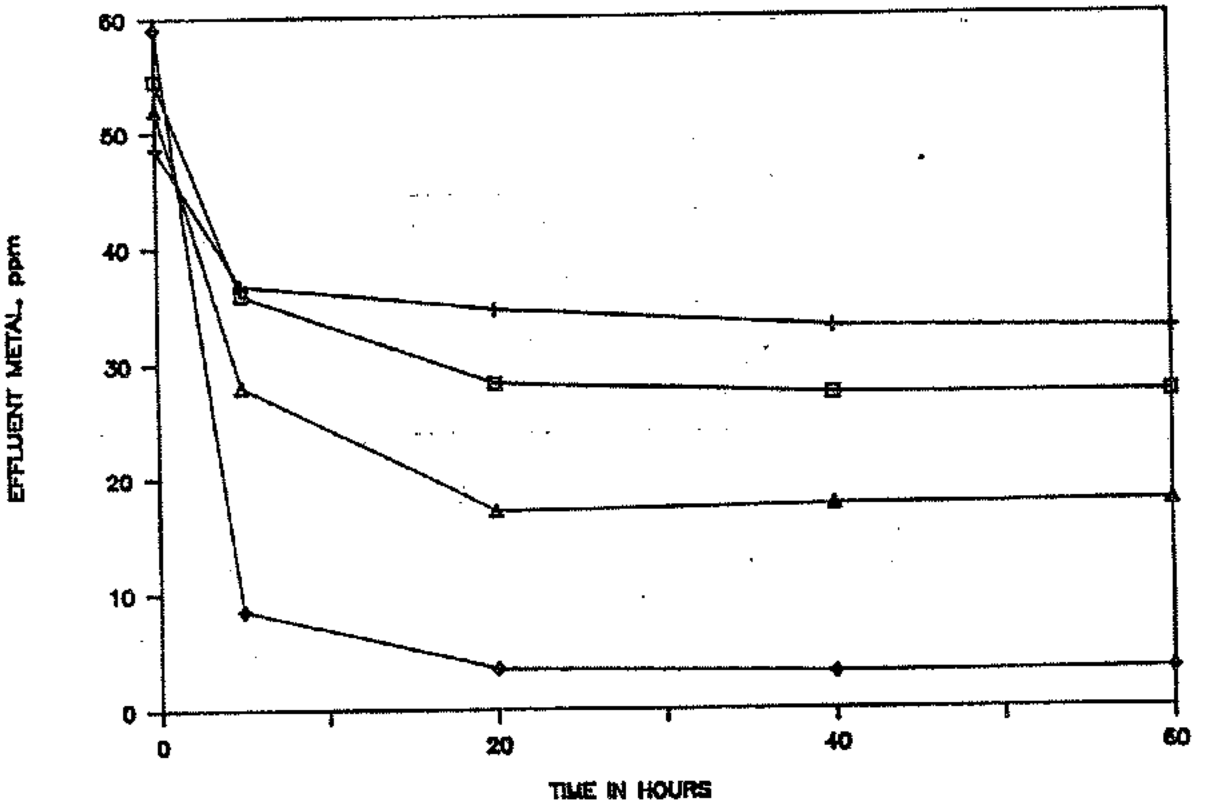
6.5 mg/ml of cells in distilled water + 0.01% yeast extract

Figure 5. Kinetics of Cr upatke by Arthrobacter HC824



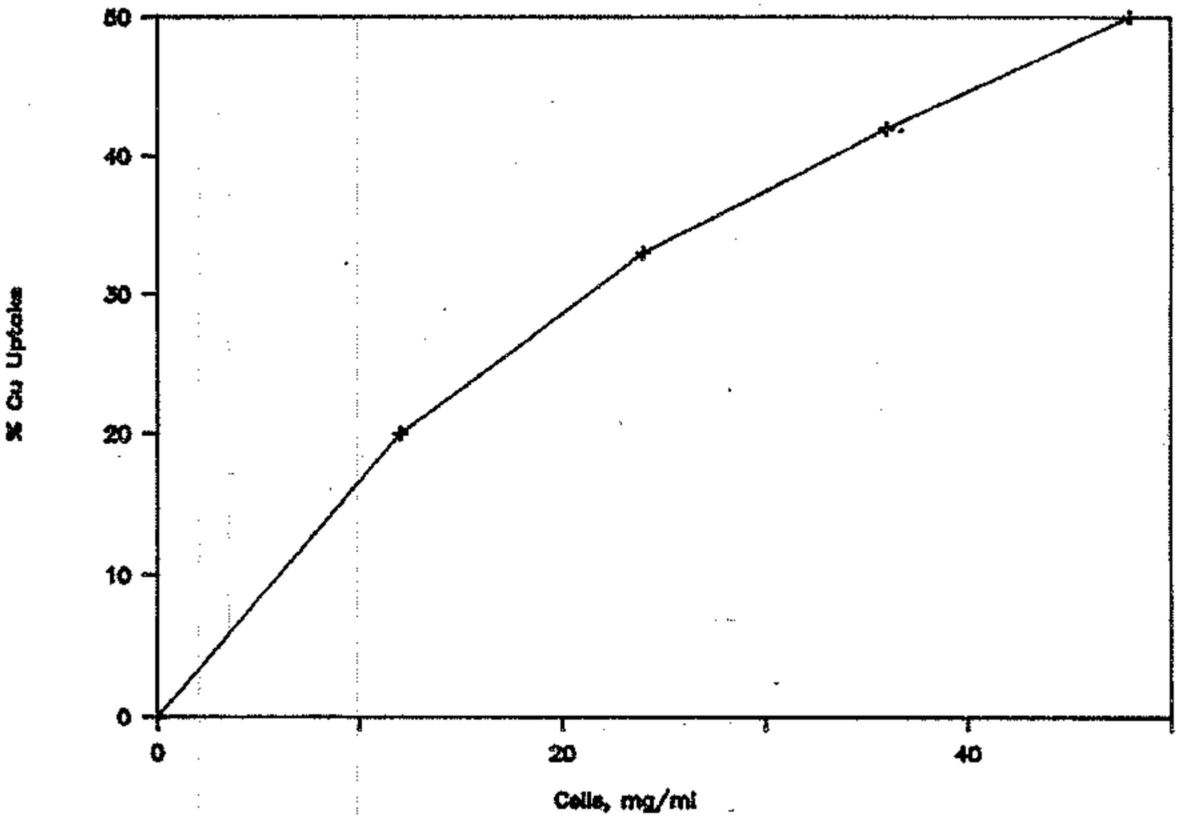
6.5 mg/ml of cells in distilled water + yeast extract

Figure 6. Kinetics of uptake of a metal mixture by Arthrobacter HC824 in distilled water plus yeast extract



