RHODE ISLAND
WATER RESOURCES CENTER

FISCAL YEAR 1988 PROGRAM REPORT

WATER RESOURCES RESEARCH INSTITUTE
THE UNIVERSITY OF RHODE ISLAND
RHODE ISLAND

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Water Resources Research Institute
University of Rhode Island
Rhode Island

ABSTRACT

The 1988 program objective was to conduct studies and research of value to the New England region as well as to assist in the solution of water resources problems in the State of Rhode Island. Current and anticipated state and regional water problems are contamination of groundwater by natural radioactivity from radon or chemicals from industrial and agricultural activities, slow progress in pretreatment programs leading to continuous surface water contamination, delayed cleanup actions of landfills with hazardous wastes resulting in pollution of aquifers, and lack of public awareness as well as participation in water quality protection and management. The FY-1988 program addressed many of these problems. Uranium, U, and Thorium, Th, which decay to radon were found to be higher in alkalic rocks. 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 on-feldspar hypersolous Scituate Granite. Contaminants from aquifers can be cleansed by natural flushing. By modeling the occurrence of rainstorms by a Poison process, and using a two-dimensional Galerkin finite-element procedure, the time required for restoring the water quality can be predicted. Leachates from an incinerator ash landfill did not contain cadmium and lead at hazardous levels. A HELP computer model was useful to simulate a landfill, predicting leachate generating rates. Nutrient retention in vegetative buffer strips were found to be related to nitrate uptake rate and the rate of nitrate reduction in plant roots. Microbial denitrification rate affects the rate of retention, depending on the pH and organic content. Heavy metals, Pb, Cd, Ni and Zn could be removed by Arthrobacter SL-1 in Pipes buffer at pH 5.5 from 94 to 98%. A plasmid has been isolated and successfully cloned to E. Coli HB101 with strong resistance to Cd toxicity. Electroflotation process was found to be successful in removing heavy metals and cyanides simultaneously. Information transfer included watershed watch, groundwater protection conference plus short courses and distribution of fact sheets and a newsletter. 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 recent years, Rhode Island and the other New England States have experienced a very high rate of growth. The rapid housing and commercial development in Rhode Island presents a potential threat to surface and groundwater contamination, threatening the water quality in the state. Sediments, nutrients, and toxic chemicals in watersheds with high development activities could be washed into streams, lakes, and ponds, or infiltrate into aquifers. While most municipal wastewater treatment facilities are being upgraded and pretreatment programs are being implemented in most towns and cities, the water quality in our surface water in the state still needs improvement.

Known petrologic and geochemical characteristics of geologic materials in Rhode Island suggest anomalously high concentrations of radioactive parent nuclide of radon and radium. Radon is an inert 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. Presently, all new houses built in Rhode Island are tested for radon. 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.

In Rhode Island, more than a dozen contaminations of aquifers due to spills and leaks of organic materials have been reported in the past few years. Restoration of aquifer water quality is expensive. One alternative is to eliminate the contamination source and allow restoration by natural flushing, dilution, and geochemical or biological reactions. An accurate estimation of the time required to restore water quality in aquifers through natural flushing will be helpful to the decision-making on management options.

Continuous leaching of chemical contaminants from landfills will remain a long term problem in many communities in the state. The largest landfill in the New England region is the Central Landfill in Johnston, Rhode Island. Part of this landfill also contains hazardous waste. Three waste incinerators have been proposed for the State of Rhode Island. The incinerator residue and ash will be disposed of in the Central Landfill. The quality of leachate from the residue/ash landfill with or without mixing in with municipal solid waste is of concern. It may contain volatile organics and heavy metals, leading to aquifer contamination. A study characterizing the residue/ash and its leachate will be very helpful in landfill management.

Strategies for protecting the water quality in the state have been concentrated on protective zones surrounding surface reservoirs and local restrictions on development over major aquifers. These efforts are being compromised by the expansion of intensive land uses in Rhode Island adjacent to tributaries and aquifer recharge areas. Presently, not much is known about the fate of materials which are washed off land surfaces by rain water. An emerging technique for controlling the movement of sediments, nutrients, heavy metals, and organic compound over land is the use of vegetative buffer strips. Small strips of grass or other vegetation can be used to trap pollutants moving from land areas before they enter water bodies. The maintenance of riparian filter strips was adopted as a "best management practice" by the U.S. Department of Agriculture and is recommended for use as a complement to structural storm water control devices in Rhode Island. The scientific basis for the effectiveness of buffer strips needs study. There is a great need for research to determine if the current guidelines for vegetative buffer strip use is appropriate.

Removal of heavy metals and cyanide from wastewaters remains a problem in Rhode Island, particularly in the Providence area where hundreds of firms with plating activities are located. The existing pretreatment program is effective only in curbing the discharge of these pollutants from large firms. Unfortunately, most plating firms are small and reluctant to apply treatment to their wastes prior to their discharge to the sewer line. There is a great need to develop a technology for heavy metal and cyanide treatment for small as well as large firms in the state. Particularly useful would be the recovery of the heavy metal for reuse.

PROGRAM 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 Management
  - Location and extent of groundwater supplies
  - Recharge characterization
  - Rural and small town water supply systems
  - Sources of toxic materials
  - Fate and transport of chemicals

- Surface Water Management
  - Land use/hydrology interactions
  - Water reuse and conservation
  - Eutrophication
  - Acid precipitation
  - Watershed management

- Ecological and Health Relationships
  - Wetland ecology
  - Effects of chemicals in water on human health

- Institute Frameworks
  - Water use planning and management
  - Water allocation and reallocation
  - Conflict resolution among competing users

Guided by these research needs, the Rhode Island Water Resources Center developed its program goals to meet some of these research needs as well as to transfer the information water resources research/management/education to the public. Both the State Advisory Committee and the University Water Resources Coordinating Committee for the Center were consulted to finalize the research topics for the FY-1988 program. Groundwater research remained to be an important part of the program. However, strong efforts and considerable resources were put into surface water quality and water quality control research.

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.

Two projects related to groundwater quality problems met the identified research needs and were selected for the FY-1988 program. Project 02 on Uranium-Thorium Concentrations in Bedrock and Surficial Materials: Primary Sources of Radon in Rhode Island Aquifers used the epithermal neutron activation technique developed and perfected in the previous year to quantitatively determine U and Th concentrations in geological material. The final results exhibited a considerable range in U and Th levels, the lower concentrations were consistently found in the Precambrian rocks of calcalkaline affinity and the Hope Valley gneissic rocks, with U levels ranging from 1.4 to 4 ppm and Th from 5.0 to 21.3 ppm. Associated volcanic rocks levels ranged from 2.0 to 3.2 ppm U and 9.3 to 12.0 ppm Th. The Permian aged Narragansett Pier Granite was found to contain low to moderated U, ranging from 2.7 to 5.7 ppm, but found to be enriched to Th, ranging from 22.0 to 103.2 ppm. The bimodal distribution of U and Th suggested that the U may have been mobilized and reprecipitated in rocks. U and Th were found higher among the alkalic rocks. The plutonic rocks ranged from 2.2 to 22.8 ppm with the highest U consistently found in the peralkaline Rhode Island Quincy Granite and one-feldspar hypersolves Scituate Granite. The clastic sediments of the Narragansett Basin yield only low to moderate U and Th values. The information is very helpful in guiding the future radon programs in the State of Rhode Island to identify possible hot spots.

Project 03 on Stochastic Study of the Natural Flushing of Contaminants from Aquifers used a two-dimensional Galerkin finite-element procedure and the Monte Carlo simulation in order to consider the stochastic nature of the source/sink term. The procedure also required the modeling of the occurrence of rainstorms by a Poison process and the amount of rainfall in each storm by an exponential probability distribution. Numerical errors resulting from the solution of the partial differential equation were related to the space and time increments and therefore a careful discretization of the space and time dimensions could keep the errors within tolerable limits. The model provides information on how an estimation of the time required for restoring water quality in aquifers through natural flushing can be carried out.

Project 04 on A Microbial Method for Removal of Metals, Cutting Oils, and Cyanide from Polluted Water, Phase II, successfully isolated a plasmid which was cloned into a bacterium E. coli HB101. The cloned bacterium has a much higher resistance to the toxic metal cadmium than ordinary E. coli. A model system inoculated with Arthrobacter SL-1 suspended in Pipes buffer at pH5.5 has been successfully tested to remove Pb, Cd, Ni, and Zn from 94 to 98% removal on a continuous flow condition. The project information is useful for the design of a biological treatment system for heavy metal removal from industrial wastewaters.

Project 05 on Evaluating Plants for Nutrient Retention in Vegetative Buffer Strips studied the kinetic parameters for nitrate absorption by selected plant species. Rates of nitrate absorption were found to be consistently low during the first 30 to 60 minutes, followed by high rates of absorption between 90 and 180 minutes which gradually declined later. Experiments have been modified so that any initial variations in the absorption rate would not compromise the accurate estimation of the linear rate constant, resulting in good uptake kinetic curves. The research is continuing and good results from all the grasses studied will be available in a couple of months.

Project 06 on Microbial Processes Controlling the Fate of Nitrogen in Vegetative Buffer Strips, similar to Project 05, studied the nitrogen changes in vegetative buffer zone but concentrated on the microbial processes instead of uptakes by vegetation. Denitrification, the main microbial process to remove nitrogen, was found to proceed at a rate of 7889 g N/ha.day for tall fescue and 4537 g N/ha.day for reeds canary grass, and 3ll and 375 g N/ha.day respectively for well drained and poorly drained forest plots. Adding lime to raise the pH of the soils in the forest plots did not increase the denitrification rate as expected. Immobilization was found to be only a temporary sink of nitrate and any N that was immobilized could be subsequently released or mineralized. Mineralization was highest in the poorly drained forest soil and was higher in the reed's canary grass than in the tall fescues soil. The findings of Projects 05 and 06 are useful to provide guidance to planning agencies in selecting, designing, and managing of vegetative buffer strips for nutrient removal.

Project Sl on Study of Fly Ash and Bottom Ash and Their Leachate Characteristics in a Simulated Landfill Condition, was a privately funded project started in December, 1987. The mixed ash from an municipal solidwaste incinerator was found to contain on the average 6.5 ppm Pb and 0.85 ppm Cd using the EPA's EP extraction procedure, and ll.0 ppm Pb and 1.25 ppm Cd using the EPA's TCLP extraction procedure. Column studies showed that simulated landfill condition with artificial acid rainfalls yield very low concentrations of Pb and Cd in the leachate. However, large amounts of organics, chloride, dissolved solids and other chemicals were found in the leachate from the ash column or the ash/MSW mixed columns. A computer HELP Model was found to be useful to predict the quantity of leachate from landfills. The results are very useful to the Rhode Island Solid Waste Management Corp. which manages a Central Landfill and will be designing an ash landfill in the near future.

Project S2 on Simultaneous Removal of Cyanide and Heavy Metals from Industrial Process Wastewaters was funded entirely by the Rhode Island State Department of Environmental Management, starting December, 1988. Unlike Project 04 which used a microbial system, Project S2 used a physical-chemical method of electroflotation to concentrate the heavy metals from wastewaters. The concentrated heavy metal in the form of a scum could be dissolved in acid solution and plated out. Chlorine was generated from the brine solution anodelyte to destroy cyanide simultaneously with metal electroflotation. The project will be carried into the FY-1989 program.

Sources and level of funding for the various projects including the information transfer activities are listed in Table 1 on the next page.

Table - Sources and Levels of Finding, FY-1988

<u>Project</u>		Funding* Level	Funding* Source
02	Uranium-Thorium Concentrations in Bedrock and Surficial Materials: Primary Sources of Radon in R.I. Aquifers	$11,350 29,363	US Geological Survey University of R.I.
03	Stochastic Study of the Natural Flushing of Contaminants from Aquifers	14,605 35,095	US Geological Survey University of R.I.
04	A Microbial Method for Removal of Metals, Cutting Oils, and Cyanide from Polluted Water	14,000 37,035	US Geological Survey University of R.I.
05	Evaluating Plants for Nutrient Retention in Vegetative Buffer Strips	9,700 23,531	US Geological Survey University of R.I.
06	Microbial Processes Controlling the Fate of Nitrogen in Vegetative Buffer Strips	9,634 15,078	US Geological Survey University of R.I.
S1	Study of Fly Ash and Bottom Ash and Their Leachate Characteristics	11,250 250	RI Solid Waste Management Corp. University of R.I.
S2	Simultaneous Removal of Cyanide and Heavy Metals from Industrial Process Wastewaters	19,947 4,930	RI Dept. of Environmental Management, University of R.I.
22	Information Transfer Activities (See description later in report)	15,250 27,875	US Geological Survey University of R.I.
	Center Administration (Including publication of newsletters)	30,591 53,798	US Geological Survey University of R.I.

*Ending May 31, 1989

PROJECT NUMBER: 02

START: 6/1/87
END: 5/31/89

TITLE: URANIUM CONCENTRATIONS IN BEDROCK AND SURFICIAL MATERIALS: PRIMARY SOURCES OF RADON IN RHODE ISLAND AQUIFERS

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CONGRESSIONAL DISTRICT: SECOND, RI

KEY WORDS: GEOCHEMISTRY, ISOTOPES, DATA, WATER QUALITY, PUBLIC HEALTH

PROBLEM AND 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 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. 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. Primary ^{238}U comprises more than ninety-nine percent of the naturally occurring uranium isotopes:

$$^{238}\mathrm{U} \text{ -- } ^{234}\mathrm{Th} \text{ -- } ^{234}\mathrm{Pa} \text{ -- } ^{234}\mathrm{U} \text{ -- } ^{230}\mathrm{Th} \text{ -- } ^{226}\mathrm{Ra} \text{ -- } ^{222}\mathrm{Rn}$$

^{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 the stable lead isotope ^{206}Pb. 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, water soluble gas which readily enters the atmosphere or groundwater and is formed as a result of alpha-decay of the parent isotope, ^{226}Ra. Previous studies (King and others, 1982; Hall and others, 1987) have shown that high radon levels in groundwater exhibit a positive correlation with high radium levels and that both radon and radium isotopes may correlate with high U in the geologic materials that comprise the aquifers. The health risk of radon-rich waters in domestic wells is two-fold. Ingestion has been associated with increased risk of stomach cancer (Donahue, 1984). Of greater concern is the inhalation of the radioactive gas which may result when ^{222}Rn partitions into the air from the water supply. Alpha-decay of this inhaled ^{222}Rn results in lung tissue damage and possibly 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 requires the establishment of an analytical technique not previously available to the URI community. The method chosen for this study is a modification of traditional neutron activation analysis known as epithermal neutron activation analysis. As a result of the work accomplished in this project, such analyses may now be routinely performed for the first time at the Rhode Island Nuclear 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.

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.

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 is much less effective in characterizing 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 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 the transmition of thermal neutrons. 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 will pass through, contributing to the activation process (Steinnes and Brune, 1969). For U and additional elements which include Th, Ta, and Hf, the fraction of activations by epithermal neutrons exceeds 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 analyses 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 a 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 x 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 stored in the 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 where a program has been written specifically to convert peak intensities corresponding to U and Th in the sample to final concentrations (ppm). Thus, approximately one month elapses between the time of irradiation and final compilation of results for each irradiation.

PRINCIPAL FINDINGS AND SIGNIFICANCE:

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.

Results of U and Th from a broad group of 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. A generalized bedrock map of southeastern New England (Figure 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. The crystalline rocks of the eastern Esmond-Dedham Terrane may be divided into two broad suites; calcalkaline and alkaline complexes, with further subdivision based on age.

Trace element data from plutonic and volcanic rocks clearly discriminate the two mentioned suites (Hermes and Murray, in press). Calcalkaline rocks, associated with island arc processes, and typical of compressional plate margins, are chemically distinct from rocks of alkalic affinity. The alkalic suites are enriched in large ion lithophile elements such as Y, Rb, Nb, Th and U and are thought to represent within plate, anorogenic plutons. Calcalkaline rocks are typically lower in these high field strength elements.

The calcalkaline plutonic and volcanic rocks have Precambrian and Permian representitives. The Precambrian calcalkaline rocks predominantly include plutonic basement complexes such as the Esmond Granite and Dedham Granodiorite. Minor associated volcanics are the Hunting Hill Greenstone, and Lynn and Mattapan Volcanics. The younger calcalkaline suite of rocks is the Permian aged Narragansett Pier Granite, a large batholith located along Rhode Island's southern coast. This granite locally intrudes Carboniferous metasedimentary rocks of the Narragansett Basin. These basin rocks are interpreted as non-marine, primarily a braided stream complex.

The alkalic units include the Devonian aged Scituate Granite and related rocks, and comprise a significant portion of the state. This suite may be divided into a two-feldspar subsolvus granite to the west and a one-feldspar hypersolvus granite to the east and northeast. An additional alkalic unit is the Carboniferous aged Rhode Island Quincy Granite, a small peralkaline pluton located in the northeast corner of the state. Alkalic volcanic counterparts include the Spencer Hill and Wamsutta volcanics.

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 is peraluminous and distinct from the more meta-aluminous Precambrian calcalkaline lithologies. It 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.

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:

Nevins,N., 1989, Uranium concentrations in Rhode Island granites: A primary guide to radon in indoor air and groundwater: Geological Society of America , Abstracts with program, v.21, n.2, p.54.*

* oral presentation was given at meeting

M.S. THESIS: Nancy Nevins, expected completion fall 1989

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Zen, E-an, *editor*, 1983 Bedrock geology map of Massachusetts: U.S., Geological Survey: 1:250,000 scale, 3 map sheets.

Table 1. Results from range of plutonic lithologies (NPG=Narragansett Pier Granite)

SAMPLE ID	ROCK UNIT	LITHOLOGY	U (ppm)	Th(ppm)
SUBALKALIC				
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
CALC-ALKALIC				
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
ALKALIC				
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

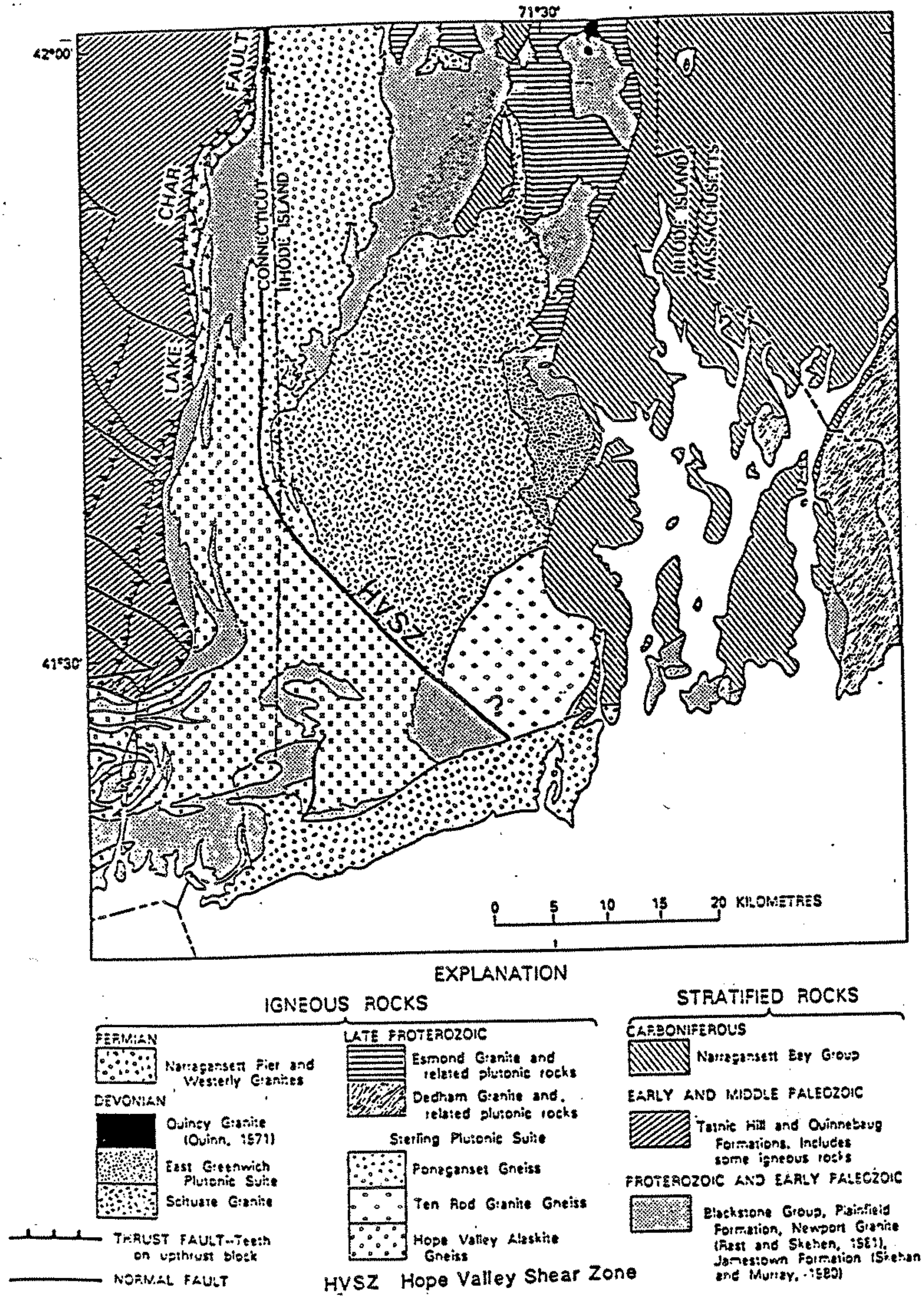


Figure 1. Generalized geologic map of southeastern New England emphasizing the volcanic and plutonic rocks referred to in this report. Geology after Quinn (1971), Zen (1983), Hermes and Zartman (1985), and O'Hara and Gromet (1985).

SYNOPSIS

Project Number: 03

Start: 6/1/88
End: 5/31/89

Title: Stochastic study of the natural flushing of contaminants from aquifers.

Investigators: Sau-Lon James Hu
Department of Ocean Engineering
University of Rhode Island.

Cheng-Jung Chang
Department of Civil Engineering
University of Rhode Island.

COWWR: 02F

Congressional Dist: 2

Key Words: Groundwater Modeling, Numerical Analysis, Rainfall, Solute Transport, Stochastic Hydrology.

Problem & Research Objectives:

Groundwater, which is a major source of water supply in the United States, is facing severe quantity and quality problems. Once contaminated, the options available for its use are both limited and costly. A contaminant usually enters groundwater from the surface of the land, percolating down through the aerated soil and the non-saturated zone. Once a contaminant reaches the aquifer, its movement is determined to some extent by its solubility in water. In considering the many different sources and causes of groundwater contamination, it becomes imperative that no simple solution can address this problem adequately and comprehensively.

Contamination has occurred in most regions of the country and will probably continue to occur. In Rhode Island, more than a dozen contaminations due to spills and leaks of organic materials have been reported in the past few years. The attempt to determine the extent of contamination in polluted area is being undertaken by the Rhode Island Department of Environmental Management. In response to public demands for positive action in cases where groundwater contamination threatens public health, aquifer cleanup programs are being required.

Once contamination is detected, there is a choice as to whether to take action and, if so, what form that action should take. Aquifer rehabilitation is feasible in some cases, but it is expensive and time-consuming with no guarantee of complete success. Because of the difficulty and uncertainty of remedial action, protection of useful, potable aquifers from contamination is a better strategy than curative effects. The appropriate response to a groundwater-pollution problem will depend upon the physical characteristics of the site and the nature of the contamination. The selection of the best approach for restoring water quality in aquifers requires the ability to predict changes in flow and chemical concentration in the aquifer for each possible management alternative. This in turn requires both adequate field data to describe the aquifer systems and the development of accurate simulation models to define the groundwater flow system, the pollutant-transport mechanism, and the nature and rates of chemical, physical and biological reactions. In many cases, restoration is so expensive that cleanup is not considered to be economically feasible. Among many management options for restoring water quality in aquifers, one is to eliminate the source of contamination but allow restoration to proceed only through natural flushing, dilution, and geochemical or biological reactions. Virtually all the water in the earth's crust will cycle back to the biosphere. However, the time for the cycle to be completed varies enormously -- from days to tens of thousands of years. Apparently, an accurate estimation of the required time for restoring water quality in aquifers through natural flushing is helpful to the decision-making on the management options.

The primary objective of this research is to develop a numerical model for predicting the time required for restoring water quality in contaminated aquifers through natural flushing.

Methodology:

The movement of contaminants in groundwater is a particularly active area of research. Most attempts at quantifying contaminant transport have relied on a system of some form of a well-known governing equation referred to as the advection-dispersion equation which may be written in its most general form:

$$\underbrace{\frac{\partial}{\partial x_i}\left(D_{ij}\frac{\partial c}{\partial x_j}\right)}_{\text{dispersion term}} - \underbrace{\frac{\partial}{\partial x_i}(c\,V_i)}_{\text{advection term}} - \underbrace{\frac{c'\,W}{n}}_{\text{sink/source term}} + \underbrace{\sum_{k=1}^{s} R_k}_{\text{chemical reaction term}} = \frac{\partial c}{\partial t}$$

where c is the solute concentration and D_{ij} is the coefficient of dispersion (the i,j indices refer to cartesian coordinates.). c' is the concentration of a solute in a source or sink fluid, v denotes the average linear velocity of groundwater, and W is the volume flow rate of the sink or source fluid per unit volume of porous material. In the chemical-reaction term, R_k is the rate of production of the solute in reaction k of s different reactions. The average linear velocity v of groundwater may be written as

$$v = KI/n$$

where K is hydraulic conductivity, I is the head gradient, and n is the effective porosity. The sink/source term W can include well discharge, recharge from precipitation, and evapotranspiration. In the model, W is computed as

$$W = Q_w - q_{re} + q_{et}$$

where Q_w = well discharge

q_{re} = recharge flux

q_{et} = evapotranspiration flux

In this study, for evaluating the natural flushing rates of contaminants from aquifers, the chemical reaction term will be ignored and the sink/source term will be modeled as a stochastic process.

Principal Findings & Significance:

A two-dimensional Galerkin finite-element procedure is used in this research. In order to consider the stochastic nature of the source/sink term, Monte Carlo simulation is adopted. It is realized that Monte Carlo techniques become particularly useful when the relationship among variables are complicated functions.

Assume that recharge from precipitation is mainly due to rainfall. It has been proposed that an event-based rainfall simulation model can be constructed by modeling the occurrence of rainstorms by a Poisson process and the amount of rain in each storm by an exponential probability distribution. Let the number of rainy weeks N be Poisson-distribution with mean ν, and the rainfall in a rainy week, Ri, be exponentially distributed with parameter λ (mean = $1/\lambda$). Denoting T as the total annual rainfall, the relationship between T, N and the Ri's is:

$$T = \sum_{i=1}^{N} R_i$$

That is, T is the sum of a random number of random variables. For convenience, it is assumed that rainfall in rainy weeks are identically distributed and mutually independent. An initial study via Monte Carlo simulations has shown that a significant difference occurs in repeated simulations. For obtaining reliably statistical data, a huge number of simulations should be carried out.

Numerical errors arise from the numerical solution of the partial differential equation are related to the space and time increments; these errors can be kept within tolerable limits through careful discretization of the space and time dimensions. The Galerkin's procedure is well-suited to solve solute-transport problems, because of its versatility in handling irregular geometries. Although advective-dispersive transport in groundwater system is inherently three-dimensional, due to that a great deal of computational time is needed, numerical simulation of field-contaminant plumes are suggested to be done in one or two dimensions.

Publications & Professional Presentation:

In preparation.

SYNOPSIS

Project Number: 04 Start 6/1/88
End 5/31/89

Title: A Microbial Method for Removal of Metals, Cutting Oils & Cyanide from Polluted Water - Phase II

Investigators: Dr. R. W. Traxler, University of Rhode Island
Dr. Tung-Ching Lee; University of Rhode Island
Dr. D. R. Nelson, University 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.

Objective 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.

Principal Findings & Significance

1. Objective 1.

The conventional agar plate assay whereby paper discs containing various concentration of metal are placed on a seeded agar plate, incubated and the zone of inhibition measured were used with the various metals studied in this project. It was possible to obtain concentration dependent values for inhibition. Assays which determine the minimal inhibitory concentration of a metal using V-B broth were compared to the agar assay and were found to give much lower (10-15 fold) inhibition concentrations. These data indicate that agar systems cannot be used to assay metal toxicity and resistance.

2. Objective 2.

A plasmid has been isolated and cloned into E. coli HB101 which increases the resistance of the clone to Cd.

3. Objective 3

The model system (Figure 1) has been tested with Arthrobacter SL-1 suspended in Pipes buffer at pH 5.5.

The results of a static system are shown in Table 1, in which the metal removed from the waste water ranged from 48 to 98% for the individual metals. Each metal was initially present in the waste at 50 ppm, therefore, the waste contained a total of 400 ppm of metal ion. The 4 main target metals, Pb, Cd, Ni, and Zn ranged from 94 to 98% removal. After treatment, the cells are recovered by centrifugation to yield a concentrated slurry of digestion and the metal precipitated as insoluble salts.

In the model system testing we used a 900 ml reactor volume containing 24.7 mg/ml of Arthrobacter SL-1 in Pipes buffer at pH 5.5, agitation at 200 rpm and temperature at 30 C. The waste was flowed through the system at a Dilution Rate of 0.2 for a total treatment time of 240 minutes. The effluent metal levels are shown in Figure 2. It is important to note that the 240 minute value for Ni only represents 0.2 ppm of effluent Ni in the system. It is concluded that the system represents a very efficient system for cleaning a metal polluted waste water.

4. Objective 4.

The progress on this objective was hindered by the availability of the safety system for working with cyanide. This hood system was not usable until early in 1989, so that only short term screening test could be performed. A number of isolates were screened for the capacity to utilize cyanide as a sole source of nitrogen for growth. None of the isolates were able to utilize cyanide. The long term enrichment system is the only likely system which will yield the desirable organisms. This process will require about 6 months to achieve, and will be reserved as a topic for a graduate project which we hope to start in September of 1989.

Publications & Professional Presentations

Traxler, R. W. and E. M. Wood, 1989. Bioaccumulation of Metals by *Arthrobacter* SL-1. To be presented at the Annual Meeting of the Society for Industrial Microbiology, Seattle, August 16, 1989. After presentation the full manuscript will be considered for publication by the Society.

M.S. Theses:

J. S. Wang, Completed August, 1988.

Ph.D. Dissertations:

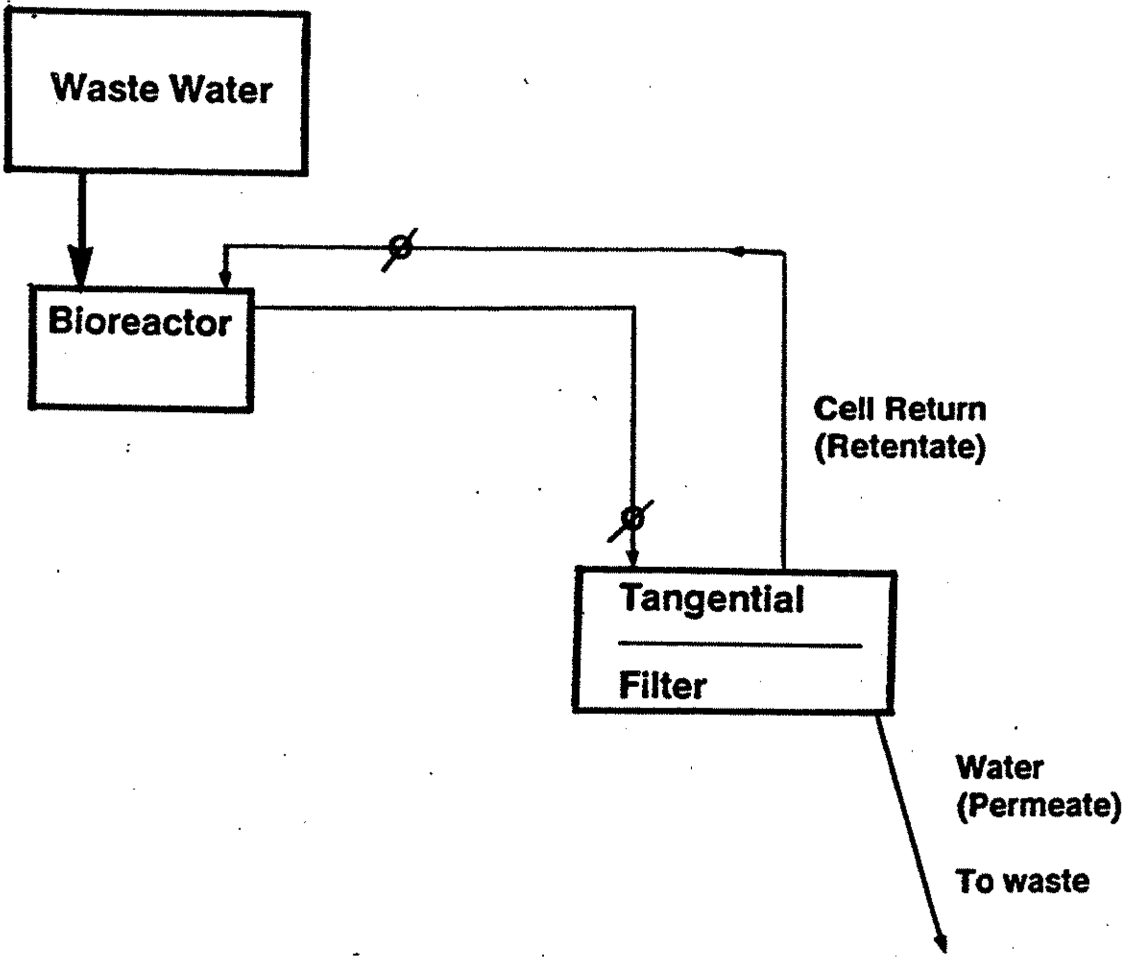
M-C. Lai, To be completed August, 1989.

Training accomplishments

Academic Level

Field of Study	Undergraduate	Masters	Ph.D.	Total
Microbiology	1		1	2
Food Science		1		1
Total				3

Figure 1. Diagram for application to clearing of metal plating waste water.



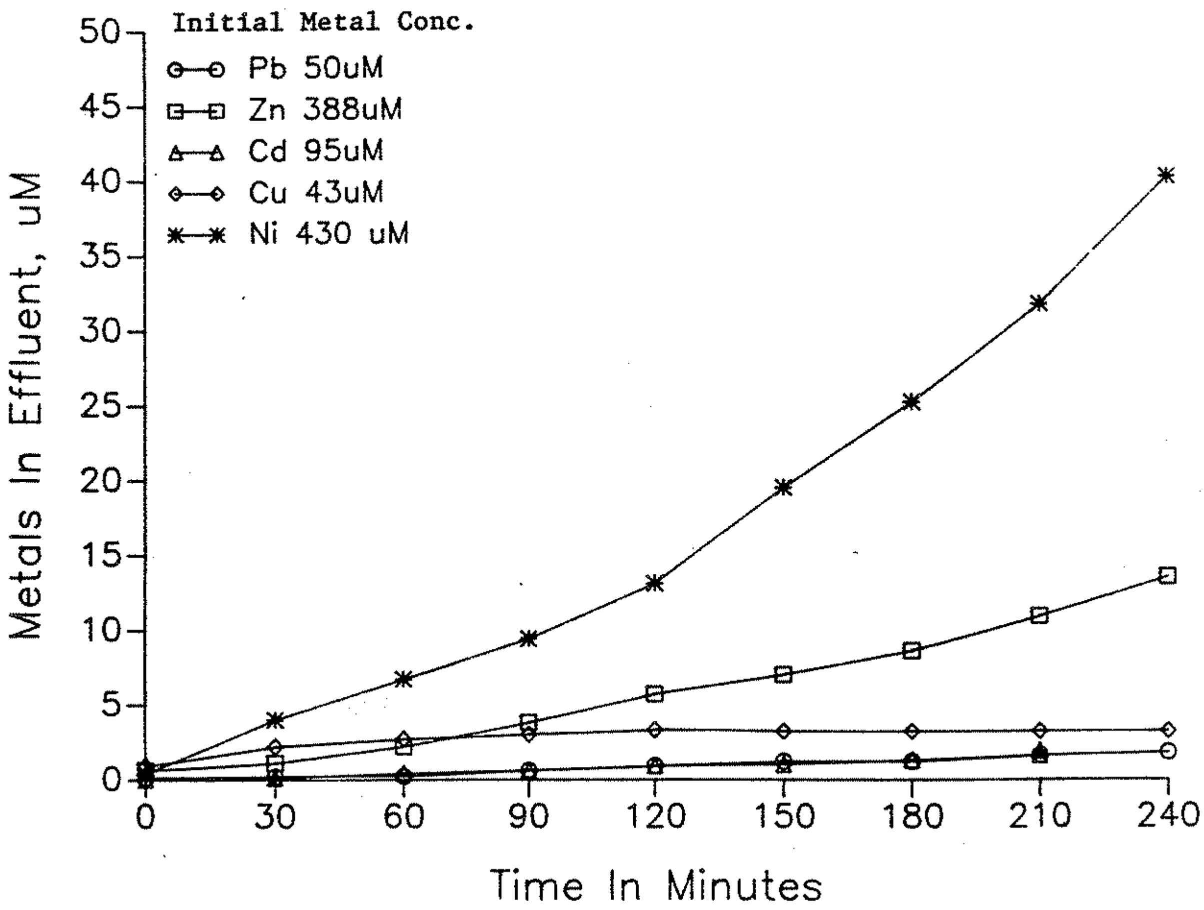


Figure 2. Effluent metal concentrations at various treatment time

Table 1. Metal Bioaccumulation by _Arthrobacter_ SL-1

Metal	Initial Conc. uM	Concentration uM 10 min	Concentration uM 130 min	Cell Dry Weight mg/ml	%Cellular Accumulation 10 min	%Cellular Accumulation 130 min
Pb	250	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

SYNOPSIS

Project Number: 05 Start: 6/1/88
End: 5/31/89

Title: Evaluating Plants for Nutrient Retention in Vegetative Buffer Strips.

Investigators: Richard J. Hull, Plant Sciences Department, University of Rhode Island, Kingston, RI 02881

COWWR: 05B, 05G Congressional District: 2nd, R. I.

Key Words: Fertilizers, Groundwater management, Infiltration, Land use, Nitrogen, Nutrients, Plant growth, Rainfall-runoff processes, Riparian vegetation, Solute transport, Surface drainage, Water-quality management, Watershed management

Problem and Research Objectives:

Ground and surface water resources constitute the primary potable water supplies available to Rhode Island and the urban Northeast. Increasingly the quality of this is being threatened by the growing intensity of land use: agricultural, domestic and industrial. Strategies for protecting the quality of water resources have concentrated on protective zones surrounding surface reservoirs and local restrictions on development over major aquifers. These efforts are being compromised by the expansion of intensive land uses adjacent to tributaries and aquifer recharge areas. The resulting deterioration of water quality is a growing concern for managers of municipal water supplies, local governments, and land-use planners.

While land management practices are being developed which will reduce the leaching of pollutants into ground water, much less is known about the fate of materials which are washed off land surfaces by rain water. Vegetative buffer strips or zones have been used effectively to retard the overland movement of soil associated with surface runoff from agricultural and other intensive land use activities. These strips are designed primarily to retain particulate materials but their capacity to trap soluble mineral nutrients, heavy metals, and organic compounds is less well understood. The capacity of vegetative buffer strips to shield surface water bodies from soluble materials washed off adjacent land areas must be evaluated before their use for this purpose can be recommended.

This research evaluates a broad range of plants for their capacity to absorb mineral nutrients and transport these elements to their shoots which can be harvested and removed from the site. The utilization of plants, which are found to be efficient in recovering nutrients from the soil, during the design and construction of buffer strips will increase the effectiveness of these structures to protect surface waters from pollution by both particulate and soluble materials.

Methodology:

a) Kinetic parameters for nutrient absorption by selected plant species were determined using a solution depletion technique. Seeds were germinated on 5 cm diameter disks of nylon screening mounted over holes in black plexyglass strips. When these strips were placed over plastic tubs filled with aerated nutrient solution the screens remained moist and the seeds germinated quickly with their roots extending into the nutrient solution.

After a vigorous root system had developed, the grass cultures were transferred from quarter-strength Hoagland's solution to a similar solution lacking nitrogen. They were maintained in this nitrogen-free solution for 24 hours at which time they were transferred to a nutrient solution containing 0.5 mM nitrate. We concentrated on nitrate because it is the nutrient of greatest concern as a ground and surface water pollutant. Total solution volume for each grass culture was about 350 ml when they were introduced to the 0.5 mM nitrate solution. One ml aliquots of solution were taken every 30 minutes until the nitrate concentration had been depleted to approximately 0.1 mM when the sampling frequency was increased to ten minute intervals. This was continued until the nitrate level was below a detectable concentration. Nitrate was analyzed by reducing it to nitrite on a Cd-Cu reduction column followed by a spectrophotometric nitrite determination.