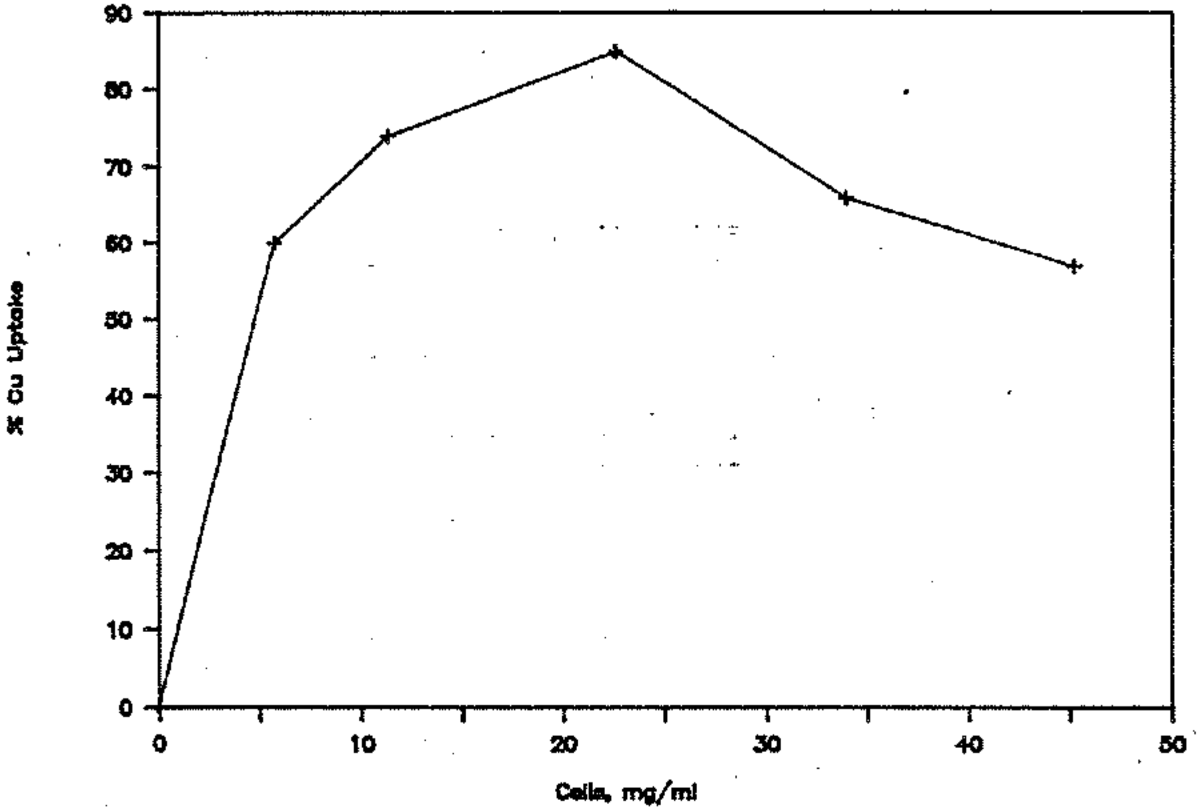
15.2 mg/ml cells; ◆Pb, ▲Cu, □Zn, +Ni

Figure 7. Percentage Cu uptake by Pseudomonas PxR in dilute mineral medium with glucose as the energy source



14.8 mg/ml of cells

Figure 8. Percentage of Cu uptake by Pseudomonas PxR in distilled water plus yeast extract



14.8 mg/ml of cells

Solanellas and Bordons (1988) used Pipes Buffer (piperazine-N,N'-bis (2-ethanesulphonic acid) in their copper uptake studies because of it negligible metal-chelate properties. We compared Cu uptake by *Pseudomonas* Pxr in Pipes and our distilled water-yeast extract system with 21 mg/ml of cell suspension. In the 3 hour experiment 83% of the Cu was cell bound in water versus 90% in Pipes. A test with *Flavobacterium* sp. at 14.8 mg/ml in Pipes, removed 71% of the added Cd.

Objective 3.

Early studies indicated that saturation of the cell mass with metal occurred at a metal:cell dry weight in the range of 1:1.4 to 1:2.8 mg metal:mg cell dry weight. From this data we had a guide to the amount of cell mass needed to clear a waste water. It is now apparent that the value for cell saturation varied depending upon the organism used in the experiments.

Objective 4.

We know that glucose used as a energy source (1%) enhances metal removal from a water solution but is not as effective as small quantities of yeast extract (0.01%). Using a mixture of glucose and yeast extract offers no advantage over yeast extract alone. A recent study by Brynhildsen, et. al. (1988) demonstrated that glucose concentration had a significant effect on the sensitivity-resistance of a *Klebsiella* sp. to Cd, Cu, Hg, and Zn.

Table 2. Effect of Nutrient Supplements on Clearing of Cu, Cr, Ag and Pb From Water

Metal	Glucose 1%		Yeast Ex .01%		Yeast Ex .1%		PO4 0.1M	
	1	2	1	2	1	6	1	2
Cu	4.09	.41	4.43	.26	4.58	.27	.18	4.36
Cr	4.67	.17	4.67	.21	4.58	.27	4.75	.03
Ag	2.4	.07	2.7	.1	3.3	.05	.4*	.1
Pb	4.3	1.5	2.0	3.2	1.3*	3.4	.4"	3.2
M:C	1:2.6		1:1.5		1:1.4		1:0.7	

1= Water phase
2= Cells
* ppt before cells added
" ppt at end 4 hrs incubation

Phosphate would appear to enhance Cu and Pb cell association but lowers the association of Cr and cells. Phosphate also has a chemical reaction with Ag (apparently the formation of silver orthophosphate which is insoluble) which removes the silver from solution.

Yeast extract is a complex mixture of compounds which are to a large extent amino acids, peptides and vitamins. It is a very promising supplement for this project in that low concentration is required for enhanced activity and it is a relatively cheap product.

Objective 5.

Due to serious problems associated with the relocation of our research laboratory this phase of the project has been delayed since mid-January. One bioreactor test was run in early January with Arthrobacter HC823 at 10 mg/ml final cell dry weigh., The cells suspended in 300 ml of distilled water yeast extract were mixed with 400 ml of water containing 50 ppm each of Cu, Ni and Zn. This mixture was mixed for 20 minutes, then a feed of the same metal solution was fed to the bioreactor at 6 ml/minute. At the time the feed was started, the bioreactor was pumped at high speed across a membrane in tangential flow filter. The cell slurry retentate was returned to the bioreactor and the permeate (aqueous phase) went to discharge at a rate of 6 ml/minute. Thus, the bioreactor maintained a constant volume and constant cell mass. The results (Figure 9) showed a steady build-up in the metal content of the permeate over the 100 minutes of system operation. However, metal was still being removed from the aqueous phase as the permeate level never reached input metal concentrations of 50 ppm.