Following an absorption experiment, the roots were excised, blotted free of water, and weighed. Based on the nitrate loss from the nutrient solution between each sampling time, nitrate absorption rates were calculated as µmoles NO_3/ gram fresh root/hour. These were plotted against nitrate concentration and the absorption parameters computed based on the equation:

$$V = \frac{Vmax \cdot Co}{km + Co} + kCo$$

where V = the nitrate absorption rate.

Vmax = the maximum rate of nitrate absorption for the saturable phase of uptake.

Co = the nitrate concentration of the nutrient solution.

km = the nitrate concentration which will support half of the Vmax rate of uptake. This is also the dissociation constant of nitrate from its transport protein.

k = the first-order rate constant of the linear phase (nonsaturable) of nitrate uptake.

The linear uptake constant (k) was derived from the uptake rate by nitrate concentration curve over the range of 0.5 mM to 0.1 mM nitrate. The saturable uptake phase of nitrate absorption was determined over the range of 0 to 0.2 mM and the kinetic parameters Vmax and km calculated from that.

Plants compared in this study included the commonly used grasses: tall fescue (Festuca arundinacea Schreb.) and reed canarygrass (Phalaris arundinacea L.). Also compared were the trufgrasses: perennial ryegrass (Lolium perenne L.) and Kentucky bluegrass (Poa pratensis L.); the forage grasses: smooth bromegrass (Bromus inermis Leyss.), orchardgrass (Dactylis glomerata L.) and timothy (Phleum pratense L.); and the prairie grasses: buffalograss (Buchloe dactyloides (Nutt.) Engelm.) and blue grama (Bouteloua gracilis (H.B.K.) lag. ex Steud.).

b. Nitrate leaching from the soil and nitrogen transport to shoots were studied for the same grasses under both greenhouse and field conditions. Ceramic lysimeter plates were installed below newly established stands of these grasses at a depth of 70 cm to intercept water that passed below the root zone. Nitrogen was applied at a rate of 177 kg/ha (160 lb/a) per year with applications made before planting on April 20, on August 22, and on September 30. Late in 1988 and following every significant rain following the spring thaw in March, lysimeter samples were collected and analyzed for nitrate.

A greenhouse study was initiated during the spring of 1988 in which the same grasses were seeded into column lysimeters. The lysimeters were constructed of PVC pipe and were 15 cm in diameter and 45 cm tall. Ceramic plates were mounted in the base of these lysimeters which permitted the recovery of all water leaching through the root zone. The greenhouse light, temperature and photoperiod were maintained so as to provide near optimum growing conditions for the grasses. Grass leaf growth was harvested at intervals appropriate to management which would occur on a buffer strip. Foliage and leachate were analyzed for total nitrogen and nitrate-nitrogen respectively.

Principal Findings and Significance:

The determination of nitrate uptake parameters did not prove to be as easy for these grasses as for other plant systems with which we have had experience. During the absorption period, uptake rates varied considerably making the calculation of a linear absorption constant difficult and unreliable. Changing greenhouse conditions as the season progressed and during a single uptake experiment accounted for some of this variability. Transferring the grass cultures to the laboratory and measuring nitrate depletion under a constant artificial light source (sodium vapor lamp) reduced the variability.

Rates of nitrate absorption were always low during the first 30 to 60 minutes of an uptake experiment. This was followed by high rates of absorption between 90 and 180 minutes which gradually declined as the solution nitrate concentration decreased. Because nitrate uptake and reduction in plant roots occurs through the action of induceable proteins (transporters and enzymes respectively) the 24 hours of nitrate-free culture preceding each absorption experiment may have produced roots deficient in these proteins. When the roots were again introduced to nitrate, the induced synthesis of nitrate transport and reduction proteins occurred but approximately one hour was required for this to support full uptake. When grass cultures were preconditioned in a nitrate containing solution, this initial low absorption rate was reduced but not eliminated.

To provide a sufficiently long uptake time so any initial variations in the absorption rate would not compromise the accurate estimation of the linear rate constant, the nitrate concentration used for these experiments was increased to 1.0 or 1.5 mM. These modifications of the experimental protocol have permitted the construction of a few good uptake kinetics curves. This research is continuing and we hope to have good results from all the grasses studied before the completion report is prepared.

The average nitrate concentration in the leachate from the grasses studied ranged from 0.88 to 31.59 mg NO_3-N/L. The low concentrations (less than 10.0 mg/L) were collected from the orchardgrass and tall fescue plots. Nitrate-N concentrations in excess of 10.0 mg/L were recovered from Kentucky bluegrass, perennial ryegrass and reed canarygrass plots. Soil solution beneath bromegrass plots contained nitrate levels greater than 20 mg/L.

The movement of nitrates towards ground water, computed as loading in kilograms per hectare, ranged from 2.2 to 106.1 kg/ha during the time since fall 1988. Orchardgrass leached least and bromegrass most (2.0 vrs. 50.0 kg N/ha) during the sampling period. Mass loading and nitrate concentration exhibited a marked increase during the fall sampling period through early spring. By mid April, the nitrate concentration declined while the leachate volume remained constant. This corresponds to the time of spring green-up and growth of many cool season grasses. This trend was not apparent for bromegrass and reed canarygrass.

Nitrate leaching from the column lysimeters was difficult to interpret. Both the concentrations of nitrate and the leachate volume were low, with mass loading values rarely higher than 1.0 kg N/ha. Leaf tissue nitrogen concentrations were highest in perennial ryegrass, reed canarygrass, Kentucky bluegrass and bromegrass grown under the same relatively constant environmental conditions.

These data are too preliminary to draw any conclusions. Kinetic constants for nitrate absorption will be correlated with nitrate levels in soil water and ground water loading estimates from both field and greenhouse lysimeter studied. It appears that such relationships will vary during the year and vegetation must be selected or combined so as to maximize the duration of nitrate uptake and removal from the soil water in the root zone.

Publications and Professional Presentations:

Lemunyon, J.L. and W.M. Sullivan. Leachate Quality in Vegetated Filter Strips. Presented to the Northeast Branch of the American Society of Agronomy, June 28, 1989, Burlington, VT.

Hull, R.J.; H. Liu; and H.J. Brown. Nitrogen Use Efficiency by Established Turf Following Late Fall Fertilizer Applications. Presented to the Northeast Branch of the American Society of Agronomy, June 28, 1989, Burlington, VT.

Informal presentations have been made to representatives of the Soil Conservation Service and other interested parties.

Thesis:

Two graduate students, J.L. Lemunyon and H. Liu are contributing to this project as part of their doctoral dissertation research.

SYNOPSIS

Project number: 06 Start: 6/1/88
End: 5/31/89

Title: MICROBIAL PROCESSES CONTROLLING THE FATE OF NITROGEN IN VEGETATIVE BUFFER STRIPS

Investigators: P.M. Groffman, W.M. Sullivan, J.L. Lemunyon
University of Rhode Island, Kingston, R.I.

COWRR Category: 05-B Congressional District: 2nd, R.I.

Keywords: Denitrification, Nitrogen, Pollution control

PROBLEM AND RESEARCH OBJECTIVES:

The movement of sediments and nutrients from terrestrial environments into water bodies is a critical threat to water quality in many areas (Karr and Schlosser 1978), including Narragansett Bay. Agricultural and suburban land uses and construction can deliver substantial loads of sediment and nutrients into water bodies, leading to eutrophication and sedimentation (Ryther and Dunstan 1971, Lowrance et al. 1984). Eutrophication and sedimentation reduce water quality for drinking supplies, navigation, fisheries and recreational uses.

An emerging technique for controlling movement of sediments, nutrients and other pollutants moving from terrestrial environments into water bodies is the use of vegetative buffer strips (VBS). Small strips of grass or other vegetation can be used to trap pollutants moving from land areas before they enter water bodies. The maintenance of riparian filter strips was adopted as a "best management practice" (BMP) by the USDA SCS (Dillaha et al. 1988) and are recommended for use as a complement to structural stormwater control devices in Rhode Island (Scott 1988). Despite the emerging widespread use of VBS, the scientific basis for their effectiveness is highly questionable (Hayes et al. 1988). There is a great need for research to determine if current buffer guidelines are too weak, too strong, or altogether inappropriate.

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). Research on optimal design and management for VBS 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). Other studies have analyzed the role of natural forest and wetland vegetation as pollutant buffers (Brown et al. 1987, Broderick et al. 1988).

A major unresolved question relating to nutrient dynamics in VBS centers around nitrogen (N). Nitrogen is heavily applied to agricultural and suburban land uses, is highly mobile and is a prime cause of eutrophication in Rhode Island waterways (Lee and Olsen 1985). Several studies have addressed removal of N by VBS (Doyle et al 1977, Thompson et al. 1978, Young et al. 1980) but results from these studies varied markedly and they did not address the specific microbial processes that regulate N dynamics in VBS. More importantly, these studies did not address the fate of N absorbed by VBS. Of particular concern is the fact that the main control mechanism of VBS is to increase infiltration of runoff which may merely transmit surface runoff pollutants to groundwater.

The key N cycle processes regulating N dynamics in VBS are plant uptake, immobilization, and denitrification. Immobilization is the uptake of mineral N by microorganisms and denitrification refers to the transformation of nitrate (NO_3^-) into N gas. Denitrification is an anaerobic process, occurring primarily in saturated, poorly drained soils. The objectives of our study were to quantify N leaching, denitrification and immobilization of N in a variety of VBS in Rhode Island.

METHODOLOGY:

This experiment was conducted at the University of Rhode Island's Peckham Farm, in Kingston, Rhode Island. Experimental VBS were established as part on 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. Each plot measured 3 meters x 5 meters in size, with a 0.70 meter alleyway between alternate plots. Situated above the grass plots was a 25 meter x 100 meter oat field which was graded to a 2% slope to provide runoff onto the grass plots.

Ceramic lysimeter plates were installed below each VBS 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. On April 20, 1988, the grass plots, along with the oat field, were treated with 33 kg/ha of N, 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.

For microbial process studies, only two of the grass treatments, common reed canary grass (Phalaris arundinacea) and tribute tall fescue (Festuca arundinacea) were used. The reed canary grass 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.

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 amendments. 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). Nitrate was added to some cores to simulate runoff events and glucose was added to some cores to test for carbon limitation of denitrification. Denitrification measurements were made over two three day periods in July, over a 9 day period in August and at two dates in September of 1988. Immobilization of N was measured by treating soils in the laboratory with simulated runoff and measuring levels of inorganic N in soil over an 8 day period.

PRINCIPAL FINDINGS AND SIGNIFICANCE:

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:

2.0 to 10.0 kg/ha	orchardgrass, sweet vernalgrass
10.0 to 25.0 kg/ha	tall fescue, creeping foxtail
25.0 to 50.0 kg/ha	perennial ryegrass, big bluestem kentucky bluegrass, reed canary
> 50.0 kg/ha	bromegrass, switchgrass

These results 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. In buffers receiving lower inputs of N from runoff, differences in uptake and leaching may be less dramatic. 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.

Unamended rates of denitrification were very low (< 10 g N ha^{-1} d^{-1}) and were highest in the poorly drained forest plot. This was as expected since soil moisture was highest in this plot. The grass plots had a much higher ability to denitrify NO_3^- in simulated runoff than the forest plots. In a three day experiment in July, rates of denitrification in the tall fescue and reeds canary grass soils were 7889 and 4537 g N ha^{-1} d^{-1} respectively, while rates in the well drained and poorly drained forest plots averaged 311 and 365 g N ha^{-1} d^{-1} respectively. A similar pattern was observed in an 11 day experiment in August. These results suggest that denitrification can significantly reduce levels of NO_3^- added to VBS, but should be interpreted with caution since they are from laboratory experiments. Measurement of denitrification during in-field runoff events was scheduled for the summer of 1988, but will not be done until the summer of 1989. Addition of glucose significantly increased rates of denitrification in NO_3^- amended cores, suggesting that the availability of carbon sources may ultimately limit the capacity of VBS to remove NO_3^- through denitrification.

We expected the forest plots to have a much higher potential for denitrification than the grass plots, since forest soils generally have higher moisture and organic matter levels than upland agricultural soils. To test the hypothesis that low pH in the forest soils reduced denitrification in these soils relative to the grass plots, we added lime to the forest 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 significantly 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 <u>in situ</u> 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 riparian zones 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.

We measured immobilization by monitoring mineral N levels in soils for eight days following addition of a 4 ppm slug of NO_3^-. All soils other than the poorly drained forest were able to immediately absorb the added NO_3^-. However, levels of mineral N increased in all soils over the eight day incubation. These results suggest that immobilization is only a temporary sink for NO_3^-, and that any N that is immobilized may be subsequently released (mineralized). Mineralization was highest in the poorly drained forest soil and was higher in the reed's canary grass than in the tall fescue soil.

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 and/or plant harvest.

PUBLICATIONS AND PROFESSIONAL PRESENTATIONS:

Groffman, P.M., E.A. Axelrod, J.L. Lemunyon and W.M. Sullivan. 1989. Microbial processes controlling the fate of N in vegetated buffer strips. To be presented at the Soil Science Society of America annual meeting in October 1989.

M.S. NON-THESIS MAJOR PROJECT:

Eric A. Axelrod. Denitrification in vegetated buffer strips.

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SYNOPSIS

Project Number: Sl **Start: 11/87**
End: 05/89

Title: Study of Fly Ash & Bottom Ash & Their Leachate Characteristics in a Simulated Landfill Condition

Investigators: Calvin P.C. Poon, University of Rhode Island

COWRR: 05A, 05B **Congressional District: Second**

Keywords: Acid Rain, Contaminant Transport, Evapotranspiration, Hazardous Waste, Infiltration, Leaching, Sanitary Landfills

Problem and Research Objective:

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 samples were collected for chemical analysis. Interactions of Cd and Pb with other substances in the simulated landfills were examined. A computer HELP model was used for the study. Experimental data were obtained to calibrate the model after which it was used to estimate the infiltration and leachate drainage rates of landfills of different designs.

Principal Findings and Significance:

Using the existing EPTC extraction procedure, the incinerator ash/residue was not

if the newly proposed TCLP procedure by USEPA was used. Either procedure showed that the ash/residue was a hazardous substance in reference to Pb. Deionized water extraction at pH 4.95 showed that the ash/residue was nonhazardous for both Cd and Pb.

The simulated landfill or column study showed that initially the landfill under saturated conditions would produce leachate containing 4.9 ppm Pb and 15-16 ppb Cd. The concentration of both metal decreased rapidly under the typical rainfall condition in Rhode Island with Pb at 5.6 ppb and Cd at 0.31 ppb after 250 days and remained at or below these low levels thereafter.

Organic acids in the leachate, mainly formic and acetic acids, facilitated Pb and Cd mobilization. However, by using the Sep-Pak separation procedure, it was shown that most of the Cd and Pb found in the leachate was in the free ionic form, despite the presence of these organic acids. The simulated landfill also converted sulfate into sulfide which helped to immobilize Cd and Pb. In a long term it was expected that more sulfide would accumulate in the landfill due to the anoxic condition, further immobilize Cd and Pb. resulting in even lower Pb and Cd concentrations in the leachate.

Under the typical rainfall conditions in Rhode Island, it was found that out of the annual 44 inches of precipitation, 5.1 inches would evaporate and 36.4 inches of leachate could be collected from drains. The HELP Model was found to be a very useful tool for the estimation of evaporation, evapotranspiration, infiltration, and leachate drainage. The results are currently being used in preliminary engineering design of ash landfill and in the development of a study of leachate treatability for the Rhode Island Solid Waste Management Corp.

Thesis:

A Ph.D. dissertation is underway.

SYNOPSIS

Project Number: S2

Start 12/88
End 12/89

Title: Simultaneous Removal of Cyanide & Heavy Metals from Industrial Process Wastewaters

Investigators: Poon, Calvin P.C., University of Rhode Island

COWRR: 05D

Congressional District: Second

Keywords: Heavy Metals, Industrial Wastewater, Wastewater Treatment

Problem and Research Objectives:

The industrial pretreatment program of the Narragansett Bay Commission has identified total metal loadings to their Field's Point Wastewater Treatment Facility to be 363,645 pounds and total cyanide loadings to be 27,043 pounds in 1987. The industrial contribution of these metals was calculated to be between 60 to 90% of the total metal load to the treatment facility but only 7% of the total flow. The three largest loadings of metals were zinc, copper, and nickel which together made up more than 91% of the total metal loadings. Within the Narragansett Bay Commission district, there are 121 electroplaters and metal finishers as well as 129 companies identified as possibly having casting operations, all contributing in part to the total metal and cyanide loadings.

The objectives of the research have been to demonstrate the feasibility of a physical-chemical treatment process, using a brine solution electrolysis, in simultaneous removal of cyanide, nickel, copper, and zinc.

Methodology:

A compact reactor was built with platinated columbium anode and stainless steel cathode. The space between the horizontally laid anode screen and cathode screen was filled with a rock salt solution as the anodelyte. The wastewater containing heavy metal and cyanide was introduced on top of the rock salt solution layer. The electrolysis of the rock salt solution generated chlorine to destroy cyanide and hydroxides to precipitate the heavy metal. Gas bubbles carried the precipitated metal to the top to form a scum layer. The scum layer was collected acid dissolved, to form a high concentrated metal solution from which the metal could be plated out.

Principal Findings and significance:

By applying a direct current from 3 to 6 volts and a current density of about 3.6

to 6 mA/cm_2, preliminary experimental results indicated successful removal of copper, nickel, and cyanide to levels meeting the pretreatment standards. Effluents of 0.5 pm Cu, 0.3 ppm Ni and 0.5 ppm CN could be achieved easily in either batch or continuous flow process. The treatment experiments with a Latin Square statistical design will be carried into the FY-89 program. Also the metal plating-out process from the acidified scum solution will be tried in the FY-89 program.

INFORMATION TRANSFER ACTIVITIES

Project No.: 22 Information Transfer Activities

Title: Environmental Education: Water Protection, Management, and Conservation

Investigators: William R. Wright,Ph.D.
Department of Natural Resource Science, URI

Calvin P. C. Poon, Ph.D.
Department of Civil and Environmental Engineering, URI

Arthur J. Gold, Ph.D.
Department of Natural Resources Science, URI

Thomas P. Husband, Ph.D.
Department of Natural Resources Science, URI

COWWR: 10C, D Congressional District: 2nd, RI

Key Words: Groundwater Quality (76), Land Use (101), Septic Tanks (163), Water Quality Monitoring (206)

Problem and Research Objectives:

Two major sources of drinking water, surface and groundwater, exist in Rhode Island. The Scituate Reservoir serves approximately 60 percent of the state, with a safe yield capacity of 78 million gallons per day (MGD). The southern part of the state is dependent on a large aquifer network. On December 1, 1987, a petition for Environmental Protection Agency designation for the Pawcatuck Basin Aquifer as a Sole Source Aquifer was submitted. The concern lies in the pressures of increased water demand and water degradation caused by accelerated urban development. Research conducted by the Rhode Island Department of Environmental Management (DEM) presented in The Groundwater Protection Strategy cites a growing number of contaminated drinking water wells throughout the state. Such nonpoint sources as agricultural and urban runoff add to pollution loading. Protection of these sole-source water supplies is critical to meet future demands for potable water. Important forces in accomplishing this protection are informed decision makers and an educated public. A comprehensive Technology Transfer Program can target key groups and disseminate information on planning strategies for effective land use and water protection.

Methodology:

To ensure that water resource management occurs in a way which both maintains areas of high water quality and improves degraded areas, people entrusted with executing planning decisions must have technical information accessible. The University of Rhode Island can implement programs of technology transfer.

As a strong research base committed to water resource issues, the University can generate technical information. The University can integrate and support existing related water quality programs at state and local levels. The University also can increase scientific information on surface water quality in Rhode Island by compiling background water quality data against which present conditions can be measured and evaluated. This Technology Transfer Program proposes to continue and to broaden the following programs initiated in FY 1987:

1. Printing of written materials, aimed at municipal decision makers and the general public on such topics as storm water management, fertilizers, buffer zones, and surface and groundwater quality;
2. Sponsoring of workshops on groundwater issues particularly addressing state and local strategies for groundwater protection;
3. Monitoring program for Watershed Watch, a citizen-based monitoring program for surface waters within the Pawcatuck Watershed, to be expanded to include the northern part of Rhode Island.

There are many benefits to the above programs. 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, the University can offer technical assistance and strengthen existing water quality programs. A good example of this is the cooperative surface water monitoring program, Watershed Watch, which increases DEM's surface water quality data-base. On the local level, university assistance can serve to galvanize the public on key water quality issues.

Principal Activities and Significance:

A. Watershed Watch, a citizen-based monitoring program for surface waters with the Pawcatuck Watershed, was expanded to include the northern part of the state. Training materials were developed as part of a four-session training workshop in lake and river management which was held at the University of Rhode Island from June 1-22, 1989. The training consisted of three classroom sessions and one Saturday morning field excercise. Topics addressed at the workshop included:

1. Physical, chemical, and biological characteristics of RI surface waters.
2. Factors affecting surface water quality, including pollution sources, natural characteristics, and man-made alterations.
3. Conducting shoreline surveys to develop an inventory of natural characteristics and pollution sources.
4. Steps that individuals and organizations can take to protect water quality.

The emphasis of the training workshops was citizen involvement to help protect and manage surface water quality. More than 25 volunteers participated in the training. Each individual agreed to perform 20 hours annually in completing shoreline surveys or other management projects on a lake or river segment, working under the direction of a watershed coordinator and Watershed Watch staff.

B. Conference on Groundwater Protection Strategies for Rhode Island. It is estimated that 24% of Rhode Island's population depends on groundwater resources for their drinking water supply. Municipalities are responsible for protecting and ensuring the quality of their groundwater supplies. A one-day workshop was designed to address the needs and concerns of Rhode Island's communities for groundwater protection. The workshop was held on November 29, 1989 at the Whispering Pines Conference Center on the W. Alton Jones Campus in West Greenwich, RI. One hundred people attended the conference, included representatives of local, state, federal governments and private organizations. Local and regional experts presented tools for developing local groundwater protection programs.

A resource room was set up and open throughout the day in which eleven different groups and organizations involved in groundwater protection issues displayed informational materials and answered questions. Those involved in the resource room included:

1. The Department of Natural Resources Science, URI
2. RI Environmental Data Center
3. RI Department of Environmental Management
4. US EPA, Region 1 Office
5. Resource Conservation and Development
6. USDA Soil Conservation Service
7. Narragansett Bay Project
8. Rural New England
9. New England Interstate Water Pollution Control Commission
10. Connecticut Department of Environmental Protection
11. US Geologic Survey

Participants received a resource notebook in addition to handouts and informational materials displayed at the resource tables. Attached are copies of the conference brochure and program.

The objectives of the conference were to: 1. present groundwater protection strategies to local decision makers, 2. increase local officials' knowledge of RI's groundwater hydrology, 3. update local officials on regulation and laws pertaining to groundwater protection, and 4. facilitate networking between groundwater professional and local decision makers. The conference accomplished all of its stated objectives.

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 other water resources related activities, as well as discussions on water related environmental issues relevant to the State of Rhode Island such as radon, sole source aquifer designation, hazardous waste handling in Rhode Island, on-site wastewater management districts, impact of environmental laws on real estate transactions, watershed watch and citizen participation.

COOPERATIVE ARRANGEMENTS

The Center has two advisory committees, the State Advisory Committee and the University Water Resource 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
Mr. Alfred L. Hawkes, Director of the Audubon Society of R. I.

University Water Resources Coordinating Committee

Pei Wen Chang, Animal Pathology
Frank DeLuise, Mechanical Engineering
Reinhard K. Frohlich, Geology
Scott W. Nixon, Oceanography & Sea Grant Coordinator
James Opaluch, Resource Economics
Calvin P. C. Poon, Environmental Engineering
Leonard Worthen, Pharmacognosy

As in the past year, both committees have contributed significantly to the development and direction of the Center's 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 District Office of the U. S. Geological Survey, in Providence, in developing the project work. With some explored geological data available, the result of this project could be used to predict the time required for cleaning a contaminated aquifer by natural flushing in Rhode Island or elsewhere.

Project 05 and 06 worked closely with U. S. Dept. of Agriculture, soil Conservation Service on project design.

Project 04 and S2 received assistance from the jewelry industry in Rhode Island. In addition, Project S2 worked closely with the Division of Environmental Coordination of the RIDEM, and the Association of Jewelry and Silversmiths of Rhode Island to develop the project objective.

Project S1 worked closely with and received technical assistance from the Rhode Island Solidwaste Management Corp. throughout the project.

The project on information transfer worked with Rhode Island Town Councils, R. I. Audubon Society, R. I. Dept. of Environmental Management, Chariho Water Resources Group, Wood-Pawcatuck Watershed Association, R. I. Resources Conservation and Development, USDA Soil Conservation Service, USEPA, Region 1 Office, Rural New England, New England Interstate Water Pollution Control Commission, and Connecticut Department of Environmental Protection to develop the program, conducting the Watershed Watch and Conference on Groundwater.

The Center also participated in the second year program of the 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	Undergraduate	Master's degree	Ph.D. degree	Post Ph.D.	Total
		Academic Level			
Engineering					
Environmental			1		1
Ocean		1			1
Chemical		1			1
Geology		1			1
Natural Resources Science	1	3			4
Plant & Soil Science	2	1			3
Microbiology/Food Sci.		1	1		2
Total	3	8	2		13

RHODE ISLAND
WATER RESOURCES CENTER

UNIVERSITY OF RHODE ISLAND

1892

COMPLETION REPORT FY-1988 PROGRAM

STOCHASTIC STUDY OF THE NATURAL FLUSHING OF CONTAMINANTS FROM AQUIFERS

by

Sau-Lon J. Hu, Dongsheng Zhao

COMPLETION REPORT

Stochastic Study of the Natural Flushing of Contaminants from Aquifers

Submitted by

Sau-Lon James Hu, Principal Investigator
Ocean Engineering Department

Dongsheng Zhao, Graduate Research Assistant
Ocean Engineering Department

Project No. G1612-03

to

U.S. Department of the Interior

A PROJECT COMPLETION REPORT

TITLE: Stochastic Study of the Natural Flushing of Contaminants From Aquifers

Problem & Research Objectives:

Groundwater, which is a major souce of water supply in the United States, is facing severe quantity and quality problems. Once contaminated, the options available for its use are both limited and costly. A contaminant usually enters groundwater from the surface of the land, percolating down through the aerated soil and the non-saturated zone. Once a contaminant reaches the aquifer, its movement is determined to some extent by its solubility in water. In considering the many different sources and causes of groundwater contamination, it becomes imperative that no simple solution can address this problem adequately and comprehensively.

Contamination has occurred in most regions of the country and will probably continue to occur. In Rhode Island, more than a dozen contaminations due to spills and leaks of organic materials have been reported in the past few years. The attempt to determine the extent of contamination in polluted area is being undertaken by the Rhode Island Department of Environmental Management. In response to public demands for positive action in cases where groundwater contamination threatens public health, aquifer cleanup programs are being required.

Once contamination is detected, there is a choice as to whether to take action and if so, what form that action should take. Aquifer rehabilitation is feasible in some cases but it is expensive and time-consuming, with no guarantee of complete success. Because of the difficulty and uncertainty of remedial action, protection of useful, potable aquifers from contamination is a better strategy than curative effects. The appropriate response to a groundwater-pollution problem will depend upon the physical characteristics of the site and the nature of the contamination. The selection of the best approach for restoring water quality in aquifers requires the ability to predict changes in flow and chemical concentration in the aquifer for each possible management alternative. This in turn requires both adequate field data to describe the aquifer systems and the development of accurate simulation models to define the groundwater flow system, the pollutant-transport mechanism, and the nature and rates of chemical, physical and biological reactions. In many cases, restoration is so expensive that cleanup is not considered to be economically feasible. Among many management options for restoring water quality in aquifers, one is to eliminate the source of contamination but allow restoration to proceed only through natural flushing, dilution, and geochemical or biological reactions. Virtually all the water in the earth's crust will cycle back to the biosphere. However, the time for the cycle to be completed varies enormously -- from days to tens of thousands of years. Apparently, an accurate estimation of the required time for restoring water quality in aquifers through natural flushing is helpful to the ecision-making on the management options.

The primary objective of this research is to develop a numerical model for predicting the time required for restoring water quality in contaminated aquifers through natural flushing.

Literature review:

In the past few years it has become clear to groundwater hydrologists that the simulation of groundwater flow regimes is often best accomplished within a stochastic framework rather than in the traditional deterministic framwwork. The traditional approach to groundwater modeling is deterministic. Stochastic modeling has been used with increasing intensity in the last few years. Two main lines of attack have been followed so far. The first one is the geostastical approach developed by Matheron(1971) and applied to groundwater flow problems by the group of Ecol des Mines, Fontainebleau, France(e.g., Journel, 1974; Delhomme, 1978, 1979), and more recently by others as well(G. dagan, 1982). The geostatistical school has mainly investigated the probelm of stochastic interpolation, i.e., the prediction of best estimates and variances of estimation, on a spatial grid, of variables measured at a few points.

The second line of attack is that groundwater modeling by stochastic differential equations. The main thrust here was in investigating the direct problem, i.e., determining the statistical structure of the head and specific discharge fields given that of hydraulic properties and given the geometry and boundary conditions(Freeze, 1975; Gelhar, 1976; Gutjahr and Gelhar, 1981). Some work has also been done toward solving the inverse problem by stochastic models(Neuman and Yakowitz,1979) and the problem of dispersion of solutes(Smith and Schwartz, 1980). The latter topic is of paramount importance, as it is essential to recognize and to account for heterogeneity of aquifers in order to understand the solute transport phenomenon in field condition.

It is clear that the previous work is common to regard aquifers properties as well as flow variables as random variables. In this study, for estimation of the required time for restoring water quality in aquifers through natural flushing, assume that recharge from precipitation is mainly due to rainfall. Thus the aquifers properties and flow variables will be considerd as constant and the rainfall, as the input, will be the random function characterized by certain probability distributions.

Methodology:

The movement of contaminants in groundwater is a particularly active area of research. Most attempts at quantifying contaminant transport have relied on a system of some form of a well-known governing equation referred to as the advection-dispersion equation which may written in its most general form:

$$\frac{\partial}{\partial x_i}\left(D_{ij}\frac{\partial c}{\partial x_j}\right) - \frac{\partial}{\partial x_i}(c\ V_i) - \frac{c'\ W}{n} + \sum_{k=1}^{s} R_k = \frac{\partial c}{\partial t}$$

dispersion term
advection term
sink/source term
chemical reaction term

where c is the solute concentration and D_{ij} is the coefficient of dispersion (the i,j indices refer to cartesian coordinates.). c' is the concentration of a solute in a source or sink fluid, v denotes the average linear velocity of groundwater, and W is the volume flow rate of the sink or source fluid per unit volume of porous material.

In the chemical-reaction term, R_k is the rate of production of the solute in reaction k of s different reactions. The average linear velocity v of groundwater may be written as

$$v = KI/n$$

where K is hydraulic conductivity, I is the head gradient, and n is the effective porosity. The sink/source term W can include well discharge, recharge from precipitation, and evapotranspiration. In the model, W is computed as

$$W = Q_w - q_{re} + q_{et}$$

where Q_w = well discharge

q_{re} = recharge flux

q_{et} = evapotranspiration flux

In this study, for evaluating the natural flushing rates of contaminants from aquifers, the chemical reaction term will be ignored and the sink/source term will be modeled as a stochastic process.

Since there is no anaylic sulotions for eq(1), a numerical method called Galerkin finite element method is used in this research and the corresponding computer programs were developed in appendix B.

In order to consider the stochastic nature of the souce/sink term, Monte Carlo simulation is adopted. It is realized that Monte Carlo techniques become particularly useful when the relationship among variables are complicated functions.

Assume that recharge from precipitation is mainly due to rainfall. It has been proposed that an event-based rainfall simulation model can be constructed by modeling the occurrence of rainstorms by a Poisson process and the amount of rain in each storm by an exponential probability distribution. Let the number of rainy weeks N be Poisson-distribution with mean ν, and the rainfall in a rainy week, Ri, be exponentially distribulted with parameter λ (mean = $1/\lambda$). Denoting T as the total annual rainfall, the relationship between T, N and the Ri's is:

$$T = \sum_{i=1}^{N} R_i$$

That is, T is the sum of a random number of random variables. For convenience, it is assumed that rainfall in rainy weeks are identically distributed and mutually indenpendent.

Principal Findings & Significance:

For simplicity, it is assumed that a fixed amount pollutant substance exists in a small area which we are intrested. It also assumes that rainfall is the only souce to affect the ground-water hydrolic head, and further determines the ground-water flow pattern. the numerical study shows that the net contaminant distribution depends only on the total amount of the rainfall, independent of the sequency. For instance, if there are two sets rainfall data, and each set has 3 rainfalls with the total amount being identical. Let the first set be in a sequency of 1,5,10, and the second is 5,1,10. The solutions corresponding to the above two sets turn out to be same.

Now, if the rainfall is assumed to be a poisson random process, an initial study by ultilizing the Monte Carlo simulation technique shows that the total amount of ranfall will be significantly differet in repeated simulations, and hence the distribution and concertration of contaminat will vary significantly too. For obtaining reliably statistical results, a large number of simulations are suggested to carried out.

Numerical errors arise from the numerical solution of the partial differential equation are related to the space and time increments; these errors can be kept within tolerable limits through careful discretization of the space and time dimensions. The Galerkin's procedure is well-suited to solve solute-transport problems, because of its versatility in handling irregular geometries. Although advective-dispersive transport in groundwater system is inherently three-dimensional, due to that a great deal of computational time is needed, numerical simulation of field-contaminant plumes are suggested to be done in one or two dimensions.

Appendix A:

The Computer Program Development of the Solute Transport in Groundwater by the Finite Element Method

Equations

The concentration of the solute in an areal two-dimensional groundwater system can be described by the mass transport equation

$$\frac{\partial C}{\partial t} + u \frac{\partial C}{\partial x} + v \frac{\partial c}{\partial y} + \frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} + Q = 0 \qquad (1)$$

where C: the concentration of the solute (time dependent varible),

u: the generalized velocity of the x direction (constant),

v: the generalized velocity of the y direction (constant), Q: the generalized rate of fluid withdrwal,

$$\begin{aligned} q_x &= \\ q_y &= \end{aligned} \begin{bmatrix} D_{xx} & D_{xy} \\ & \\ D_{yx} & D_{yy} \end{bmatrix} \begin{Bmatrix} \frac{\partial c}{\partial x} \\ \\ \frac{\partial c}{\partial y} \end{Bmatrix} \qquad (2)$$

D_{ij}: the generalized effective hydrodynamic

despersion coefficient,

In the above equation, the u and v may be obtained based on the Darcy's law such that

$$v_i = - T_{ij} \frac{\partial h}{\partial x_j} \qquad (3)$$

where T_{ij} is transmissivity and h is the hydraulic head. The hydraulic head may be obtained based on the formula

$$\frac{\partial}{\partial x_i} \left(k_{ij} \, b \frac{\partial h}{\partial x_j} \right) = S_s b \frac{\partial h}{\partial t} + w^* b \qquad (4)$$

where b: the saturated thickness of the aquifer, for two dimensional areal flow, i,j=1,2. The boundary conditions can be formulated and the necessary parameters can be obtained in the field.

Finite Element Formulation

For illustration purpose, since eq.(1) is more compliced to solve than eq.(4), the finite element formulation will only be carry on eq.(1). But the computer programs solving for both eq.(1) and eq.(4) were given in thr appendix B and appendix C, respectively.

The solution domain Ω of the equation (1) may be divided into M elements of r nodes each. By the usual procedure the solute concetration C and the solute concetration gradients within each element may be expressed as

$$C(x,y,t) = \sum_{i=1}^{r} N_i(x,y)\ \hat{C}_i(t) \tag{5}$$

$$\frac{\partial C}{\partial x}(x,y,t) = \sum_{i=1}^{r} \frac{\partial N_i}{\partial x}(x,y,t)\ \hat{C}_i(t) \tag{6}$$

$$\frac{\partial C}{\partial y}(x,y,t) = \sum_{i=1}^{r} \frac{\partial N_i}{\partial y}(x,y,t)\ \hat{C}_i(t) \tag{7}$$

or in matrix notation

$$C(x,y,t) = [N\ (x,y)]\ \{\hat{C}_i(t)\} \tag{8}$$

$$\begin{Bmatrix} \frac{\partial C}{\partial x}\ (x,y,t) \\ \\ \frac{\partial C}{\partial y}\ (x,y,t) \end{Bmatrix} = [B(x,y)]\ \{\hat{C}(t)\} \qquad (9)$$

where [N] is the solute concentration interpolation matrix, [B] is the solute concentration gradient interpolation matrix

$$[N(x,y)] = [\ N_1\ N_2\ \ldots.\ N_r\ ] \qquad (10)$$

$$[N(x,y)] = \begin{bmatrix} \frac{\partial N_1}{\partial x} & \frac{\partial N_2}{\partial x} & \ldots. & \frac{\partial N_r}{\partial x} \\ \\ \frac{\partial N_1}{\partial y} & \frac{\partial N_2}{\partial y} & \ldots. & \frac{\partial N_r}{\partial y} \end{bmatrix} \qquad (11)$$

$C_i(t)$ is the value of the solute concentration at each node and {C(t)} is the vector of element nodel solute concentrations. The second-order solute concentration equation requires only C° continuity, and the solute concentration C(t) may be considered as the only nodal unknown. Applying the virtual work method, the equation (1) may be written as

$$\int_{\Omega} \delta C\left(\frac{\partial C}{\partial t} + u \frac{\partial C}{\partial x} + v \frac{\partial C}{\partial y} + \frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} + Q\right) d\Omega = 0 \quad (12)$$

where Ω is the domain for element (e). For simplicity, a row vector and a matrix will be further distingushed by a { } and a [ ], respectively. If $\delta C=[N]\delta\{\hat{C}\}$, then the equation (12) becomes

$$\int_{\Omega}[N]^T[N][\hat{C}]^T\delta\Omega + \int_{\Omega}u[N]^T[B_1][\hat{C}]^T\delta\Omega + \int_{\Omega}v[N][B_2][\hat{C}]^T \delta\Omega +$$

$$\int_{\Omega} [B]^T[D][B][\hat{C}]^T \delta\Omega = - \int_{\Omega} [N]^T Q \delta\Omega \quad (13)$$

$$\text{where } [B_1] = [\frac{\partial N_1}{\partial x} \; . \; . \; . \; . \; \frac{\partial N_r}{\partial x}] \quad (14)$$

$$[B_2] = [\frac{\partial N_1}{\partial y} \; . \; . \; . \; . \; \frac{\partial N_r}{\partial y}] \quad (15)$$

the resulting equation may takes the form

$$[K_t][\hat{C}]^T + [K_u][\hat{C}]^T + [K_r][\hat{C}]^T + [K_D][\hat{C}]^T = \{P\}^T \quad (16)$$

where

$$[K_t] = \int_\Omega [N]^T[N]\ \delta\Omega \ ; \qquad [K_u] = \int_\Omega u[N]^T[B_1]\ \delta\Omega \qquad (17)$$

$$[K_v] = \int_\Omega v[N]^T[B_2]\ \delta\Omega \ ; \ [K_D] = \int_\Omega [B]^T[D][B]\ \delta\Omega \qquad (18)$$

$$\{P\}^T = \int_\Omega [N]^T Q\ \delta\Omega \qquad (19)$$

For simplicity,let $[K] = [K_u] + [K_v] + [K_D]$

equation (16) can be written as

$$[K_t]\ [\hat{\bar{C}}]^T + [K][\hat{C}]^T = \{P\}^T \qquad (20)$$

Note that the above equations is written in the form of glob coordinate (X-Y coordinate), for convennient it is usually written in the form of local coordinate ($\xi-\eta$ coordinate). The transformation between two coordinate is usually based on the isoparametric element approach. In this study, the node in the $\xi-\eta$ plan are mapped onto corresponding nodes in the X-Y plane by using the same interpolation function that are used to interpolate the solute concentrate C(t), From equation (4),

$$x(\xi,\eta) = \sum_{i=1}^{r} N_i(\xi,\eta)\ \hat{x}_i \qquad (21)$$

$$y(\xi,\eta) = \sum_{i=1}^{r} N_i(\xi,\eta)\ \hat{y}_i \tag{22}$$

$$C(\xi,\eta) = \sum_{i=1}^{r} N_i(\xi,\eta)\ \hat{C}_i \tag{23}$$

Element matrices involving volume integrals are evaluated by writing

$$d\Omega = t\ dx\ dy = t\ |J(\xi,\eta)|\ d\xi\ d\eta \tag{24}$$

where $|J|$ is the determinant of the Jacobian

$$[J(\xi,\eta)] = \begin{bmatrix} \frac{\partial x}{\partial \xi} & \frac{\partial y}{\partial \eta} \\ \frac{\partial x}{\partial \xi} & \frac{\partial y}{\partial \eta} \end{bmatrix} \tag{25}$$

This transformation permits the element integrals to be evaluated by integration over the unit square of the parent element. For example, the $[k_D]$ matrix is

$$[K_D] = \iint_{-1}^{1} [B]^T[D][B]\ |J|t\ d\xi\ d\eta \tag{26}$$

which is normally evaluated by numerical integration. In this study, the Gauss-Legendrature quadrature method is used. Thus, the corresponding matrices can be written as

$$[K_t] = \sum_{i=1}^{n}\sum_{j=1}^{n} W_i W_j \; [N]^T[N] \; |J| \qquad (27)$$

$$[K_u] = \sum_{i=1}^{n}\sum_{j=1}^{n} W_i W_j u[N]^T[B_1] \; |J| \qquad (28)$$

$$[K_v] = \sum_{i=1}^{n}\sum_{j=1}^{n} W_i W_j v[N]^T[B_2] \; |J| \qquad (29)$$

$$[K_D] = \sum_{i=1}^{n}\sum_{j=1}^{n} W_i W_j \; [B]^T[D][B] \; |J| \qquad (30)$$

$$\{P\}^T = \sum_{i=1}^{n}\sum_{j=1}^{n} W_i W_j \; [N]^T \; Q \; |J| \qquad (31)$$

where W_i and W_j are Gauss weights, ξ_i and η_j are the coordinates of the Gauss points, and NG is the number of Gauss points in each integration direction.