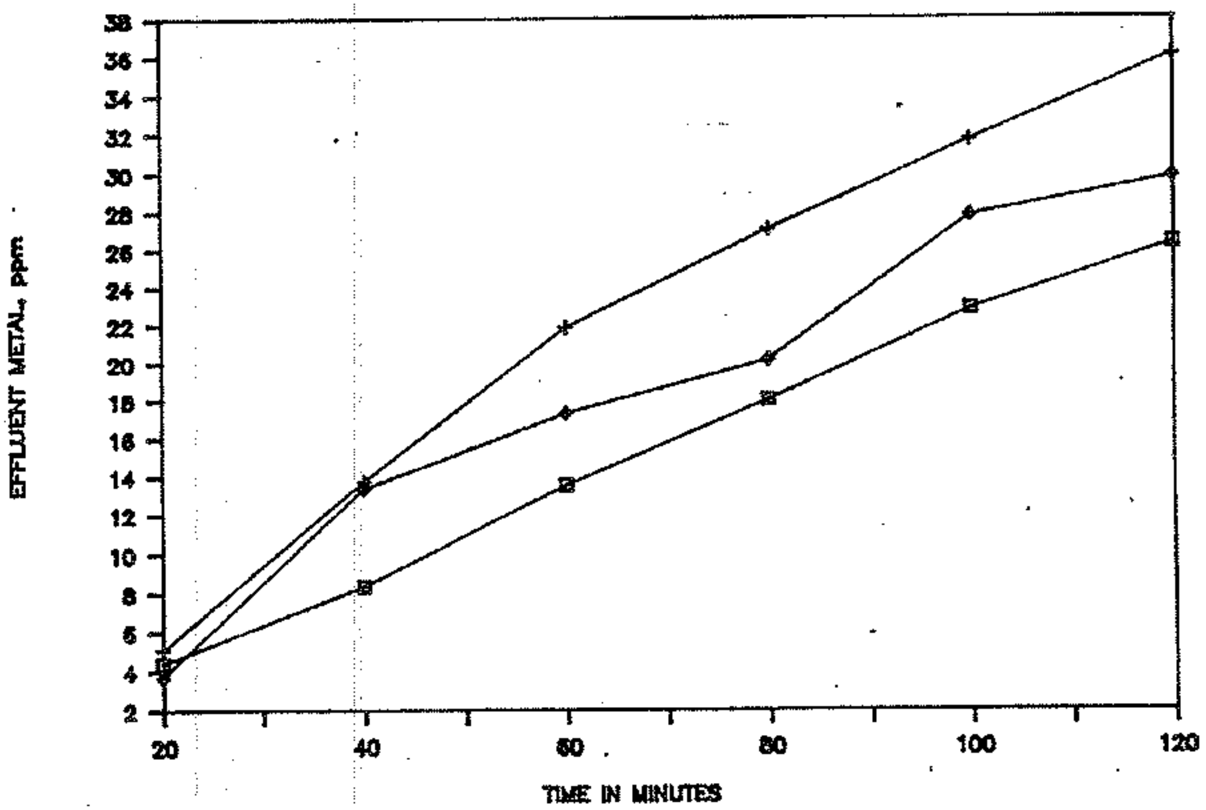
The experiment was repeated using four metals, Cu, Cr, Ni, Zn, and Ag, with a lower feed rate of the waste metal solution (3 ml/minute) and a cell mass of 8 mg/ml. The results in (Figure 10) demonstrated a good removal of Ag from the aqueous phase and poor but fairly constant removal of the other metals.

The data from other studies suggests that a much greater cell mass must be used in the bioreactors. Our objective in Phase II of this project will be the use of cell dry weights in the range of 20-30 mg/ml.

Objective 6.

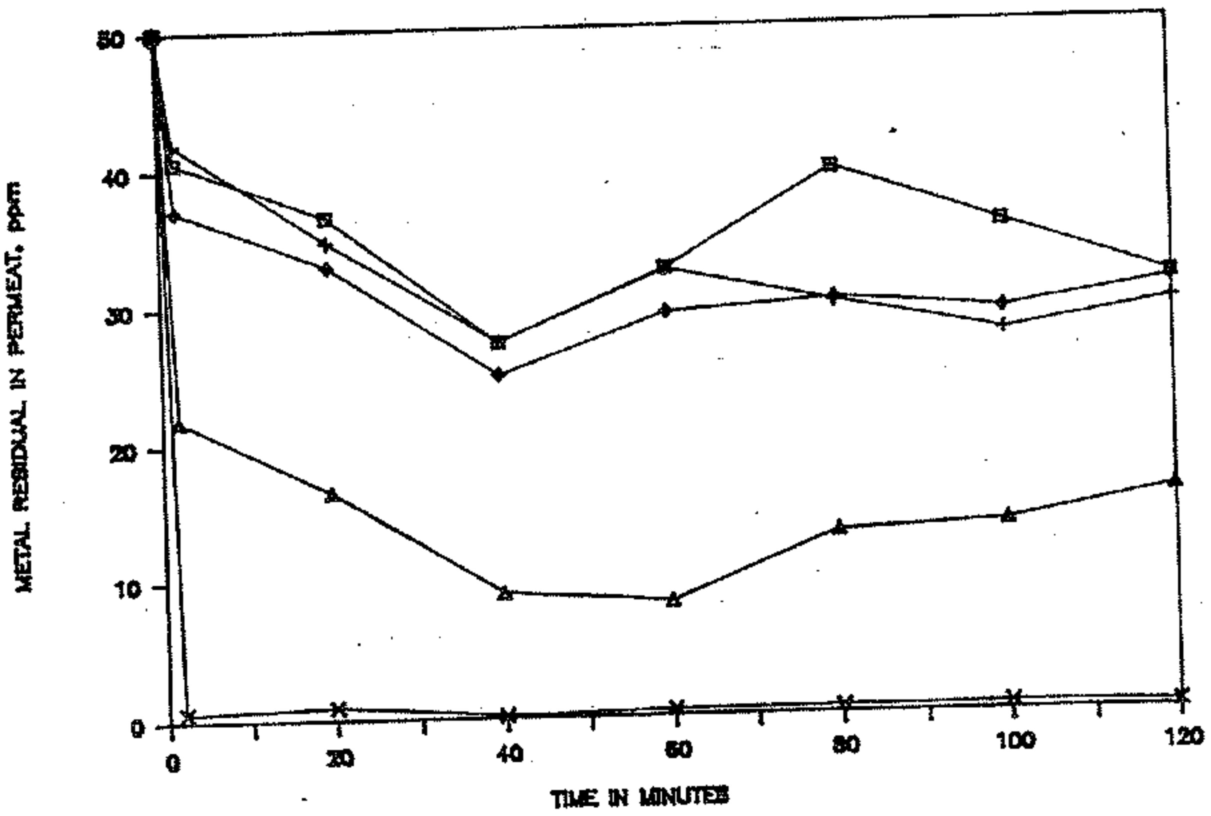
A variety of different digestion methods have been tried for the isolation of plasmid DNA from Arthrobacter HC823. All of these attempts have isolated only chromosomal DNA. In a recent test using a modification of the alkaline digestion method, there is evidence for a very high molecular weight plasmid near the chromosomal DNA region of the gel. Further tests during Phase II of this project will be done to confirm this observation.

Figure 9. Bioreactor fed mixed metals Cu, Ni, and Zn



10 mg/ml Cell mass, feed rate 6 ml/min, feed atart 20 min.
□ Cu, ◈ Zn, + Ni

Figure 10. Bioreactor fed mixed metals, Cu, Cr, Ni, Zn, and Ag



8 mg/ml cells, 600 ml volume, fed at 3 ml/minute

At least one plasmid has been detected in the *Pseudomonas* PxR strain by the alkaline lysis method. The molecular weight of the plasmid is approximately 11 kb. It was cut by EcoRI into two fragments, 9kb and 2 kb, which demonstrated that the plasmid has a single EcoRI restriction site. In addition, the PxR gels show a high molecular weight band, which may indicate the presence of a large molecular weight plasmid. The alkaline lysis method has been used for a plasmid screen of clinical isolates of *Pseudomonas aeruginosa* and of *Ps. fluorescens*. These screens have not detected plasmids in these strains. Work will continue during Phase II of this project to isolate and restrict this potential plasmid from *Ps.* PxR.

In order to confirm the function of the plasmid(s) in the *Ps.* PxR strain, it is necessary to transform it into a suitable recipient strain and test for the retained function and plasmid presence in the recipient strain. Since antibiotic resistance is normally coded on the same plasmid as metal resistance, we have two markers to use in the transformation studies. We have screened metal and antibiotic resistance in three potential recipient organisms, *Ps. aeruginosa*, *Ps. fluorescens* and *E. coli* HB101. The results of the metal and antibiotic resistance screens are shown in Tables 3 and4. The two Pseudomonads are not good candidates as recipients as the patterns are similar to *Ps.* PxR. *E. coli* HB101 may be a good transformation recipient due to the Cd, Cr, Hg, ampicillin and chloramphenicol sensitive markers not present in the PxR strain.

Table 3. Metal resistance of strains

Agents and Concentration	E. coli HB101	Ps. PxR	Ps. fluorescens	Ps. aeruginosa
Control	R	R	R	R
Pb, 0.5 mM	R	R	R	R
Zn, 2 mM	R	R	R	R
Cd, 0.5 mM	S	R	S	R
Cr, 2 mM	S	S-R	S	S
Ni, 2 mM	R	R	R	R
Cu, 2 mM	R	R	R	R
Hg, 0.5 mM	S	R	S	S
Ag, 0.5 mM	S	S	S	S

Table 4. Antibiotic sensitivity pattern of strains

Agent	E. coli HB 101	Ps. PxR	Ps. fluorescens	Ps. aeruginosa
Control	R	R	R	R
LB+Amp 50 ug/ml	S	R	R	R
LB+Kan 50 ug/ml	S	S	S	S
LB+Tet 10 ug/ml	S	S	S	R
LB+Chl 30 ug/ml	S	R	R	R

Additional Observations

While not included as an initial objective of this project, it has become apparent that the metal binding organisms may produce and secrete into the metal compounds which function as metal chelate agents. *Ps.* HC823 was grown in Trypticase Soy Broth in the presence of 5 ppm of Cd, the cells removed and the supernatant collected for analyses. The protein content of the supernatant was estimated by the Warburg-Christen method by measuring the Absorbance at 260 and 280 nM and using their table to estimate protein. The supernatant was divided into aliquots to which were added varying (0-50 ppm) of the metals under study in this project. A UV-Vis scan of the native supernatant with and without added metals was performed. Comparison of the scans indicates the possible chelation of Cd, Cu, Pb, Cr, and Zn by extracellular products of the organism, but not the chelation of Ag, Ni or Hg. The spectral shifts in the presence of metal are metal specific and represent the formation of new peaks, magnification of peak shoulders, and changes in Absorbance maxima.

It is too early to equate these findings with metal removal from aqueous solution but it suggests that events other than metal uptake are associated with the clearing of metals from aqueous solutions,

C. New Literature Summary and References

Erardi, et. al. (1987) used a copper tolerant strain of *Mycobacterium scrofulaceum* to remove copper from culture medium by sulfate-dependent precipitation as copper sulfide. A derivative of this strain which lacked a 173-kilobase plasmid did not precipitate copper. The plasmid-carrying strain had a sulfate-independent copper resistance mechanism.

Chlorella stigmatophora grown in artificial seawater produced cell wall polysaccharides which dissolved in the growth medium (Kaplan, et. al., 1987). This polysaccharide had a varying complexing capacity for Zn, Cd, Pb, and Cu.

Brynhildsen, et. al. (1988) found that the nutritional state of an organism has a profound effect on its sensitivity to metals. Metals taken up by an energy-driven transport system may be less toxic under conditions of carbon starvation. The toxicity of Cu, Cd, and Zn to a Klebsiella sp was affected considerably by the carbon concentration, whereas the toxicity of Hg is independent of carbon concentration.

Solanellas and Bordons (1988) surveyed copper accumulation by resting cells of copper-resistant bacteria isolated from sewage sludge. Their best strain for accumulation was a Bacillus which retained copper at up to 3.8% of its cell dry weight, in the absence of glucose.

Belliveau, et. al. (1987) reviewed metal resistance and accumulation in bacteria, and in this paper summarize most of the current data and concepts of metal transport, resistance and accumulation.

D. Conclusions

The studies with PS. HC823 demonstrate that it is possible to enhance the metal resistance pattern of an environmental isolate with limited resistance to a series of heavy metals, to an organism with high resistance to the metals. It is found that environmental isolates obtained by enrichment isolation from heavily polluted sediments readily yield bacteria which carry multiple metal resistance to the metal pollutants of the area.

We are surprised at the rapid metal uptake by metal resistant bacteria. The kinetics of uptake vary with different isolates and with different metals, but the bulk of the metal which becomes cell associated occurs within a few minutes after addition of the organism. Of the metals studied Pb, Cu, Zn and Ni are the easily removed, whereas Cr is the most difficult.

Initially it was thought that the metal-cell saturation levels were constant. However, it is now apparent that this is a somewhat more variable and complex relationship. It is apparent that actively growing cells will accumulate or bind metal, but that resting cells with a minimum of nutrient supplement give superior results in metal removal. The non-chelating buffer, Pipes, seems to be a an ideal system with Pseudomonads for the removal of metal.

The bioreactor visualized for this system shows promise but will require additional study, particularly using reactor cell mass in the range of 20 mg/ml or greater. The results with clearing of Ag from solution are very good even in the preliminary experiments.

It is becoming apparent that the strains we are using for this study probably carry plasmids which carry the genetic information for specific metal resistances. This may allow us to optimize the system by carrying genetic information from more than one strain into a common organism to clear the various metals from solution.