It should be noted that the equation (20) is a first order time dependent probelem. In this study, the implicit method is employed to solve this equation with a time-marching algorithms based on finite difference methods. Let t_n denote a typical time in the response so that $t_{n+1}=t_n+\Delta t$, where n=1,2,3,...N. Introducing a parameter θ such that $t_\theta = t_n + \theta\Delta t$, where $0 \leqq \theta \leqq 1$. the equation (20) at time t may be written as

$$[K_t]\ [\hat{C}_\theta]^T + [K][\hat{C}_\theta]^T = \{P_\theta\}^T \tag{32}$$

and introduce the approximations

$$\{\hat{C}_\theta\}^T = \frac{\{\hat{C}_{n+1}\}^T - \{\hat{C}_n\}^T}{\Delta t} \tag{33}$$

$$\{C_\theta\}^T = (1-\theta)\ \{C_n\}^T + \theta\ \{C_{n+1}\}^T \tag{34}$$

$$\{P_\theta\}^T = (1-\theta)\ \{P_n\}^T + \theta\ \{P_{n+1}\}^T \tag{35}$$

Substituting the above equations into equation (32) gives

$$\left(\ \theta[K] + \frac{1}{\Delta t}\ [K_t]\ \right)\ \{\hat{C}_{n+1}\}^T = \left(-(1-\theta)[K] + \frac{1}{\Delta t}\ [K_t]\ \right)$$

$$\{C_n\}^T + (1-\theta)\ \{P_n\}^T + \theta\ \{P_{n+1}\}^T \tag{36}$$

For simplicity equation (36) can be expressed as

$$[\bar{K}]\ \{\hat{C}_{n+1}\}^T = \{\bar{P}_{n+1}\}^T \tag{37}$$

where

$$[\bar{K}] = \left(\theta[K] + \frac{1}{\Delta t} [K_t] \right) \tag{38}$$

$$\{\bar{P}_{n+1}\} = \left(-(1-\theta)\ [K] + \frac{1}{\Delta t} [K_t] \right) \{\hat{C}_n\}^T +$$

$$(1-\theta)\ \{P_n\}^T + \theta\ \{P_{n+1}\}^T \tag{39}$$

The Crank-Nicolson method is applyed and the parameter θ = 0.5. Since the Crank-Nicolson method is unconditionally stable, the stability requirement for equation (37) is always satisfied.

The corresponding computer program of solving equation (1) is developed and listed in appendix B, and the computer program of solving equation (4) is list in appendix C, the computer program of solving equation (3) is list in appendix D.