C. Results and Discussion Phase II.

Objective 1. Metal Resistance Assays

We used paper discs saturated with varying concentrations of metal, which were placed on the surface of Vogel-Bonner medium seeded with Arthrobacter SL-1. These plates were incubated for 24 hours and the diameter of the zone of inhibition measured. Each zone was measured at three different locations of the zone and the results are reported as the average of the three measurements (fig.1). The results in Table 1 are the Minimum Inhibitory Concentration (MIC) of Arthrobacter SL-1 in liquid Vogel-Bonner medium.

Figure 1. Plate disc assay of metal toxicity to Arthrobacter SL-1 on V-B agar.

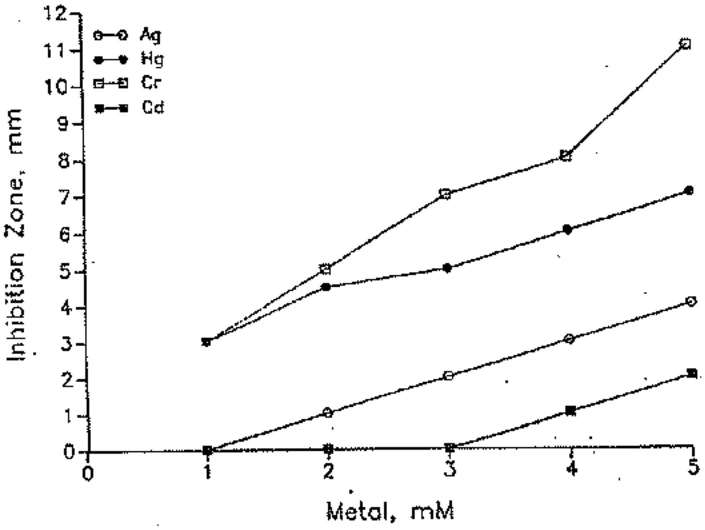


Table 1. MIC of metals to <u>Arthrobacter</u> SL-1 in Vogel-Bonner broth, at 30 °C

Metal	Minimum Inhibitory concentration mM	 ppm
Ag	0.188	20
Cd	>0.3	>100
Cr	0.384	20
Cu	>0.16	>100
Ni	>1.7	>100
Pb	>0.48	>100
Zn	>1.54	>100

Figure 2. Growth response of <u>Arthrobacter</u> SL-1 in V-B broth with Cr 0.1 mM. Temperature 30°C, agitation 200 rpm.

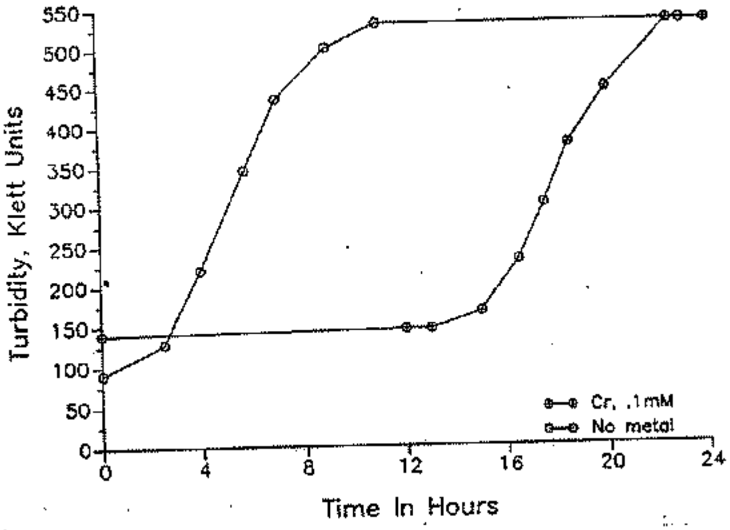
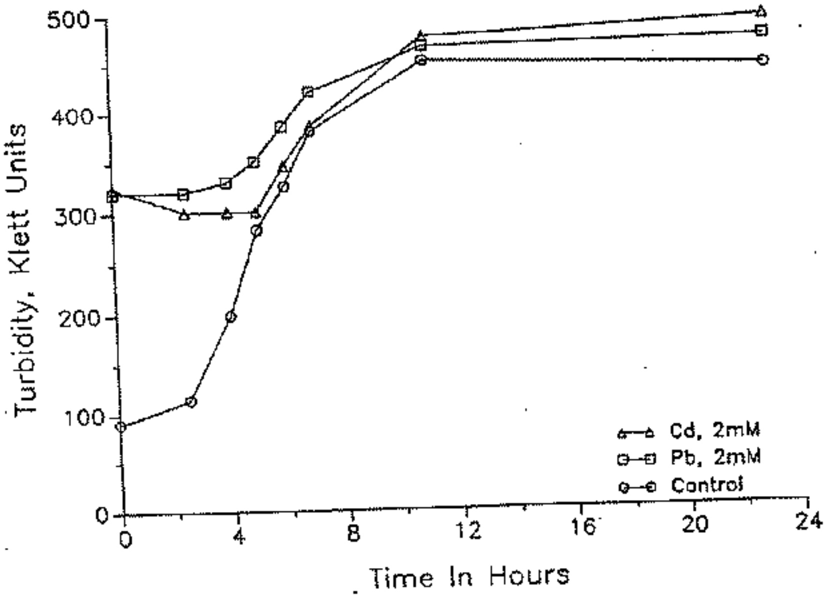


Figure 3. Growth response of <u>Arthrobacter</u> SL-1 in V-B broth with 2 mM Cd and 2 nM Pb. Temperature 30°C, agitation 200 rpm.



In another form of assay we examined the effect of subinhibitory concentrations of Cr, Cd, and Pb on the growth response of Arthrobacter SL-1 (Figures 2 and 3). In each of the metals the only observed response was on the duration of the lag phase of growth. This is most apparent in the case of Cr where there was a 24 lag phase. This leads us to believe that the toxic effects may be related to the uptake of essential metals for initiation of cell division.

Objective 2. Metal resistance genetic transfere system

As reported in FY 88 Pseudomonas PxR has one large plasmid (20KB) and 1-3 small plasmids (1-4 Kb). The metal and antibiotic resistance characteristics of Ps. PxR and E. coli are listed in Table 2. Ps. PxR is Cr^r, Hg^r, Amp^r, Chl^r and the E. coli HB101 strain is Cr^s, Hg^s, Amp^s, and Chl^s.

Table 2 Metal and Antibiotic Resistance of Test Organisms

Inhibitor	E. coli HB101	Ps. PxR
Pb .5mM	+	+
Cd .5mM	+	+
Cr .5mM	−	+
Hg .5mM	−	+
Hg .1mM	−	+
Zn 2.0mM	+	+
Ni 2.0mM	+	+
Cu 2.0mM	+	+
Amp 50ug/ml	−	+
Chl 30ug/ml	−	+

Recombinant plasmids were constructed by the ligation between pBR323/BamHI fragments and pPXRI/BamHI. The ligate was transformed to HB101 competent cells and Amp^r Tet^s transformants were selected. Five colonies shown to be Amp^r Tet^s were selected and four of these (named HB101-pPXR101, 102, 103, 104) have small plasmids in the molecular weight range from 2 to 4.5 Kb. In comparing the size of these plasmids (transformants with pBR322 and pPXR1), it appears that they may originate from pPXR1 and be directly transformed into HB101 cells with or without modification by the process of restriction enzymes cuts and ligation. PBR322 may act as a helper plasmid since direct transformation from pPRX1 to HB101 was not successful.