Appendix B: Computer Program

```
C    This program computes the  pollutant coefficient factor C(x,y)
c        based on equation (1) in Appendix A.
C
C       *************************************************************
C
C
C             TAPE      CONTENTS
C              1        ELEMENT DATA
C              5        INPUT
C              6        OUTPUT
      COMMON/SOL/NUMNP,NELGRP,MTOT,NANA
      COMMON/EL/ISW,NPAR(4),NFIRST,NLAST,LELST,MAXEST
      COMMON/DYN/N1,N2,N3,N4,N5,N6,N7,N8,N9,N10
      COMMON/EQS/NEQ,NCOLS,MBAND
      COMMON/HEAD/HED(20)
      COMMON/IO/IN,IT
        COMMON/DD/ITW0
C
C     IF ITW0=1 MEANS SINGL PRICISION
C     IF ITW0=2 MEANS DOUBLE PRECISION
      COMMON A(4000)
        REAL A
      ITW0=2
      MTOT=4000
C
      IN=5
      IT=9
C
      READ (IN,1000) HED
      READ (IN,*) NUMNP,NELGRP,NANA
      WRITE (IT,2000) HED,NUMNP,NELGRP,NANA
C
C      INPUT NODE DATA
      N1=1
      N2=N1+NUMNP
      N3=N2+NUMNP*ITW0
      N4=N3+NUMNP*ITW0
      N5=N4+NUMNP*ITW0
      N6=N5+NUMNP*ITW0
C
      IF (N6.GT.MTOT) CALL ERROR (N6-MTOT)
C
      CALL NODES (A(N1),A(N2),A(N3),A(N4),A(N5),NUMNP)
C
C               CURRENT CONTENTS OF COMMON AREA A(I)
C
C                 LOCATION        VARIABLE      DEFINITION
C
C     STARTING AT N1................ID(1)       BOUNDARY CONDITION ID
C                 N2.................T(1)       NODAL TEMPERATURES
C                 N3.................X(1)       X NODAL COORDINATES
C                 N4.................Y(1)       Y NODAL COORDINATES
C                 N5.................Z(1)       Z NODAL COORDINATES
C                 N6....TEMPORARY STORAGE FOR ELEMENT INPUT
C
C     INPUT,GENERATE AND STORE ELEMENT DATA
C
      CALL ELDAT
C
      NEQ=NUMNP
      NCOLS=2*MBAND-1
      NWK=NEQ*NCOLS
      N7=N6+NWK*ITW0
```

```
      N8=N7+NEQ*ITW0
      N9=N8+NEQ*ITW0
      N10=N9+MAXEST*ITW0
      WRITE (IT,2030)
      WRITE (IT,2040) NEQ,MBAND
      IF (N10.GT.MTOT) CALL ERROR (N10-MTOT)
C
C       NOW USE.....A(N6)  - A(1,1)   CONDUCTANCE MATRIX
C                   A(N7)  - Q(1)     LOAD VECTOR FROM BOUND.COND.
C                   A(N8)  - B(1)     TOTAL LOAD VECTOR,OR
C                   A(N8)  - B(1)     TEMP. FROM LINEAR ANALYSIS
C                   A(N9)  - ELEMENT DATA
      IF (NANA.EQ.0) STOP
C
C      LINEAR STEADY ANALYSIS
C
      CALL ZERO (A(N6),NWK)
      CALL ZERO (A(N7),NEQ)
      CALL ZERO (A(N8),NEQ)
      CALL ELCAL (A(N9))
      CALL TEMPBC (NEQ,NCOLS,MBAND,A(N1),A(N2),A(N6),A(N7))
      CALL FACTOR (NEQ,NCOLS,MBAND,A(N6),IPUNT)
      IF (IPUNT.EQ.1) STOP
      CALL ADDBC (NEQ,A(N7),A(N8))
      CALL SOLVE (NEQ,NCOLS,MBAND,A(N6),A(N8),IPUNT)
      IF (IPUNT.EQ.1) STOP
      CALL PRINTT (A(N8),NUMNP)
C      CALL FLUX (A(N9))
C
C
      STOP
C
1000  FORMAT (20A4)
2000  FORMAT (1H1,20A4///38H C O N T R O L   I N F O R M A T I O N,//4X,
     127H NUMBER OF NODAL POINTS  =,I5/4X,27H NUMBER OF ELEMENT GROUPS
     2=,I5/4X,27H ANALYSIS CODE(NANA)      =,I5/4X,27H   EQ.0,  DATA CHE
     3CK ONLY, /4X,27H   EQ.1,  LINEAR STEAY     /4X)
2030  FORMAT (1H1,38H S O L U T I O N   P A R A M E T E R S,//)
2040  FORMAT (5X,34H  TOTAL NUMBER OF EQUATIONS      =,I5,/,5X,34H SEMI
     1 BANDWIDTH                    =,I5)
      END
      SUBROUTINE ZERO (A,N)
C
C      ZERO AN ARRAY A(I)
C
      DIMENSION A(1)
      DO 10 I=1,N
      A(I)=0.0
10    CONTINUE
      RETURN
      END
      SUBROUTINE ERROR (N)
      COMMON/IO/IN,IT
      WRITE (IT,2000) N
      STOP
C
2000  FORMAT (//,20H STORAGE EXCEEDED BYI6)
      END
      SUBROUTINE NODES (ID,T,X,Y,Z,NUMNP)
        IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION ID(1),X(1),Y(1),Z(1),T(1)
      COMMON/IO/IN,IT
C
```

```
C       READ OR GENERATE NODAL POINT DATA
C
      WRITE (IT,2040)
      NOLD=0
10    CONTINUE
      READ (IN,*) N,ID(N),X(N),Y(N),Z(N),KN,T(N)
      IF (NOLD.EQ.0) GO TO 30
C
C       CHECK IF GENERATION IS REQUIRED
C
      IF (KN.EQ.0) GO TO 30
      NUM=(N-NOLD)/KN
      NUMN=NUM-1
      IF (NUMN.LT.1) GO TO 30
      XNUM=NUM
      DX=(X(N)-X(NOLD))/XNUM
      DY=(Y(N)-Y(NOLD))/XNUM
      DZ=(Z(N)-Z(NOLD))/XNUM
      DT=(T(N)-T(NOLD))/XNUM
      K=NOLD
      DO 20 J=1,NUMN
      KK=K
      K=K+KN
      X(K)=X(KK)+DX
      Y(K)=Y(KK)+DY
      Z(K)=Z(KK)+DZ
C      T(K)=T(KK)+DT
      ID(K)=ID(KK)
20    CONTINUE
30    CONTINUE
      NOLD=N
      IF (N.NE.NUMNP) GO TO 10
C
C       PRINT ALL NODAL POINT DATA
C
      WRITE (IT,2050)
      WRITE (IT,2060) (N,ID(N),X(N),Y(N),Z(N),T(N),N=1,NUMNP)
C
      RETURN
C
2040  FORMAT (//23H NODAL POINT INPUT DATA/)
2050  FORMAT (/,1X,4HNODE3X,12H  B.C. CODE 11X,23HNODAL POINT COORDINATE
     1S/7H NUMBER22X,1HX12X,1HY12X,1HZ8X,11HTEMPERATURE,/)
2060  FORMAT (I5,5X,I5,6X,3E13.5,2X,E13.5)
      END
      SUBROUTINE ELDAT
C
C       CALLS ELTYPE TO BRANCH TO ELEMENT ROUTINES
C       FOR ELEMENT INPUT DATA
C
      COMMON/SOL/NUMNP,NELGRP,MTOT,NANA
      COMMON/EL/ISW,NPAR(4),NFIRST,NLAST,LELST,MAXEST
      COMMON/EQS/NEQ,NCOLS,MBAND
      COMMON/IO/IN,IT
      COMMON A(1)
      NUMEL=0
      MBAND=0
      MAXEST=0
      ISW=1
      REWIND 1
      DO 10 M=1,NELGRP
      WRITE (IT,2000) M
      READ (IN,*) (NPAR(I),I=1,4)
```

```
      NUMEL=NUMEL+NPAR(2)
      MTYPE=NPAR(1)
      CALL ELTYPE (MTYPE)
      IF (LELST.GT.MAXEST) MAXEST=LELST
      WRITE (1) LELST,NPAR,(A(I),I=NFIRST,NLAST)
10    CONTINUE
      RETURN
C
2000  FORMAT (1H1,//,1X,13HELEMENT GROUP,I3)
      END
      SUBROUTINE ELCAL (AA)
C
C      CALLS ELTYPE TO BRANCH TO ELEMENT ROUTINES
C      TO FORM EQUIVALENT SYSTEM MATRICES
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      REAL AA
      COMMON/SOL/NUMNP,NELGRP,MTOT,NANA
      COMMON/EL/ISW,NPAR(4),NFIRST,NLAST,LELST,MAXEST
      DIMENSION AA(1)
      ISW=2
      REWIND 1
      DO 10 M=1,NELGRP
      READ (1) LRD,NPAR,(AA(I),I=1,LRD)
      MTYPE=NPAR(1)
      CALL ELTYPE (MTYPE)
10    CONTINUE
      RETURN
      END
      SUBROUTINE ELTYPE (MTYPE)
      COMMON/IO/IN,IT
C
C      CALLED BY MAIN AND FLUX
C
      GO TO (10,20,30) MTYPE
10    CALL PLANE
      RETURN
20    CONTINUE
30    WRITE (IT,2040) MTYPE
      RETURN
C
2040  FORMAT (8H ELEMENT,I4,26H HAS NOT BEEN IMPLEMENTED ,/)
      END
      SUBROUTINE CALBAN (ND,LM)
C
C      CALLED BY ELEMENT SUBROUTINES
C
C      CALCULATES SEMI- BANDWIDTH
C
      COMMON/EQS/NEQ,NCOLS,MBAND
      DIMENSION LM(ND)
      MIN=100000
      MAX=0
      DO 10 L=1,ND
      IF (LM(L).GT.MAX) MAX=LM(L)
      IF (LM(L).LT.MIN) MIN=LM(L)
10    CONTINUE
      NDIF=MAX-MIN+1
      IF (NDIF.GT.MBAND) MBAND=NDIF
      RETURN
      END
      SUBROUTINE ADDSTF (ND,LM,NEQ,NCOLS,MBAND,S,A)
C
```

```
C       FORMS SYSTEM CONDUCTANCE MATRIX
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DIMENSION A(NEQ,NCOLS),S(ND,ND),LM(ND)
      DO 20 I=1,ND
      II=LM(I)
      DO 10 J=1,ND
      JJ=MBAND-LM(I)+LM(J)
      A(II,JJ)=A(II,JJ)+S(I,J)
10    CONTINUE
20    CONTINUE
      RETURN
      END
      SUBROUTINE ADDLD (ND,LM,NEQ,ID,Q,B)
C
C       FORMS LOAD VECTOR
C
        IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DIMENSION ID(NEQ),B(NEQ),Q(ND),LM(ND)
      DO 10 I=1,ND
      II=LM(I)
      IF (ID(II).NE.0) GO TO 10
      B(II)=B(II)+Q(I)
10    CONTINUE
      RETURN
      END
      SUBROUTINE ADDBC (NEQ,Q,B)
C
C       ADDS CONTRIBUTION OF TEMP. BOUNDARY CONDITION
C       TO LOAD VECTOR
C
        IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DIMENSION Q(NEQ),B(NEQ)
      DO 10 L=1,NEQ
      B(L)=B(L)+Q(L)
10    CONTINUE
      RETURN
      END
      SUBROUTINE TEMPID (T,NTP,LTP,TND)
C
C       DETERMINES ELEMENT TEMP. FOR AN INPUT NODE LIST.
C
        IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DIMENSION T(1),LTP(NTP),TND(NTP)
      DO 10 I=1,NTP
      IDUM=LTP(I)
      TND(I)=T(IDUM)
10    CONTINUE
      END
      SUBROUTINE TEMPBC (NEQ,NCOLS,MBAND,ID,T,A,B)
C
C       IMPOSES BOUNDARY CONDITIONS ON THERMAL EQUILIBRIUM EQUATIONS
C
        IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DIMENSION A(NEQ,NCOLS),B(NEQ),ID(NEQ),T(NEQ)
C       DO 11 I=1,NEQ
C       DO 11 J=1,NCOLS
C11     WRITE(*,*)'A(I,J)',A(I,J)
      DO 30 I=1,NEQ
      IF (ID(I).EQ.0) GO TO 30
      DO 20 JJ=1,NCOLS
      II=I+MBAND-JJ
      IF (II.LT.1) GO TO 10
```

```
      IF (II.GT.NEQ) GO TO 10
      IF (A(II,JJ).EQ.0.0) GO TO 10
      B(II)=B(II)-T(I)*A(II,JJ)
      A(II,JJ)=0.0
10    CONTINUE
      IF (A(I,JJ).EQ.0.0) GO TO 20
      A(I,JJ)=0.0
20    CONTINUE
      B(I)=T(I)
      A(I,MBAND)=1.0
30    CONTINUE
      RETURN
      END
      SUBROUTINE FACTOR (NEQ,NCOLS,MBAND,A,IPUNT)
C
C       REDUCE MATRIX BY GAUSS ELIMINATION
C
C       A(I,J) HAS SEMI-BANDWIDTH MBAND AND MAY BE ASYMMETRIC
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      COMMON/IO/IN,IT
      DIMENSION A(NEQ,NCOLS)
      IPUNT=0
      KMIN=MBAND+1
      DO 50 N=1,NEQ
      IF (A(N,MBAND).EQ.0.0) GO TO 60
      IF (A(N,MBAND).EQ.1.0) GO TO 20
      C=1./A(N,MBAND)
      DO 10 K=KMIN,NCOLS
      IF (A(N,K).EQ.0.0) GO TO 10
      A(N,K)=C*A(N,K)
10    CONTINUE
20    CONTINUE
      DO 40 L=2,MBAND
      JJ=MBAND-L+1
      I=N+L-1
      IF (I.GT.NEQ) GO TO 40
      IF (A(I,JJ).EQ.0.0) GO TO 40
      KI=MBAND+2-L
      KF=NCOLS+1-L
      J=MBAND
      DO 30 K=KI,KF
      J=J+1
      IF (A(N,J).EQ.0.0) GO TO 30
      A(I,K)=A(I,K)-A(I,JJ)*A(N,J)
30    CONTINUE
40    CONTINUE
50    CONTINUE
      RETURN
60    CONTINUE
      IPUNT=1
      WRITE (IT,2070) N,A(N,MBAND)
      RETURN
C
C
C
2070  FORMAT (1H1,5X,34H SET OF EQUATIONS ARE SINGULAR ,//,5X,25HDIAGONA
     IL TERM OF EQUATION,I5,13H IS EQUAL TO ,E15.8)
      END
      SUBROUTINE SOLVE (NEQ,NCOLS,MBAND,A,B,IPUNT)
C
C       REDUCTION OF A LOAD VECTOR B(I)
C
```

```
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      COMMON/IO/IN,IT
      DIMENSION A(NEQ,NCOLS),B(NEQ)
      IPUNT=0
      DO 30 N=1,NEQ
      IF (A(N,MBAND).EQ.0.0) GO TO 60
      IF (A(N,MBAND).EQ.1.0) GO TO 10
      B(N)=B(N)/A(N,MBAND)
10    CONTINUE
      DO 20 L=2,MBAND
      JJ=MBAND-L+1
      I=N+L-1
      IF (I.GT.NEQ) GO TO 20
      IF (A(I,JJ).EQ.0.0) GO TO 20
      B(I)=B(I)-A(I,JJ)*B(N)
20    CONTINUE
30    CONTINUE
C
C      BACKSUBSTITUTION
C
      LL=MBAND+1
      DO 50 M=1,NEQ
      N=NEQ+1-M
      DO 40 L=LL,NCOLS
      IF (A(N,L).EQ.0) GO TO 40
      K=N+L-MBAND
      B(N)=B(N)-A(N,L)*B(K)
40    CONTINUE
50    CONTINUE
      RETURN
60    CONTINUE
      IPUNT=1
      WRITE (IT,2070) N,A(N,MBAND)
      RETURN
C
2070  FORMAT (1H1,5X,31H SET OF EQUATIONS ARE SINGULAR ,//,5X,25HDIAGONA
     1L TERM OF EQUATION,I5,13H IS EQUAL TO ,E15.8)
      END
      SUBROUTINE PRINTT (T,NUMNP)
C
C      PRINT TEMP. SOLUTION
C
        IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      COMMON/IO/IN,IT
      DIMENSION T(NUMNP)
      WRITE (IT,20)
      WRITE (IT,30)
      NLINES=NUMNP/5+1
      J1=1
        OPEN(UNIT=15,FILE='G24.DAT',STATUS='NEW')
      DO 10 I=1,NLINES
      NO=(I-1)*5+1
      IF (NO.GT.NUMNP) GO TO 10
      J2=J1+4
      IF (J2.GT.NUMNP) J2=NUMNP
      WRITE (IT,40) NO,(T(J),J=J1,J2)
        WRITE(15,21) (T(J),J=J1,J2)
      J1=J1+5
10    CONTINUE
      RETURN
C
20    FORMAT (//,36H T E M P E R A T U R E   V E C T O R,/)
30    FORMAT (80H NODE NO.      NO    VALUE     NO+1 VALUE     NO+2 VALUE
```

```
    1 NO+3 VALUE    NO+4 VALUE,/)
40    FORMAT (I6,4X,5E14.6)
21    FORMAT (5E14.6)
      END
      SUBROUTINE FLUX (AA)
C
C      CALCULATE FLUX FOR ALL ELEMENTS
C
        IMPLICIT DOUBLE PRECISION (A-H,O-Z)
        REAL AA
      COMMON/SOL/NUMNP,NELGRP,MTOT,NANA
      COMMON/EL/ISW,NPAR(4),NFIRST,NLAST,LELST,MAXEST
      COMMON/IO/IN,IT
      DIMENSION AA(1)
      ISW=3
      REWIND 1
      DO 10 M=1,NELGRP
      WRITE (IT,20) M
      READ (1) LRD,NPAR,(AA(I),I=1,LRD)
      MTYPE=NPAR(1)
      CALL ELTYPE (MTYPE)
10    CONTINUE
      RETURN
C
20    FORMAT (1H1,//,1X,13HELEMENT GROUP,I3)
      END
      FUNCTION DOT(A,B)
C
C      COMPUTES THE PRODUCTS OF TWO VECTORS A,B
C
        IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DIMENSION A(4),B(4)
      DOT=A(1)*B(1)+A(2)*B(2)+A(3)*B(3)
C
      RETURN
      END
      SUBROUTINE CROSS (A,B,C)
C
C      COMPUTES......THE MAGNITUDE C(4) OF A VECTOR C=A CROSS B,AND
C                    COMPONENTS OF A UNIT VECTOR IN THE C DIRECTION.
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      COMMON/IO/IN,IT
      DIMENSION A(4),B(4),C(4)
      X=A(2)*B(3)-A(3)*B(2)
      Y=A(3)*B(1)-A(1)*B(3)
      Z=A(1)*B(2)-A(2)*B(1)
      C(4)=SQRT(X*X+Y*Y+Z*Z)
      IF (C(4).GT.0.1E-8) GO TO 10
      WRITE (IT,2020)
      STOP
10    CONTINUE
      C(3)=Z/C(4)
      C(2)=Y/C(4)
      C(1)=X/C(4)
      RETURN
C
2020  FORMAT (//,5X,20HFATAL ERROR IN CROSS,16H,CHECK GEOMETRY//)
      END
      SUBROUTINE VECTOR (V,XI,YI,ZI,XJ,YJ,ZJ)
C
C      COMPUTES......THE MAGNITUDE V(4) OF A VECTOR FROM I TO J,AND
C                    COMPONENTS V(1),V(2),V(3) OF A UNIT VECTOR
C                    FROM I TO J.
```

```
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      COMMON/IO/IN,IT
      DIMENSION V(4)
      X=XJ-XI
      Y=YJ-YI
      Z=ZJ-ZI
      V(4)=SQRT(X*X+Y*Y+Z*Z)
      IF (V(4).GT.0.1E-8) GO TO 10
      WRITE (IT,2000)
      STOP
10    CONTINUE
      V(3)=Z/V(4)
      V(2)=Y/V(4)
      V(1)=X/V(4)
      RETURN
C
2000  FORMAT (//,5X,21HFATAL ERROR IN VECTOR,16H, CHECK GEOMETRY//)
      END
      SUBROUTINE PLANE
C
C      SETS UP STORAGE FOR PLANE ELEMENT
C
      COMMON/SOL/NUMNP,NELGRP,MTOT,NANA
      COMMON/EL/ISW,NPAR(4),NFIRST,NLAST,LELST,MAXEST
      COMMON/DYN/N1,N2,N3,N4,N5,N6,N7,N8,N9,N10
      COMMON A(1)
        COMMON/DD/ITW0
      NFIRST=N6
      IF (ISW.GT.1) NFIRST=N9
      L1=NFIRST
      L2=L1+NPAR(3)*ITW0
      L3=L2+NPAR(3)*ITW0
      L4=L3+NPAR(3)*ITW0
      L5=L4+NPAR(3)*ITW0
      L6=L5+NPAR(2)
      L7=L6+NPAR(2)*ITW0
      NLAST=L7+4*NPAR(2)
      LELST=NLAST-NFIRST
      MM=NLAST-MTOT
      IF (MM.GT.0) CALL ERROR (MM)
      CALL CPLANE (A(N1),A(N2),A(N3),A(N4),A(N5),A(L1),A(L2),A(L3),A(L4)
     1,A(L5),A(L6),A(L7))
      RETURN
      END
      SUBROUTINE CPLANE (ID,T,X,Y,Z,TH,KXX,KXY,KYY,MTYPE,VOLQ,LM)
C
C      COMPUTES ELEMENT MATRICES FOR PLANE ELEMENT
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
        REAL A
        DIMENSION IA(1)
        EQUIVALENCE (A(1),IA(1))
      COMMON/SOL/NUMNP,NELGRP,MTOT,NANA
      COMMON/DYN/N1,N2,N3,N4,N5,N6,N7,N8,N9,N10
      COMMON/IO/IN,IT
      COMMON/EQS/NEQ,NCOLS,MBAND
      COMMON/EL/ISW,NPAR(4),NFIRST,NLAST,LELST,MAXEST
      COMMON A(1)
      DIMENSION ID(1),T(1),X(1),Y(1),Z(1)
      DIMENSION MTYPE(1),VOLQ(1),LM(4,1)
      DIMENSION S(4,4),PVOL(4),TH(1)
      DIMENSION TND(4),ST(2,4),IE(4),IX(4)
```

```
      DIMENSION XL(4),YL(4),VX(200),VY(200)
      REAL KXX(1),KXY(1),KYY(1)
      NUME=NPAR(2)
      NUMAT=NPAR(3)
      ND=NPAR(4)
      KAT=3
      IF (ND.LT.0) KAT=2
      IF (ND.LT.0) ND=-ND
      IF (ISW.EQ.1) GO TO 10
      IF (ISW.EQ.2) GO TO 100
      IF (ISW.EQ.3) GO TO 120
C
C       ELEMENT DATA INPUT
C
10    CONTINUE
      WRITE (IT,2040) NUME, NUMAT,ND
      IF (KAT.EQ.2) WRITE (IT,2050)
      DO 20 I=1,NUMAT
      READ (IN,*) N,TH(N),KXX(N),KXY(N),KYY(N)
20    CONTINUE
C
        OPEN (UNIT=14,FILE='G23.DAT',STATUS='OLD')
        DO 25 I=1,NUME
C       READ(IN,*)VX(I),VY(I)
        READ(14,301) VX(I),VY(I)
25      CONTINUE
301     FORMAT(2X,E14.6,6X,E14.6)
      WRITE (IT,2100)
      DO 30 I=1,NUMAT
      WRITE (IT,2200) I,TH(I),KXX(I),KXY(I),KYY(I)
30    CONTINUE
C
        WRITE(IT,2111)
        DO 32 I=1,NUME
        WRITE(IT,2112)VX(I),VY(I)
32      CONTINUE
      WRITE (IT,2070)
      N=1
40    READ (IN,*) M,(IE(I),I=1,ND),MTYP,KK,VOL
      IF (KK.EQ.0) KK=1
50    IF (M.NE.N) GO TO 70
      IF (ND.EQ.3) IE(4)=0
      DO 60 I=1,4
      IX(I)=IE(I)
60    CONTINUE
      KKK=KK
C
C       SAVE ELEMENT INFORMATION
C
70    CONTINUE
      MTYPE(N)=MTYP
      VOLQ(N)=VOL
C
C       FORM LOCATION MATRIX AND COMMPUTE BANDWIDTH
C
      DO 80 I=1,4
      LM(I,N)=IX(I)
80    CONTINUE
      CALL CALBAN (ND,LM(1,N))
C
C       CHECK FOR MORE ELEMENTS
C
      WRITE (IT,2080) N,IX,MTYPE(N),VOLQ(N)
```

```
      IF (N.EQ.NUME) RETURN
      N=N+1
      DO 90 I=1,ND
      IX(I)=IX(I)+KKK
90    CONTINUE
      IF (N.GT.M) GO TO 40
      GO TO 50
C
C      ELEMENT CONDUCTION MATRIX AND HEAT LOAD VECTORS
C
100   CONTINUE
      DO 110 N=1,NUME
      MTYP=MTYPE(N)
        CVX=VX(N)
        CVY=VY(N)
      CXX=KXX(MTYP)
      CXY=KXY(MTYP)
      CYY=KYY(MTYP)
      IF (KAT.NE.2) CALL QCORD (ND,LM(1,N),X,Y,Z,XL,YL,AS)
      IF (KAT.EQ.2) CALL AXCORD (ND,LM(1,N),X,Y,Z,XL,YL)
      CALL KISO4 (KAT,0,ND,TH(MTYP),XL,YL,CXX,CXY,CYY,VOLQ(N),S,ST,PVOL,
     & CVX,CVY)
      CALL ADDSTF (ND,LM(1,N),NEQ,NCOLS,MBAND,S,A(N6))
      CALL ADDLD (ND,LM(1,N),NEQ,A(N1),PVOL,A(N8))
110   CONTINUE
      RETURN
C
C      FLUX COMPUTATION
C
120   CONTINUE
      WRITE (IT,2060)
      WRITE (IT,2090)
      DO 130 N=1,NUME
      MTYP=MTYPE(N)
        CVX=VX(N)
        CVY=VY(N)
      CXX=KXX(MTYP)
      CXY=KXY(MTYP)
      CYY=KYY(MTYP)
      IF (KAT.NE.2) CALL QCORD (ND,LM(1,N),X,Y,Z,XL,YL,AS)
      IF (KAT.EQ.2) CALL AXCORD (ND,LM(1,N),X,Y,Z,XL,YL)
      CALL KISO4 (KAT,1,ND,TH(MTYP),XL,YL,CXX,CXY,CYY,VOLQ(N),S,ST,PVOL,
     & CVX,CVY)
      CALL TEMPID (A(N8),ND,LM(1,N),TND)
      CALL QCOND4 (ND,TND,ST,QX,QY)
      WRITE (IT,2000) N,QX,QY
130   CONTINUE
      RETURN
C
2040  FORMAT (//,1X,27HP L A N E   E L E M E N T S,///,2X,26HNUMBER OF P
     1LANE ELEMENTS =,I3,/2X,26HNUMBER OF MATERIALS        =,I3,/2X,26HNUM
     2BER OF NODES          =,I3,///)
2050  FORMAT (2X,17HAXISYMMETRIC CASE,///)
2060  FORMAT (//,1X,26HP L A N E E L E M E N T  ,2X,20HH E A T  F L U X
     1 E S,//)
2070  FORMAT (//,37H     N     I     J     K     L     MATID  ,5X,1HQ/)
2080  FORMAT (5I5,2X,I5,5X,E11.4)
2090  FORMAT (9X,7HELEMENT,6X,2HQX,8X,2HQY,/)
2000  FORMAT (9X,I4,1X,E11.4,2X,E11.4)
2100  FORMAT (//,1X,8HMATERIAL,2X,9HTHICKNESS,9X,19HCONDUCTIVITY TENSOR/
     127X,3HKXX,8X,3HKXY,8X,3HKYY)
2111  FORMAT (//,1X,9HXVELOCITY,3X,9HYVELOCITY)
2112  FORMAT (1X,2(E11.4))
```

```
2200   FORMAT (1X,I4,4X,4(E11.4))
       END
       SUBROUTINE AXCORD (ND,IX,X,Y,Z,XL,YL)
C
C       FINDS LOCAL COORDINATES OF AXISYMETRIC ELEMENTS
C       IN GLOBAL REFERENCE FRAME. NOTE ELEMENTS MUST
C       LIE IN GLOBAL X-Z PLANE
C
         IMPLICIT DOUBLE PRECISION (A-H,O-Z)
       DIMENSION X(1),Y(1),Z(1)
       DIMENSION IX(4),XL(4),YL(4)
       I=IX(1)
       J=IX(2)
       K=IX(3)
       XL(1)=X(I)
       XL(2)=X(J)
       XL(3)=X(K)
       YL(1)=Z(I)
       YL(2)=Z(J)
       YL(3)=Z(K)
       IF (ND.EQ.3) RETURN
       L=IX(4)
       XL(4)=X(L)
       YL(4)=Z(L)
       RETURN
       END
       SUBROUTINE QCORD (ND,IX,X,Y,Z,XL,YL,AS)
C
C       COMPUTES LOCAL COORDINATES AND AREA FOR TRIANGLE OR QUAD
C       WITH LOCAL X AXIS FROM NODE I TO J
C
         IMPLICIT DOUBLE PRECISION (A-H,O-Z)
       DIMENSION X(1),Y(1),Z(1)
       DIMENSION IX(4),XL(4),YL(4),G(4),U(4),V(4),W(4)
       I=IX(1)
       J=IX(2)
       K=IX(3)
       CALL VECTOR (V,X(I),Y(I),Z(I),X(J),Y(J),Z(J))
       CALL VECTOR (G,X(I),Y(I),Z(I),X(K),Y(K),Z(K))
       CALL CROSS (V,G,W)
       CALL CROSS (W,V,U)
       XL(1)=0.0
       YL(1)=0.0
       XL(2)=V(4)
       YL(2)=0.0
       XL(3)=G(4)*DOT(G,V)
       YL(3)=G(4)*DOT(G,U)
       XL(4)=XL(3)
       YL(4)=YL(3)
       AS=0.0
       AS=AS+0.5*V(4)*G(4)*W(4)
       IF (ND.EQ.3) RETURN
       L=IX(4)
       CALL VECTOR (W,X(I),Y(I),Z(I),X(L),Y(L),Z(L))
       XL(4)=W(4)*DOT(W,V)
       YL(4)=W(4)*DOT(W,U)
       CALL CROSS (G,W,U)
       AS=AS+0.5*W(4)*G(4)*U(4)
       RETURN
       END
       SUBROUTINE KISO4 (KAT,KODE,ND,THICK,XL,YL,XKXX,XKXY,XKYY,Q,S,ST,P,
      & VX,VY)
C       COMPUTES CONDUCTANCE MATRIX,LOAD VECTOR,AND
C       FLUX RECOVERY MATRIX FOR A 3 NODE TRIANGLE AND A 4 NODE
```

```
C       ISOPARAMETRIC QUADILATERAL
C
C       CALLED BY CISO4
C       CALLS     SHAPE
C
C       IF KODE.EQ.0 COMPUTES S,P
C                  1 COMPUTES ST
C
        IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DIMENSION S(ND,ND),ST(2,ND),P(ND),B(2,4),E(2,2),C(2,2)
      DIMENSION XL(ND),YL(ND),XN(4),S1(4,4),S2(4,4),S3(4,4)
C      REAL N(4),KXX,KXY,KYY
      COMMON/IO/IN,IT
      CXX=XKXX*THICK
      IF (CXX.EQ.0.0) GO TO 130
      CXY=XKXY*THICK
      CYY=XKYY*THICK
      IF (KODE.EQ.1) GO TO 90
      DO 10 I=1,ND
      P(I)=0.0
      DO 10 J=1,ND
      S(I,J)=0.0
 10   CONTINUE
 C
 C     COMPUTE UPPER TRIANGLE OF CHOLESKY FACTOR OF CONDUCTANCE MATRIX.
 C
      E(1,1)=SQRT(CXX)
      E(1,2)=CXY/E(1,1)
      E(2,1)=0.0
      E(2,2)=SQRT(CYY-E(1,2)*E(1,2))
 C
 C     START GAUSS QUADRATIC LOOP. FOUR POINT INTIGRATION.
 C
      DO 70 II=1,2
      DO 70 JJ=1,2
      CALL SHAPE (ND,II,JJ,XL,YL,XN,B,DETJAC)
      IF (KAT.EQ.2) CALL AXI (ND,XN,XL,DETJAC)
 C
 C     MULTIPLY CHOLESKY FACTOR OF E TIMES B.
 C     OVERWRITE RESULT IN B. FORM THERMAL CONDUCTANCE MATRIX.
 C
      DO 30 K=1,2
      DO 30 L=1,ND
      DUMY=0.0
      DO 20 M=K,2
      DUMY=DUMY+E(K,M)*B(M,L)
 20   CONTINUE
      B(K,L)=DUMY
 30   CONTINUE
 C
 C      CALCULATE KVX & KVY MATRIX
 C
        DO 23 NROW=1,ND
        DO 23 NCOL=1,ND
        S1(NROW,NCOL)=XN(NROW)*B(1,NCOL)*DETJAC*VX
        S2(NROW,NCOL)=XN(NROW)*B(2,NCOL)*DETJAC*VY
 23     CONTINUE
 C     ADD CONTRIBUTIONS. GAUSS WEIGHTS ARE 1.0
 C
 C    MULTIBLY E*B TRANSPOSE *E*B
 C
      DO 50 NROW=1,ND
      DO 50 NCOL=NROW,ND
```

```
      DUMY=0.0
      DO 40 L=1,2
      DUMY=DUMY+B(L,NROW)*B(L,NCOL)
40    CONTINUE
      S3(NROW,NCOL)=DUMY*DETJAC
50    CONTINUE
C
        DO 44 NROW=1,ND
        DO 44 NCOL=1,ND
        S(NROW,NCOL)=S(NROW,NCOL)+S1(NROW,NCOL)+S2(NROW,NCOL)+
     &                 S3(NROW,NCOL)
44      CONTINUE
C
C      COMPUTE THERMAL LOAD VECTOR
C
      DO 60 I=1,ND
      P(I)=P(I)+Q*THICK*XN(I)*DETJAC
60    CONTINUE
70    CONTINUE
C
C      QUADRATURE COMPLETE. COMPLETE CONDUCTANCE MATRIX BY SYMETRY.
C
      DO 80 K=2,ND
      DO 80 L=1,K
      S(K,L)=S(L,K)
80    CONTINUE
      RETURN
C
C      COMPUTE FLUX RECOVERY MATRIX
C
90    CONTINUE
      DO 100 I=1,2
      DO 100 J=1,ND
      ST(I,J)=0.0
100   CONTINUE
      C(1,1)=CXX
      C(1,2)=CXY
      C(2,1)=CXY
      C(2,2)=CYY
C
C      EVALUATE B MATRIX AT CENTROID FOR FLUX RECOVERY
C
      CALL SHAPE (ND,3,3,XL,YL,XN,B,DETJAC)
      IF (KAT.EQ.2) CALL AXI (ND,XN,XL,DETJAC)
      DO 120 K=1,2
      DO 120 L=1,ND
      DUMY=0.0
      DO 110 M=1,2
      DUMY=DUMY+C(K,M)*B(M,L)
110    CONTINUE
      ST(K,L)=ST(K,L)-DUMY
120   CONTINUE
      RETURN
130   CONTINUE
      STOP
C
2040  FORMAT (/,5X,28HFATAL ERROR, KXX EQUALS ZERO,/)
      END
      SUBROUTINE SHAPE (ND,II,JJ,XL,YL,XN,B,DETJAC)
        IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DIMENSION B(2,ND),XL(ND),YL(ND),XII(4),ETI(4),AA(3)
      DIMENSION XN(4),XNXI(4),XJAC(2,2),XNET(4)
      COMMON/IO/IN,IT
```

```
      DATA  AA /-0.57735026918963 , 0.57735026918963 , 0.0 /
      DATA XII /-1.,1.,1.,-1. /
      DATA ETI /-1.,-1.,1.,1. /
      DO 10 I=1,4
      DUM1=(1.+XII(I)*AA(II))*0.25
      DUM2=(1.+ETI(I)*AA(JJ))*0.25
      XN(I)=4.*DUM1*DUM2
      XNXI(I)=XII(I)*DUM2
      XNET(I)=ETI(I)*DUM1
10    CONTINUE
      IF (ND.EQ.4) GO TO 20
C
C      FORM TRIANGLE BY ADDING THIRD AND FOURTH TOGETHER
C
      XN(3)=XN(3)+XN(4)
      XNXI(3)=XNXI(3)+XNXI(4)
      XNET(3)=XNET(3)+XNET(4)
20    CONTINUE
C
      DO 30 I=1,2
      DO 30 J=1,2
      XJAC(I,J)=0.0
30    CONTINUE
      DO 40 I=1,ND
      XJAC(1,1)=XJAC(1,1)+XNXI(I)*XL(I)
      XJAC(1,2)=XJAC(1,2)+XNXI(I)*YL(I)
      XJAC(2,1)=XJAC(2,1)+XNET(I)*XL(I)
      XJAC(2,2)=XJAC(2,2)+XNET(I)*YL(I)
40    CONTINUE
      DETJAC=XJAC(1,1)*XJAC(2,2)-XJAC(2,1)*XJAC(1,2)
      DUMY=XJAC(1,1)/DETJAC
      XJAC(1,1)=XJAC(2,2)/DETJAC
      XJAC(1,2)=-XJAC(1,2)/DETJAC
      XJAC(2,1)=-XJAC(2,1)/DETJAC
      XJAC(2,2)=DUMY
C
C      FORM THE GRADIENT - TEMPERATURE MATRIX...B(2,ND)
C
      DO 50 I=1,2
      DO 50 J=1,ND
      B(I,J)=XJAC(I,1)*XNXI(J)+XJAC(I,2)*XNET(J)
50    CONTINUE
      RETURN
      END
      SUBROUTINE AXI (ND,XN,XL,DETJAC)
C
C      MODIFIES JACOBIAN DETERMINANT FOR AXISYMMETRY
C
        IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C      REAL N(4)
      DIMENSION XL(4),XN(4)
      RR=0.0
      DO 10 I=1,ND
      RR=RR+XN(I)*XL(I)
10    CONTINUE
      DETJAC=RR*DETJAC
      RETURN
      END
      SUBROUTINE QCOND4 (ND,TND,ST,QX,QY)
C
C      CALLED BY CPLANE
C      COMPUTE TRIANGLE AND QUAD. CONDUCTION HEAT FLUXES
C
```

```
        IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DIMENSION TND(ND),ST(2,ND)
      QX=0.0
      QY=0.0
      DO 10 JJ=1,ND
      QX=QX+ST(1,JJ)*TND(JJ)
      QY=QY+ST(2,JJ)*TND(JJ)
10    CONTINUE
      RETURN
      END
```

Appendix C: Computer Program

```
C     This program computes the hydrolic head based on equation (4) in Appendix
C       A.
C
C
C
C              TAPE      CONTENTS
C               1        ELEMENT DATA
C               5        INPUT
C               6        OUTPUT
      COMMON/SOL/NUMNP,NELGRP,MTOT,NANA
      COMMON/EL/ISW,NPAR(4),NFIRST,NLAST,LELST,MAXEST
      COMMON/DYN/N1,N2,N3,N4,N5,N6,N7,N8,N9,N10
      COMMON/EQS/NEQ,NCOLS,MBAND
      COMMON/HEAD/HED(20)
      COMMON/IO/IN,IT
        COMMON/DD/ITW0
C
C     IF ITW0=1 MEANS SINGL PRICISION
C     IF ITW0=2 MEANS DOUBLE PRECISION
      COMMON A(14000)
        REAL A
      ITW0=2
      MTOT=14000
C
      IN=7
      IT=8
C
      READ (IN,1000) HED
      READ (IN,*) NUMNP,NELGRP,NANA
      WRITE (IT,2000) HED,NUMNP,NELGRP,NANA
C
C      INPUT NODE DATA
      N1=1
      N2=N1+NUMNP
      N3=N2+NUMNP*ITW0
      N4=N3+NUMNP*ITW0
      N5=N4+NUMNP*ITW0
      N6=N5+NUMNP*ITW0
C
      IF (N6.GT.MTOT) CALL ERROR (N6-MTOT)
C
      CALL NODES (A(N1),A(N2),A(N3),A(N4),A(N5),NUMNP)
C
C               CURRENT CONTENTS OF COMMON AREA A(I)
C
C                 LOCATION        VARIABLE       DEFINITION
C
C     STARTING AT N1................ID(1)        BOUNDARY CONDITION ID
C                 N2.................T(1)        NODAL TEMPERATURES
C                 N3.................X(1)        X NODAL COORDINATES
C                 N4.................Y(1)        Y NODAL COORDINATES
C                 N5.................Z(1)        Z NODAL COORDINATES
C                 N6....TEMPORARY STORAGE FOR ELEMENT INPUT
C
C     INPUT,GENERATE AND STORE ELEMENT DATA
C
      CALL ELDAT
C
      NEQ=NUMNP
      NCOLS=2*MBAND-1
      NWK=NEQ*NCOLS
      N7=N6+NWK*ITW0
      N8=N7+NEQ*ITW0
```

```
      N9=N8+NEQ*ITW0
      N10=N9+MAXEST*ITW0
      WRITE (IT,2030)
      WRITE (IT,2040) NEQ,MBAND
      IF (N10.GT.MTOT) CALL ERROR (N10-MTOT)
C
C       NOW USE.....A(N6)  - A(1,1)   CONDUCTANCE MATRIX
C                   A(N7)  - Q(1)     LOAD VECTOR FROM BOUND.COND.
C                   A(N8)  - B(1)     TOTAL LOAD VECTOR,OR
C                   A(N8)  - B(1)     TEMP. FROM LINEAR ANALYSIS
C                   A(N9)  - ELEMENT DATA
      IF (NANA.EQ.0) STOP
C
C      LINEAR STEADY ANALYSIS
C
      CALL ZERO (A(N6),NWK)
      CALL ZERO (A(N7),NEQ)
      CALL ZERO (A(N8),NEQ)
      CALL ELCAL (A(N9))
      CALL TEMPBC (NEQ,NCOLS,MBAND,A(N1),A(N2),A(N6),A(N7))
      CALL FACTOR (NEQ,NCOLS,MBAND,A(N6),IPUNT)
      IF (IPUNT.EQ.1) STOP
      CALL ADDBC (NEQ,A(N7),A(N8))
      CALL SOLVE (NEQ,NCOLS,MBAND,A(N6),A(N8),IPUNT)
      IF (IPUNT.EQ.1) STOP
      CALL PRINTT (A(N8),NUMNP)
C      CALL FLUX (A(N9))
C
C
      STOP
C
1000  FORMAT (20A4)
2000  FORMAT (1H1,20A4///38H C O N T R O L   I N F O R M A T I O N,//4X,
     127H NUMBER OF NODAL POINTS  =,I5/4X,27H NUMBER OF ELEMENT GROUPS
     2=,I5/4X,27H ANALYSIS CODE(NANA)      =,I5/4X,27H   EQ.0,  DATA CHE
     3CK ONLY, /4X,27H   EQ.1,  LINEAR STEAY    /4X)
2030  FORMAT (1H1,38H S O L U T I O N   P A R A M E T E R S,//)
2040  FORMAT (5X,34H  TOTAL NUMBER OF EQUATIONS        =,I5,/,5X,34H SEMI
     1 BANDWIDTH                    =,I5)
      END
      SUBROUTINE ZERO (A,N)
C
C      ZERO AN ARRAY A(I)
C
      DIMENSION A(1)
      DO 10 I=1,N
      A(I)=0.0
10    CONTINUE
      RETURN
      END
      SUBROUTINE ERROR (N)
      COMMON/IO/IN,IT
      WRITE (IT,2000) N
      STOP
C
2000  FORMAT (//,20H STORAGE EXCEEDED BYI6)
      END
      SUBROUTINE NODES (ID,T,X,Y,Z,NUMNP)
        IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION ID(1),X(1),Y(1),Z(1),T(1)
      COMMON/IO/IN,IT
C
C      READ OR GENERATE NODAL POINT DATA
```

```
C
      WRITE (IT,2040)
      NOLD=0
10    CONTINUE
      READ (IN,*) N,ID(N),X(N),Y(N),Z(N),KN,T(N)
      IF (NOLD.EQ.0) GO TO 30
C
C      CHECK IF GENERATION IS REQUIRED
C
      IF (KN.EQ.0) GO TO 30
      NUM=(N-NOLD)/KN
      NUMN=NUM-1
      IF (NUMN.LT.1) GO TO 30
      XNUM=NUM
      DX=(X(N)-X(NOLD))/XNUM
      DY=(Y(N)-Y(NOLD))/XNUM
      DZ=(Z(N)-Z(NOLD))/XNUM
      DT=(T(N)-T(NOLD))/XNUM
      K=NOLD
      DO 20 J=1,NUMN
      KK=K
      K=K+KN
      X(K)=X(KK)+DX
      Y(K)=Y(KK)+DY
      Z(K)=Z(KK)+DZ
      T(K)=T(KK)+DT
      ID(K)=ID(KK)
20    CONTINUE
30    CONTINUE
      NOLD=N
      IF (N.NE.NUMNP) GO TO 10
C
C      PRINT ALL NODAL POINT DATA
C
      WRITE (IT,2050)
      WRITE (IT,2060) (N,ID(N),X(N),Y(N),Z(N),T(N),N=1,NUMNP)
C
      RETURN
C
2040  FORMAT (//23H NODAL POINT INPUT DATA/)
2050  FORMAT (/,1X,4HNODE3X,12H  B.C. CODE 11X,23HNODAL POINT COORDINATE
     1S/7H NUMBER22X,1HX12X,1HY12X,1HZ8X,11HTEMPERATURE,/)
2060  FORMAT (I5,5X,I5,6X,3E13.5,2X,E13.5)
      END
      SUBROUTINE ELDAT
C
C      CALLS ELTYPE TO BRANCH TO ELEMENT ROUTINES
C      FOR ELEMENT INPUT DATA
C
      COMMON/SOL/NUMNP,NELGRP,MTOT,NANA
      COMMON/EL/ISW,NPAR(4),NFIRST,NLAST,LELST,MAXEST
      COMMON/EQS/NEQ,NCOLS,MBAND
      COMMON/IO/IN,IT
      COMMON A(1)
      NUMEL=0
      MBAND=0
      MAXEST=0
      ISW=1
      REWIND 1
      DO 10 M=1,NELGRP
      WRITE (IT,2000) M
      READ (IN,*) (NPAR(I),I=1,4)
      NUMEL=NUMEL+NPAR(2)
```

```
      MTYPE=NPAR(1)
      CALL ELTYPE (MTYPE)
      IF (LELST.GT.MAXEST) MAXEST=LELST
      WRITE (1) LELST,NPAR,(A(I),I=NFIRST,NLAST)
10    CONTINUE
      RETURN
C
2000  FORMAT (1H1,//,1X,13HELEMENT GROUP,I3)
      END
      SUBROUTINE ELCAL (AA)
C
C      CALLS ELTYPE TO BRANCH TO ELEMENT ROUTINES
C      TO FORM EQUIVALENT SYSTEM MATRICES
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      REAL AA
      COMMON/SOL/NUMNP,NELGRP,MTOT,NANA
      COMMON/EL/ISW,NPAR(4),NFIRST,NLAST,LELST,MAXEST
      DIMENSION AA(1)
      ISW=2
      REWIND 1
      DO 10 M=1,NELGRP
      READ (1) LRD,NPAR,(AA(I),I=1,LRD)
      MTYPE=NPAR(1)
      CALL ELTYPE (MTYPE)
10    CONTINUE
      RETURN
      END
      SUBROUTINE ELTYPE (MTYPE)
      COMMON/IO/IN,IT
C
C      CALLED BY MAIN AND FLUX
C

      GO TO (10,20,30) MTYPE
10    CALL PLANE
      RETURN
20    CONTINUE
30    WRITE (IT,2040) MTYPE
      RETURN
C
2040  FORMAT (8H ELEMENT,I4,26H HAS NOT BEEN IMPLEMENTED ,/)
      END
      SUBROUTINE CALBAN (ND,LM)
C
C      CALLED BY ELEMENT SUBROUTINES
C
C      CALCULATES SEMI- BANDWIDTH
C
      COMMON/EQS/NEQ,NCOLS,MBAND
      DIMENSION LM(ND)
      MIN=100000
      MAX=0
      DO 10 L=1,ND
      IF (LM(L).GT.MAX) MAX=LM(L)
      IF (LM(L).LT.MIN) MIN=LM(L)
10    CONTINUE
      NDIF=MAX-MIN+1
      IF (NDIF.GT.MBAND) MBAND=NDIF
      RETURN
      END
      SUBROUTINE ADDSTF (ND,LM,NEQ,NCOLS,MBAND,S,A)
C
```

```
C        FORMS SYSTEM CONDUCTANCE MATRIX
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DIMENSION A(NEQ,NCOLS),S(ND,ND),LM(ND)
      DO 20 I=1,ND
      II=LM(I)
      DO 10 J=1,ND
      JJ=MBAND-LM(I)+LM(J)
      A(II,JJ)=A(II,JJ)+S(I,J)
10    CONTINUE
20    CONTINUE
      RETURN
      END
      SUBROUTINE ADDLD (ND,LM,NEQ,ID,Q,B)
C
C        FORMS LOAD VECTOR
C
        IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DIMENSION ID(NEQ),B(NEQ),Q(ND),LM(ND)
      DO 10 I=1,ND
      II=LM(I)
      IF (ID(II).NE.0) GO TO 10
      B(II)=B(II)+Q(I)
 10   CONTINUE
      RETURN
      END
      SUBROUTINE ADDBC (NEQ,Q,B)
C
C        ADDS CONTRIBUTION OF TEMP. BOUNDARY CONDITION
C        TO LOAD VECTOR
C
        IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DIMENSION Q(NEQ),B(NEQ)
      DO 10 L=1,NEQ
      B(L)=B(L)+Q(L)
 10   CONTINUE
      RETURN
      END
      SUBROUTINE TEMPID (T,NTP,LTP,TND)
C
C        DETERMINES ELEMENT TEMP. FOR AN INPUT NODE LIST.
C
        IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DIMENSION T(1),LTP(NTP),TND(NTP)
      DO 10 I=1,NTP
      IDUM=LTP(I)
      TND(I)=T(IDUM)
 10   CONTINUE
      END
      SUBROUTINE TEMPBC (NEQ,NCOLS,MBAND,ID,T,A,B)
C
C        IMPOSES BOUNDARY CONDITIONS ON THERMAL EQUILIBRIUM EQUATIONS
C
        IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DIMENSION A(NEQ,NCOLS),B(NEQ),ID(NEQ),T(NEQ)
C       DO 11 I=1,NEQ
C       DO 11 J=1,NCOLS
C11     WRITE(*,*)'A(I,J)',A(I,J)
      DO 30 I=1,NEQ
      IF (ID(I).EQ.0) GO TO 30
      DO 20 JJ=1,NCOLS
      II=I+MBAND-JJ
      IF (II.LT.1) GO TO 10
```

```
      IF (II.GT.NEQ) GO TO 10
      IF (A(II,JJ).EQ.0.0) GO TO 10
      B(II)=B(II)-T(I)*A(II,JJ)
      A(II,JJ)=0.0
10    CONTINUE
      IF (A(I,JJ).EQ.0.0) GO TO 20
      A(I,JJ)=0.0
20    CONTINUE
      B(I)=T(I)
      A(I,MBAND)=1.0
30    CONTINUE
      RETURN
      END
      SUBROUTINE FACTOR (NEQ,NCOLS,MBAND,A,IPUNT)
C
C      REDUCE MATRIX BY GAUSS ELIMINATION
C
C      A(I,J) HAS SEMI-BANDWIDTH MBAND AND MAY BE ASYMMETRIC
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      COMMON/IO/IN,IT
      DIMENSION A(NEQ,NCOLS)
      IPUNT=0
      KMIN=MBAND+1
      DO 50 N=1,NEQ
      IF (A(N,MBAND).EQ.0.0) GO TO 60
      IF (A(N,MBAND).EQ.1.0) GO TO 20
      C=1./A(N,MBAND)
      DO 10 K=KMIN,NCOLS
      IF (A(N,K).EQ.0.0) GO TO 10
      A(N,K)=C*A(N,K)
10    CONTINUE
20    CONTINUE
      DO 40 L=2,MBAND
      JJ=MBAND-L+1
      I=N+L-1
      IF (I.GT.NEQ) GO TO 40
      IF (A(I,JJ).EQ.0.0) GO TO 40
      KI=MBAND+2-L
      KF=NCOLS+1-L
      J=MBAND
      DO 30 K=KI,KF
      J=J+1
      IF (A(N,J).EQ.0.0) GO TO 30
      A(I,K)=A(I,K)-A(I,JJ)*A(N,J)
30    CONTINUE
40    CONTINUE
50    CONTINUE
      RETURN
60    CONTINUE
      IPUNT=1
      WRITE (IT,2070) N,A(N,MBAND)
      RETURN
C
C
C
2070  FORMAT (1H1,5X,34H SET OF EQUATIONS ARE SINGULAR ,//,5X,25HDIAGONA
     IL TERM OF EQUATION,I5,13H IS EQUAL TO ,E15.8)
      END
      SUBROUTINE SOLVE (NEQ,NCOLS,MBAND,A,B,IPUNT)
C
C        REDUCTION OF A LOAD VECTOR B(I)
C
```

```
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      COMMON/IO/IN,IT
      DIMENSION A(NEQ,NCOLS),B(NEQ)
      IPUNT=0
      DO 30 N=1,NEQ
      IF (A(N,MBAND).EQ.0.0) GO TO 60
      IF (A(N,MBAND).EQ.1.0) GO TO 10
      B(N)=B(N)/A(N,MBAND)
10    CONTINUE
      DO 20 L=2,MBAND
      JJ=MBAND-L+1
      I=N+L-1
      IF (I.GT.NEQ) GO TO 20
      IF (A(I,JJ).EQ.0.0) GO TO 20
      B(I)=B(I)-A(I,JJ)*B(N)
20    CONTINUE
30    CONTINUE
C
C      BACKSUBSTITUTION
C
      LL=MBAND+1
      DO 50 M=1,NEQ
      N=NEQ+1-M
      DO 40 L=LL,NCOLS
      IF (A(N,L).EQ.0) GO TO 40
      K=N+L-MBAND
      B(N)=B(N)-A(N,L)*B(K)
40    CONTINUE
50    CONTINUE
      RETURN
60    CONTINUE
      IPUNT=1
      WRITE (IT,2070) N,A(N,MBAND)
      RETURN
C
2070  FORMAT (1H1,5X,31H SET OF EQUATIONS ARE SINGULAR ,//,5X,25HDIAGONA
     1L TERM OF EQUATION,I5,13H IS EQUAL TO ,E15.8)
      END
      SUBROUTINE PRINTT (T,NUMNP)
C
C      PRINT TEMP. SOLUTION
C
        IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      COMMON/IO/IN,IT
      DIMENSION T(NUMNP)
      WRITE (IT,20)
      WRITE (IT,30)
      NLINES=NUMNP/5+1
      OPEN(UNIT=13,FILE='G22.DAT',STATUS='NEW')
        J1=1
      DO 10 I=1,NLINES
      NO=(I-1)*5+1
      IF (NO.GT.NUMNP) GO TO 10
      J2=J1+4
      IF (J2.GT.NUMNP) J2=NUMNP
      WRITE (IT,40) NO,(T(J),J=J1,J2)
        WRITE (13,41)(T(J),J=J1,J2)
      J1=J1+5
10    CONTINUE
      RETURN
C
20    FORMAT (//,36H T E M P E R A T U R E   V E C T O R,/)
30    FORMAT (80H NODE NO.      NO    VALUE     NO+1 VALUE     NO+2 VALUE
```

```
     1 NO+3 VALUE    NO+4 VALUE,/)
40    FORMAT (I6,4X,5E14.6)
41    FORMAT (5E14.6)
      END
      SUBROUTINE FLUX (AA)
C
C      CALCULATE FLUX FOR ALL ELEMENTS
C
        IMPLICIT DOUBLE PRECISION (A-H,O-Z)
        REAL AA
      COMMON/SOL/NUMNP,NELGRP,MTOT,NANA
      COMMON/EL/ISW,NPAR(4),NFIRST,NLAST,LELST,MAXEST
      COMMON/IO/IN,IT
      DIMENSION AA(1)
      ISW=3
      REWIND 1
      DO 10 M=1,NELGRP
      WRITE (IT,20) M
      READ (1) LRD,NPAR,(AA(I),I=1,LRD)
      MTYPE=NPAR(1)
      CALL ELTYPE (MTYPE)
10    CONTINUE
      RETURN
C
20    FORMAT (1H1,//,1X,13HELEMENT GROUP,I3)
      END
      FUNCTION DOT(A,B)
C
C      COMPUTES THE PRODUCTS OF TWO VECTORS A,B
C
        IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DIMENSION A(4),B(4)
      DOT=A(1)*B(1)+A(2)*B(2)+A(3)*B(3)
C
      RETURN
      END
      SUBROUTINE CROSS (A,B,C)
C
C      COMPUTES......THE MAGNITUDE C(4) OF A VECTOR C=A CROSS B,AND
C                    COMPONENTS OF A UNIT VECTOR IN THE C DIRECTION.
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      COMMON/IO/IN,IT
      DIMENSION A(4),B(4),C(4)
      X=A(2)*B(3)-A(3)*B(2)
      Y=A(3)*B(1)-A(1)*B(3)
      Z=A(1)*B(2)-A(2)*B(1)
      C(4)=SQRT(X*X+Y*Y+Z*Z)
      IF (C(4).GT.0.1E-8) GO TO 10
      WRITE (IT,2020)
      STOP
10    CONTINUE
      C(3)=Z/C(4)
      C(2)=Y/C(4)
      C(1)=X/C(4)
      RETURN
C
2020  FORMAT (//,5X,20HFATAL ERROR IN CROSS,16H,CHECK GEOMETRY//)
      END
      SUBROUTINE VECTOR (V,XI,YI,ZI,XJ,YJ,ZJ)
C
C      COMPUTES......THE MAGNITUDE V(4) OF A VECTOR FROM I TO J,AND
C                    COMPONENTS V(1),V(2),V(3) OF A UNIT VECTOR
C                    FROM I TO J.
```

```
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      COMMON/IO/IN,IT
      DIMENSION V(4)
      X=XJ-XI
      Y=YJ-YI
      Z=ZJ-ZI
      V(4)=SQRT(X*X+Y*Y+Z*Z)
      IF (V(4).GT.0.1E-8) GO TO 10
      WRITE (IT,2000)
      STOP
10    CONTINUE
      V(3)=Z/V(4)
      V(2)=Y/V(4)
      V(1)=X/V(4)
      RETURN
C
2000  FORMAT (//,5X,21HFATAL ERROR IN VECTOR,16H, CHECK GEOMETRY//)
      END
      SUBROUTINE PLANE
C
C      SETS UP STORAGE FOR PLANE ELEMENT
C
      COMMON/SOL/NUMNP,NELGRP,MTOT,NANA
      COMMON/EL/ISW,NPAR(4),NFIRST,NLAST,LELST,MAXEST
      COMMON/DYN/N1,N2,N3,N4,N5,N6,N7,N8,N9,N10
      COMMON A(1)
        COMMON/DD/ITW0
      NFIRST=N6
      IF (ISW.GT.1) NFIRST=N9
      L1=NFIRST
      L2=L1+NPAR(3)*ITW0
      L3=L2+NPAR(3)*ITW0
      L4=L3+NPAR(3)*ITW0
      L5=L4+NPAR(3)*ITW0
      L6=L5+NPAR(2)
      L7=L6+NPAR(2)*ITW0
      NLAST=L7+4*NPAR(2)
      LELST=NLAST-NFIRST
      MM=NLAST-MTOT
      IF (MM.GT.0) CALL ERROR (MM)
      CALL CPLANE (A(N1),A(N2),A(N3),A(N4),A(N5),A(L1),A(L2),A(L3),A(L4)
     1,A(L5),A(L6),A(L7))
      RETURN
      END
      SUBROUTINE CPLANE (ID,T,X,Y,Z,TH,KXX,KXY,KYY,MTYPE,VOLQ,LM)
C
C      COMPUTES ELEMENT MATRICES FOR PLANE ELEMENT
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
        REAL A
        DIMENSION IA(1)
        EQUIVALENCE (A(1),IA(1))
      COMMON/SOL/NUMNP,NELGRP,MTOT,NANA
      COMMON/DYN/N1,N2,N3,N4,N5,N6,N7,N8,N9,N10
      COMMON/IO/IN,IT
      COMMON/EQS/NEQ,NCOLS,MBAND
      COMMON/EL/ISW,NPAR(4),NFIRST,NLAST,LELST,MAXEST
      COMMON A(1)
      DIMENSION ID(1),T(1),X(1),Y(1),Z(1)
      DIMENSION MTYPE(1),VOLQ(1),LM(4,1)
      DIMENSION S(4,4),PVOL(4),TH(1)
      DIMENSION TND(4),ST(2,4),IE(4),IX(4)
```

```
      DIMENSION XL(4),YL(4)
      REAL KXX(1),KXY(1),KYY(1)
      NUME=NPAR(2)
      NUMAT=NPAR(3)
      ND=NPAR(4)
      KAT=3
      IF (ND.LT.0) KAT=2
      IF (ND.LT.0) ND=-ND
      IF (ISW.EQ.1) GO TO 10
      IF (ISW.EQ.2) GO TO 100
      IF (ISW.EQ.3) GO TO 120
C
C      ELEMENT DATA INPUT
C
10    CONTINUE
      WRITE (IT,2040) NUME, NUMAT,ND
      IF (KAT.EQ.2) WRITE (IT,2050)
      DO 20 I=1,NUMAT
      READ (IN,*) N,TH(N),KXX(N),KXY(N),KYY(N)
20    CONTINUE
C
      WRITE (IT,2100)
      DO 30 I=1,NUMAT
      WRITE (IT,2200) I,TH(I),KXX(I),KXY(I),KYY(I)
30    CONTINUE
      WRITE (IT,2070)
        OPEN(UNIT=12,FILE='G21.DAT',STATUS='NEW')
      N=1
40    READ (IN,*) M,(IE(I),I=1,ND),MTYP,KK,VOL
      IF (KK.EQ.0) KK=1
50    IF (M.NE.N) GO TO 70
      IF (ND.EQ.3) IE(4)=0
      DO 60 I=1,4
      IX(I)=IE(I)
60    CONTINUE
      KKK=KK
C
C      SAVE ELEMENT INFORMATION
C
70    CONTINUE
      MTYPE(N)=MTYP
      VOLQ(N)=VOL
C
C      FORM LOCATION MATRIX AND COMMPUTE BANDWIDTH
C
      DO 80 I=1,4
      LM(I,N)=IX(I)
80    CONTINUE
      CALL CALBAN (ND,LM(1,N))
C
C      CHECK FOR MORE ELEMENTS
C
      WRITE (IT,2080) N,IX,MTYPE(N),VOLQ(N)
        WRITE (12,3000) N,IX
3000   FORMAT (5I5)
      IF (N.EQ.NUME) RETURN
      N=N+1
      DO 90 I=1,ND
      IX(I)=IX(I)+KKK
90    CONTINUE
      IF (N.GT.M) GO TO 40
      GO TO 50
C
```

```
C      ELEMENT CONDUCTION MATRIX AND HEAT LOAD VECTORS
C
100   CONTINUE
      CLOSE (12)
      DO 110 N=1,NUME
      MTYP=MTYPE(N)
      CXX=KXX(MTYP)
      CXY=KXY(MTYP)
      CYY=KYY(MTYP)
      IF (KAT.NE.2) CALL QCORD (ND,LM(1,N),X,Y,Z,XL,YL,AS)
      IF (KAT.EQ.2) CALL AXCORD (ND,LM(1,N),X,Y,Z,XL,YL)
      CALL KISO4 (KAT,0,ND,TH(MTYP),XL,YL,CXX,CXY,CYY,VOLQ(N),S,ST,PVOL)
      CALL ADDSTF (ND,LM(1,N),NEQ,NCOLS,MBAND,S,A(N6))
      CALL ADDLD (ND,LM(1,N),NEQ,A(N1),PVOL,A(N8))
110   CONTINUE
      RETURN
C
C      FLUX COMPUTATION
C
120   CONTINUE
      WRITE (IT,2060)
      WRITE (IT,2090)
      DO 130 N=1,NUME
      MTYP=MTYPE(N)
      CXX=KXX(MTYP)
      CXY=KXY(MTYP)
      CYY=KYY(MTYP)
      IF (KAT.NE.2) CALL QCORD (ND,LM(1,N),X,Y,Z,XL,YL,AS)
      IF (KAT.EQ.2) CALL AXCORD (ND,LM(1,N),X,Y,Z,XL,YL)
      CALL KISO4 (KAT,1,ND,TH(MTYP),XL,YL,CXX,CXY,CYY,VOLQ(N),S,ST,PVOL)
      CALL TEMPID (A(N8),ND,LM(1,N),TND)
      CALL QCOND4 (ND,TND,ST,QX,QY)
      WRITE (IT,2000) N,QX,QY
130   CONTINUE
      RETURN
C
2040  FORMAT (//,1X,27HP L A N E   E L E M E N T S,///,2X,26HNUMBER OF P
     1LANE ELEMENTS =,I3,/2X,26HNUMBER OF MATERIALS       =,I3,/2X,26HNUM
     2BER OF NODES          =,I3,///)
2050  FORMAT (2X,17HAXISYMMETRIC CASE,///)
2060  FORMAT (//,1X,26HP L A N E E L E M E N T  ,2X,20HH E A T  F L U X
     1 E S,//)
2070  FORMAT (//,37H    N    I    J    K     L    MATID  ,5X,1HQ/)
2080  FORMAT (5I5,2X,I5,5X,E11.4)
2090  FORMAT (9X,7HELEMENT,6X,2HQX,8X,2HQY,/)
2000  FORMAT (9X,I4,1X,E11.4,2X,E11.4)
2100  FORMAT (//,1X,8HMATERIAL,2X,9HTHICKNESS,9X,19HCONDUCTIVITY TENSOR/
     127X,3HKXX,8X,3HKXY,8X,3HKYY)
2200  FORMAT (1X,I4,4X,4(E11.4))
      END
      SUBROUTINE AXCORD (ND,IX,X,Y,Z,XL,YL)
C
C      FINDS LOCAL COORDINATES OF AXISYMETRIC ELEMENTS
C      IN GLOBAL REFERENCE FRAME. NOTE ELEMENTS MUST
C      LIE IN GLOBAL X-Z PLANE
        IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DIMENSION X(1),Y(1),Z(1)
      DIMENSION IX(4),XL(4),YL(4)
      I=IX(1)
      J=IX(2)
      K=IX(3)
      XL(1)=X(I)
      XL(2)=X(J)
```

```
      XL(3)=X(K)
      YL(1)=Z(I)
      YL(2)=Z(J)
      YL(3)=Z(K)
      IF (ND.EQ.3) RETURN
      L=IX(4)
      XL(4)=X(L)
      YL(4)=Z(L)
      RETURN
      END
      SUBROUTINE QCORD (ND,IX,X,Y,Z,XL,YL,AS)
C
C      COMPUTES LOCAL COORDINATES AND AREA FOR TRIANGLE OR QUAD
C      WITH LOCAL X AXIS FROM NODE I TO J
C
        IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DIMENSION X(1),Y(1),Z(1)
      DIMENSION IX(4),XL(4),YL(4),G(4),U(4),V(4),W(4)
      I=IX(1)
      J=IX(2)
      K=IX(3)
      CALL VECTOR (V,X(I),Y(I),Z(I),X(J),Y(J),Z(J))
      CALL VECTOR (G,X(I),Y(I),Z(I),X(K),Y(K),Z(K))
      CALL CROSS (V,G,W)
      CALL CROSS (W,V,U)
      XL(1)=0.0
      YL(1)=0.0
      XL(2)=V(4)
      YL(2)=0.0
      XL(3)=G(4)*DOT(G,V)
      YL(3)=G(4)*DOT(G,U)
      XL(4)=XL(3)
      YL(4)=YL(3)
      AS=0.0
      AS=AS+0.5*V(4)*G(4)*W(4)
      IF (ND.EQ.3) RETURN
      L=IX(4)
      CALL VECTOR (W,X(I),Y(I),Z(I),X(L),Y(L),Z(L))
      XL(4)=W(4)*DOT(W,V)
      YL(4)=W(4)*DOT(W,U)
      CALL CROSS (G,W,U)
      AS=AS+0.5*W(4)*G(4)*U(4)
      RETURN
      END
      SUBROUTINE KISO4 (KAT,KODE,ND,THICK,XL,YL,XKXX,XKXY,XKYY,Q,S,ST,P)
C      COMPUTES CONDUCTANCE MATRIX,LOAD VECTOR,AND
C      FLUX RECOVERY MATRIX FOR A 3 NODE TRIANGLE AND A 4 NODE
C      ISOPARAMETRIC QUADILATERAL
C
C      CALLED BY CISO4
C      CALLS     SHAPE
C
C      IF KODE.EQ.0 COMPUTES S,P
C                1 COMPUTES ST
C
        IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DIMENSION S(ND,ND),ST(2,ND),P(ND),B(2,4),E(2,2),C(2,2)
      DIMENSION XL(ND),YL(ND),XN(4)
C      REAL N(4),KXX,KXY,KYY
      COMMON/IO/IN,IT
      CXX=XKXX*THICK
      IF (CXX.EQ.0.0) GO TO 130
      CXY=XKXY*THICK
```

```
      CYY=XKYY*THICK
      IF (KODE.EQ.1) GO TO 90
      DO 10 I=1,ND
      P(I)=0.0
      DO 10 J=1,ND
      S(I,J)=0.0
10    CONTINUE
C
C      COMPUTE UPPER TRIANGLE OF CHOLESKY FACTOR OF CONDUCTANCE MATRIX.
C
      E(1,1)=SQRT(CXX)
      E(1,2)=CXY/E(1,1)
      E(2,1)=0.0
      E(2,2)=SQRT(CYY-E(1,2)*E(1,2))
C
C      START GAUSS QUADRATIC LOOP. FOUR POINT INTIGRATION.
C
      DO 70 II=1,2
      DO 70 JJ=1,2
      CALL SHAPE (ND,II,JJ,XL,YL,XN,B,DETJAC)
      IF (KAT.EQ.2) CALL AXI (ND,XN,XL,DETJAC)
C
C      MULTIPLY CHOLESKY FACTOR OF E TIMES B.
C      OVERWRITE RESULT IN B. FORM THERMAL CONDUCTANCE MATRIX.
C
      DO 30 K=1,2
      DO 30 L=1,ND
      DUMY=0.0
      DO 20 M=K,2
      DUMY=DUMY+E(K,M)*B(M,L)
 20   CONTINUE
      B(K,L)=DUMY
 30   CONTINUE
C
C      ADD CONTRIBUTIONS. GAUSS WEIGHTS ARE 1.0
C
C     MULTIBLY E*B TRANSPOSE *E*B
C
      DO 50 NROW=1,ND
      DO 50 NCOL=NROW,ND
      DUMY=0.0
      DO 40 L=1,2
      DUMY=DUMY+B(L,NROW)*B(L,NCOL)
 40   CONTINUE
      S(NROW,NCOL)=S(NROW,NCOL)+DUMY*DETJAC
 50   CONTINUE
C
C      COMPUTE THERMAL LOAD VECTOR
C
      DO 60 I=1,ND
      P(I)=P(I)+Q*THICK*XN(I)*DETJAC
 60   CONTINUE
 70   CONTINUE
C
C      QUADRATURE COMPLETE. COMPLETE CONDUCTANCE MATRIX BY SYMETRY.
C
      DO 80 K=2,ND
      DO 80 L=1,K
      S(K,L)=S(L,K)
 80   CONTINUE
      RETURN
C
C      COMPUTE FLUX RECOVERY MATRIX
```