Four transformants also showed the same level of resistance to Cu, Cr, Pb and slightly lower level of resistance to Hg (as shown in table 3). Plasmids from these four strains were retransformed into HB101 competent cells with high transformation efficiencies (= 4 X 10^3 colonies/ug DNA). These reclones showed the same plasmid patterns as HB101/pPXR101, 102, 103, 104 and they are Amp^r, Cr^r,g^r. These results indicate that these small plasmids are responsible for metal and amplicillin resistance, and that were able to transfer these resistances from one organism to another.

Table 3. Resistance and sensitivity of transformants

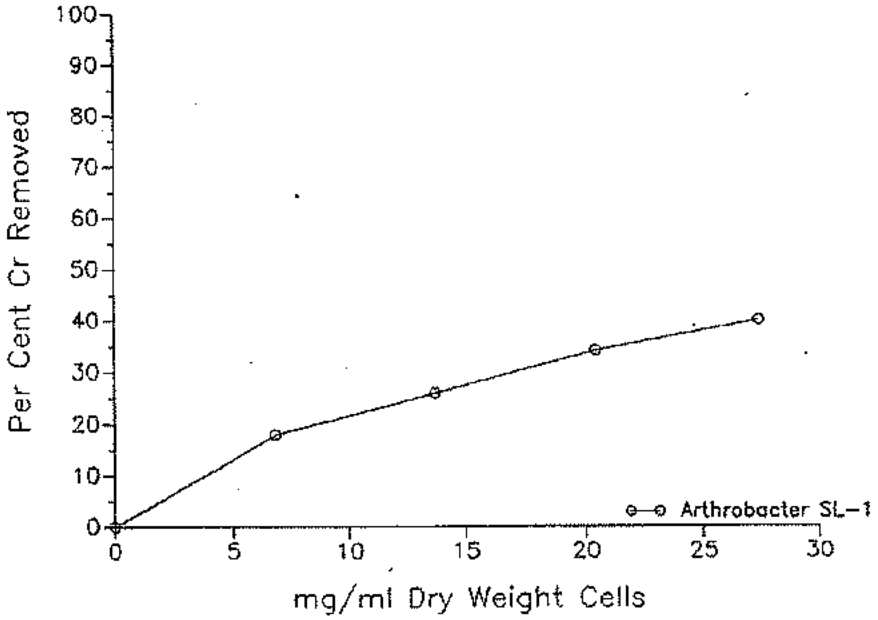
Inhibitor	HB101	PxR	H-101*	H102*	H103*	H1014*
Amp 50ug/ml	S	R	R	R	R	R
Tet 35ug/ml	S	S	S	S	S	S
Hg 0.1 mM	-	+++	+	+	+	+**
Cr 0.5 mM	+/-	+++	+	++	+	++

* represents HB101-pPXR101 and reclones H-101, H-103, H-104
** growth level in LB agar plates - to ++++

Objective 3. Model System Test for Bioaccumulation of metal

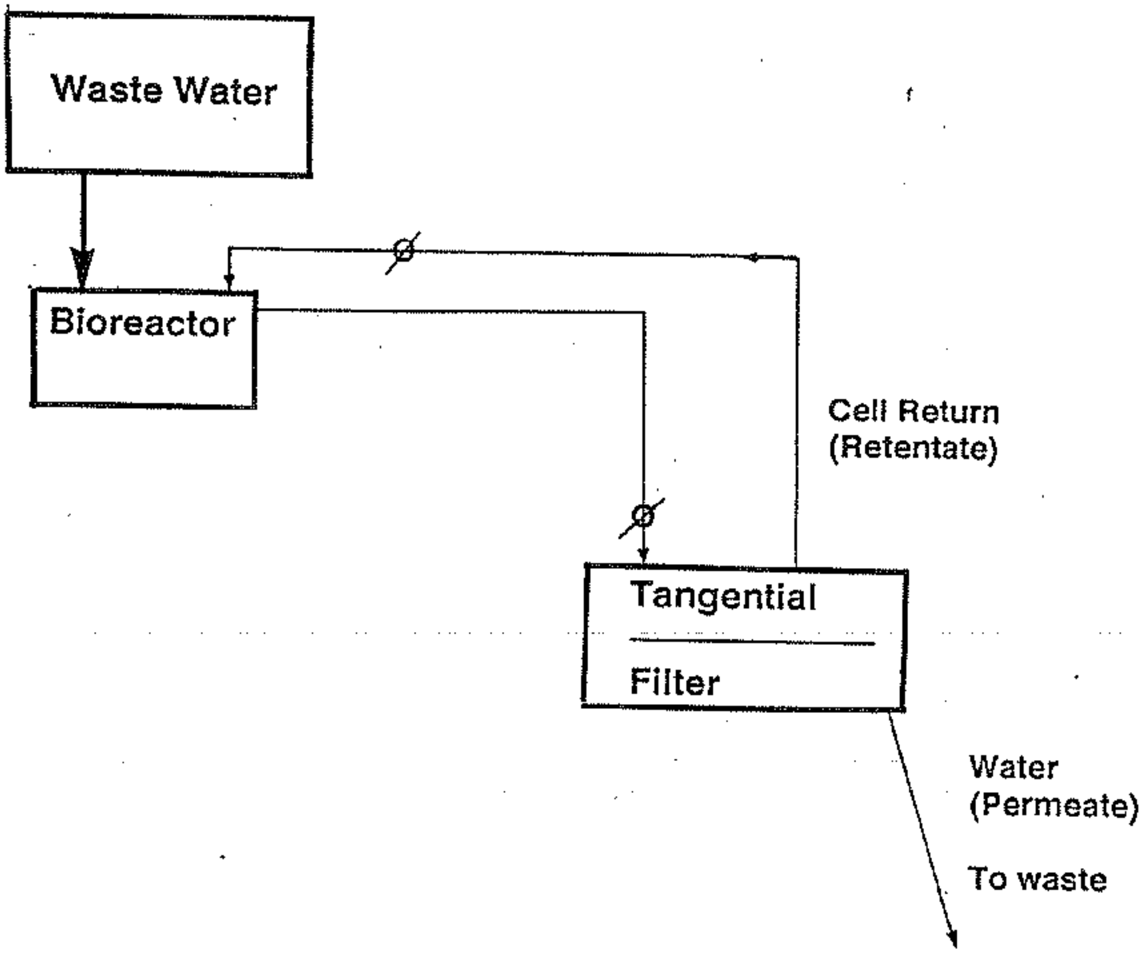
The basic objective of this project was to develop a system to bioaccumulate metals from aqueous solution and then recover the metals from the bacteria for recycle to industry. Early experiments determined the relationship between the cell mass used in a bio-reactor and percentage metal removal (fig 4). It was determined that the optimum cell mass was in the range of 20 to 30 mg/ml dry weight of cells.

Figure 4. Effect of cell mass on Cr removal from water



Above 30 mg/ml of cell mass the suspension became extremely viscous, and the amount of metal that could be removed decreased to a significant extent. This is due to the difficulty of mixing and contact of the cell exterior with metal ions. The system used was a continuous flow through system in which metal was fed to a bio-reactor at a set rate (D = 0.6 in most experiments). While fed, the reactor content was pumped to a cell separation device (BioPrem), with the permeate (water) to waste and the cells (retentate) returned to the bio-reactor (fig 5).

Figure 5. Diagram of model treatment system



The first series was performed with Arthrobacter HC823, one of our earlier isolates, which has been enhanced for multiple metal resistance. The results of this experiment are shown in

Figure 6.

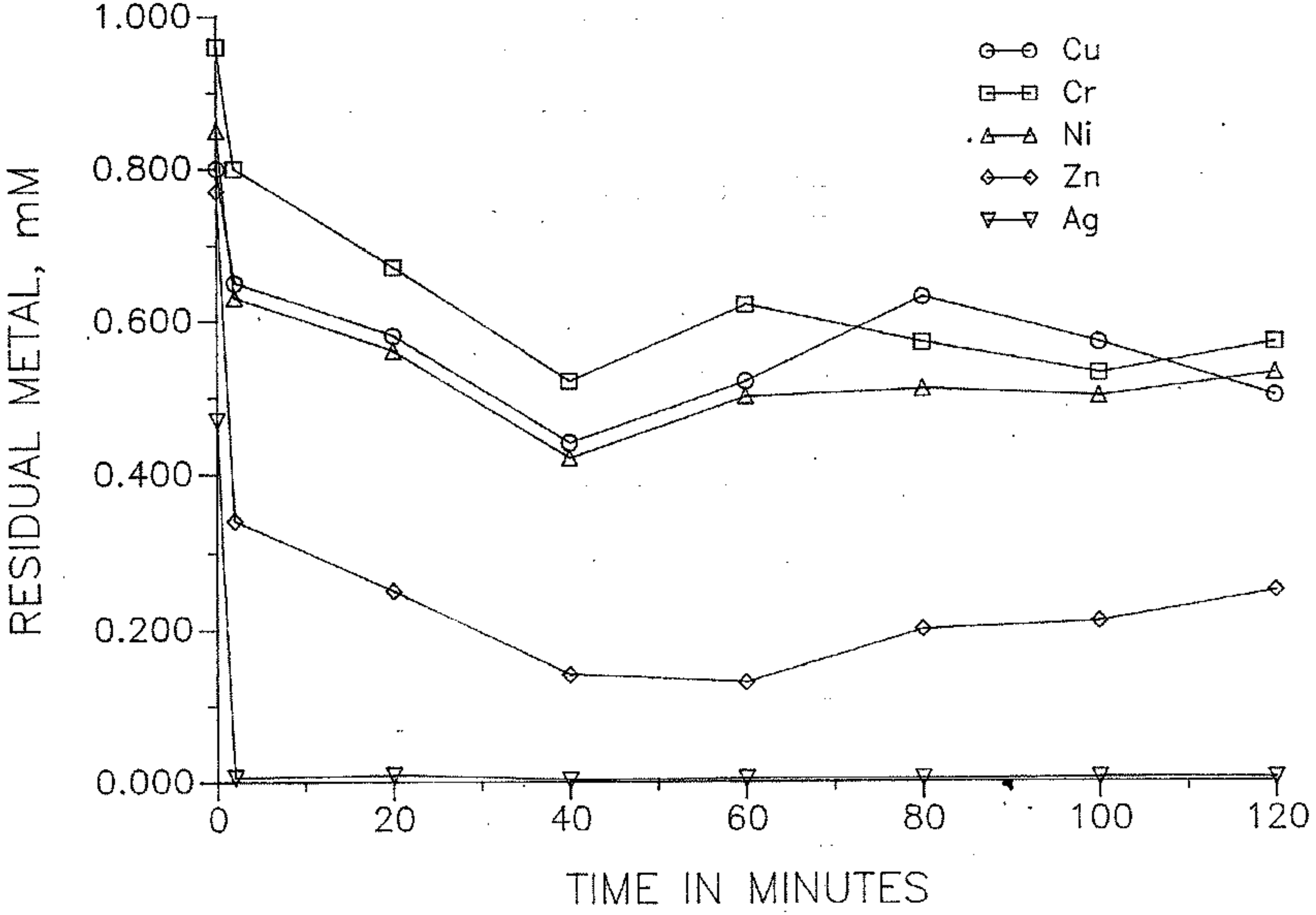

1.000
0.800
0.600
0.400
0.200
0.000
RESIDUAL METAL, mM
0
20
40
60
80
100
120
TIME IN MINUTES
Cu
Cr
Ni
Zn
Ag

Figure 6. Silver was removed to a very low value within the first few minutes of treatment and remained at low levels until termination of the experiment at 120 minutes. Zn, Ni, Cr, and Cu were rapidly decrease in the effluent water to waste up the level of metal removal stabilized at about 40 minutes and remained about the same for the rest of the experiment. The waste used in this experiment contained an initial level of 50 ppm of each metal. Our cell mass was very low in this experiment (7.5 mg/ml) which reduced the efficiency of the system.

Arthrobacter SL-1 was used for re-testing the system at more optimum conditions. The cell mass used in this test was 24.7 mg/ml, in Pipes buffer at pH 5.5, a dilution rate = 0.2, with agitation at 200 rpm and the temperature at 30°C. The results of this experiment are shown in Figure 7. The model system was shown to efficiently remove a mixture of 50 ppm of 5 metals continuously fed through the system at a dilution rate of 0.2 for 240 minutes. Even though the levels of Ni and Zn in the effluent water have increased by the end of the treatment period they reflect a significant reduction of these metals, Ni from 50 to 2.4 ppm and Zn from 50 to 0.8 ppm. We obtained a sample of metal containing effluent water from a Providence company. Upon analysis this waste was too low in metal for our purposes. The analyses in our laboratory were below detection limits for Pb, Hg, Ag, and Cr. Cd was measured at 4 ppb, Cu at 0.15 ppm and Ni at 0.03 ppm. We did learn from a visit to this facility that the only liquid waste they generate is the rinse water from their plate operations. The mixed rinse waters generally are below 50 ppm and represent a single metal rather than a mixture. These discoveries were made during the last 6 weeks of this project. Our continuing work will concentrate on the single metal systems.

The efficiencies of single metal systems are shown in Table 4. In the case of Pb, Ag, and Cd are rapidly removed with accumulations of 89 to 99 per cent. After 130 minutes reaction time the bioaccumulation of metals had increased except for Ag and Hg. In the case of Hg this may be do to a microbially mediated transformation of Hg to the methyl- or ethylmercury species which are volatile. The mechanisms of Ag transformation are unknown at this time.

In various studies on bioaccumulation the residual metal in the effluent water is measured and/or the cell-bound metal. The standard procedure for cell-bound metal is a HNO_3-H_2SO_4 digestion in which the cells are oxidized to CO_2 and N_2, leaving a clear acid solution of the metals. For analysis these are diluted to a set volume and analyzed by atomic absorption. For metal recovery this acid solution can be treated with anions such as CL^- to precipitate the metals. A very inexpensive and simple method of recovery. The anion used is adjusted for specific metals.

Objective 4. Cyanide utilization

Figure 7. Residual metal in effluent of treatment system fed with simulated metal waste.

The bioreactor volume was 900 ml containing 24.7 mg/ml of Arthrobacter SL-1 suspended in Pipes buffer at pH 5.5. The flow through rate was 3 ml/min which gave a D = 0.2, with agitation at 200 rpm and temperature at 30°C.

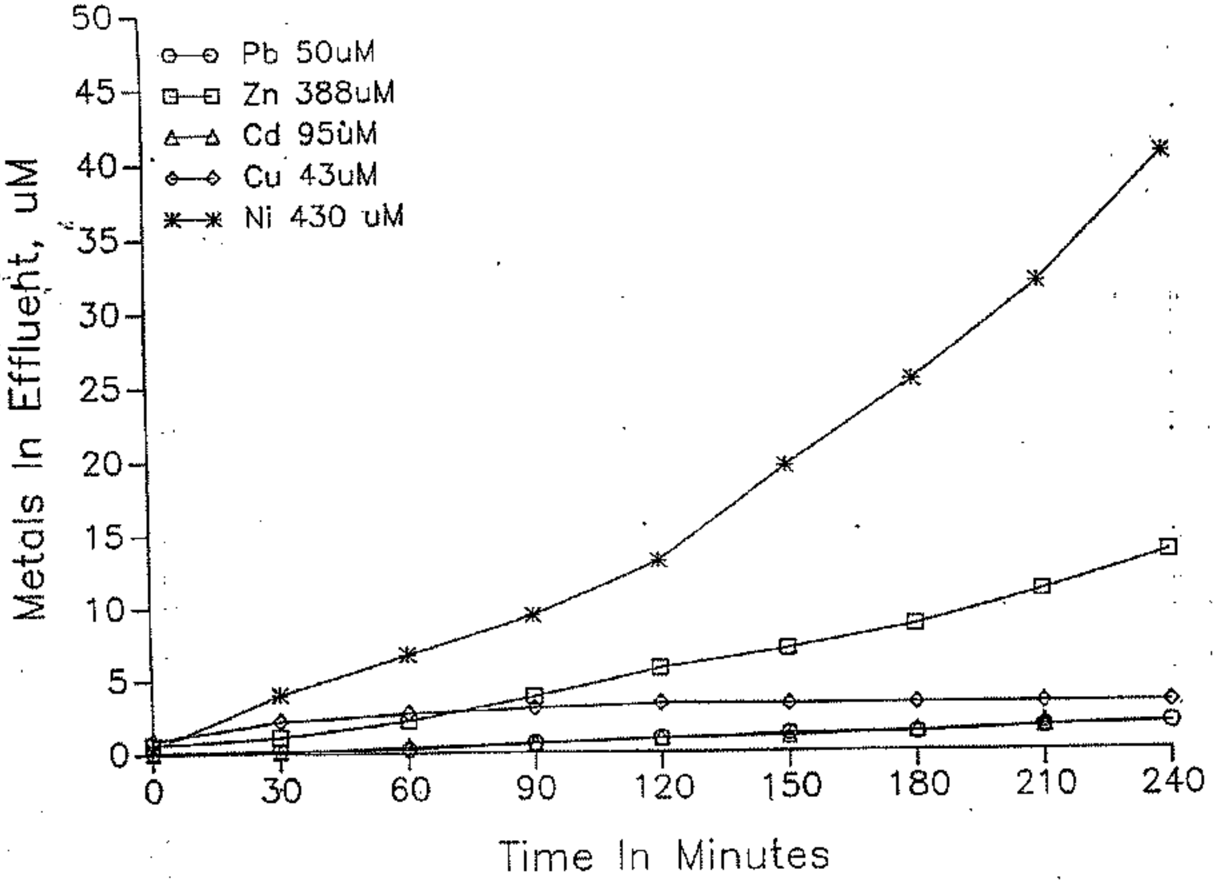


Table 2. Metal Bioaccumulation By <u>Arthrobacter</u> SL-1

Metal	Initial Conc. uM	Residual Concentration uM 10 min	130 min	Cell Dry Weight mg/ml	% Cellular Accumulation 10 min	130 min
Pb	240	1.9	5	22.6	99	98
Ag	470	53	133	22.6	89	72
Cd	150	17	8	23.9	89	95
Hg	250	47	105	23.9	81	58
Cr	960	960	498	24.6	0	48
Cu	800	48	38	24.6	40	53
Ni	850	286	48	24.6	66	94
Zn	770	177	29	24.6	77	96

Reaction Times, 10 and 130 minutes in Pipes buffer, 30 C

The studies of cyanide utilization never progressed beyond the first screening step. This work could not be performed until the very end of the project due to the non-availabilty of a safety system for these experiments. It is not prudent to do batch culture experiment with cyanide in an open laboratory nor in a conventional fume hood. I personally would work with this compound only in a special chemical safety food. Our safety hood was available in April of 1989 at which time we screened a series of potential cyanide utilizing bacteria. In these experiments cyanide serves as the sole source of nitrogen for growth. None of the screened members of the Genera Pseudomonas and Bacillus were able to grow at the expense of cyanide. Enrichment studies were not performed since these series generally require up to six months for a successful enrichment isolation.

D. Conclusions

The use of bacterial cells for the removal of metals from aqueous solution is feasible and can be applied to the cleaning of effluent waters. Additional work will be required to improve the removal of Cr, but the technology is now available to recover Pb, Ag, Cd, Hg, Cu, Ni and Zn. The molecular biology of these bacteria is most interesting and has demonstrated that resistance to a particular metal can be genetically transferred from environmental isolates to common bacteria such as E. coli. It is of some question at this time if this will be necessary in the application of these finding. It now appears that metal resistance is not required for bioaccumulation of a metal. Work performed after the completion of this project demonstrates that a Cr non-resistanat bacteria is capable of Cr bioaccumulation. Further studies have also demonstrated that Arthrobacter SL-1 used for the bioaccumulation of a metal mixture are not viable when removed from the test reactor. If genetic engineering were necessary to improve the system, the lethal effect of the treatment on the cells would provide an additional ecological safe guard.

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