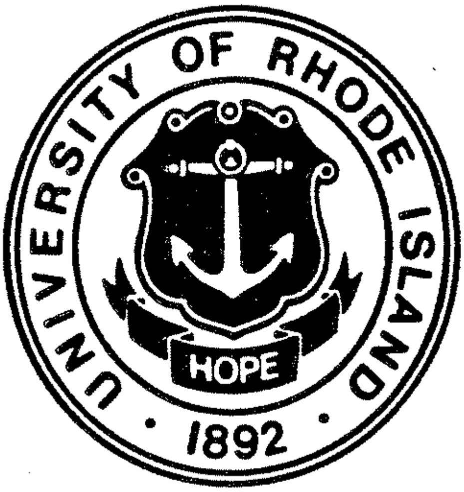
```
C
90     CONTINUE
       DO 100 I=1,2
       DO 100 J=1,ND
       ST(I,J)=0.0
100    CONTINUE
       C(1,1)=CXX
       C(1,2)=CXY
       C(2,1)=CXY
       C(2,2)=CYY
C
C       EVALUATE B MATRIX AT CENTROID FOR FLUX RECOVERY
C
       CALL SHAPE (ND,3,3,XL,YL,XN,B,DETJAC)
       IF (KAT.EQ.2) CALL AXI (ND,XN,XL,DETJAC)
       DO 120 K=1,2
       DO 120 L=1,ND
       DUMY=0.0
       DO 110 M=1,2
       DUMY=DUMY+C(K,M)*B(M,L)
110     CONTINUE
       ST(K,L)=ST(K,L)-DUMY
120    CONTINUE
       RETURN
130    CONTINUE
       STOP
C
2040   FORMAT (/,5X,28HFATAL ERROR, KXX EQUALS ZERO,/)
       END
       SUBROUTINE SHAPE (ND,II,JJ,XL,YL,XN,B,DETJAC)
         IMPLICIT DOUBLE PRECISION (A-H,O-Z)
       DIMENSION B(2,ND),XL(ND),YL(ND),XII(4),ETI(4),AA(3)
       DIMENSION XN(4),XNXI(4),XJAC(2,2),XNET(4)
       COMMON/IO/IN,IT
       DATA  AA /-0.57735026918963 , 0.57735026918963 , 0.0 /
       DATA XII /-1.,1.,1.,-1. /
       DATA ETI /-1.,-1.,1.,1. /
       DO 10 I=1,4
       DUM1=(1.+XII(I)*AA(II))*0.25
       DUM2=(1.+ETI(I)*AA(JJ))*0.25
       XN(I)=4.*DUM1*DUM2
       XNXI(I)=XII(I)*DUM2
       XNET(I)=ETI(I)*DUM1
10     CONTINUE
       IF (ND.EQ.4) GO TO 20
C
C       FORM TRIANGLE BY ADDING THIRD AND FOURTH TOGETHER
C
       XN(3)=XN(3)+XN(4)
       XNXI(3)=XNXI(3)+XNXI(4)
       XNET(3)=XNET(3)+XNET(4)
20     CONTINUE
C
       DO 30 I=1,2
       DO 30 J=1,2
       XJAC(I,J)=0.0
30     CONTINUE
       DO 40 I=1,ND
       XJAC(1,1)=XJAC(1,1)+XNXI(I)*XL(I)
       XJAC(1,2)=XJAC(1,2)+XNXI(I)*YL(I)
       XJAC(2,1)=XJAC(2,1)+XNET(I)*XL(I)
       XJAC(2,2)=XJAC(2,2)+XNET(I)*YL(I)
40     CONTINUE
```

```
      DETJAC=XJAC(1,1)*XJAC(2,2)-XJAC(2,1)*XJAC(1,2)
      DUMY=XJAC(1,1)/DETJAC
      XJAC(1,1)=XJAC(2,2)/DETJAC
      XJAC(1,2)=-XJAC(1,2)/DETJAC
      XJAC(2,1)=-XJAC(2,1)/DETJAC
      XJAC(2,2)=DUMY
C
C      FORM THE GRADIENT - TEMPERATURE MATRIX...B(2,ND)
C
      DO 50 I=1,2
      DO 50 J=1,ND
      B(I,J)=XJAC(I,1)*XNXI(J)+XJAC(I,2)*XNET(J)
50    CONTINUE
      RETURN
      END
      SUBROUTINE AXI (ND,XN,XL,DETJAC)
C
C      MODIFIES JACOBIAN DETERMINANT FOR AXISYMMETRY
C
        IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C      REAL N(4)
      DIMENSION XL(4),XN(4)
      RR=0.0
      DO 10 I=1,ND
      RR=RR+XN(I)*XL(I)
10    CONTINUE
      DETJAC=RR*DETJAC
      RETURN
      END
      SUBROUTINE QCOND4 (ND,TND,ST,QX,QY)
C
C      CALLED BY CPLANE
C      COMPUTE TRIANGLE AND QUAD. CONDUCTION HEAT FLUXES
C
        IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DIMENSION TND(ND),ST(2,ND)
      QX=0.0
      QY=0.0
      DO 10 JJ=1,ND
      QX=QX+ST(1,JJ)*TND(JJ)
      QY=QY+ST(2,JJ)*TND(JJ)
10    CONTINUE
      RETURN
      END
```

Appendix D: Computer Program

```
c       This program computes the velocity based on the hydrolic head
c       different.
c       ***************************************************************
         PARAMETER(NUMPS=25,N1=16,DETX=1.,DETY=1.)
C       NUMPS---# OF NODE POINTS
C       N1   ---# OF ELEMENTS
C       NOD(I,J)--- NODE # OF EACH ELEMENT (ANTICLOCK-WISE)
C       AH(I) --- VALUE FO HYDROLIC HEAD
        REAL*8 XH(NUMPS),AH(NUMPS),U(N1),V(N1)
        INTEGER NOD(4,N1), NELE(NUMPS),NNOD(NUMPS)
        OPEN(UNIT=12,FILE='G21.DAT',STATUS='OLD')
        OPEN(UNIT=13,FILE='G22.DAT',STATUS='OLD')
        OPEN(UNIT=14,FILE='G23.DAT',STATUS='NEW')
        DO 10 I=1,N1
        READ(12,100) NELE(I),NOD(1,I),NOD(2,I),NOD(3,I),NOD(4,I)
 10     CONTINUE
        READ(13,101)(AH(I),I=1,NUMPS)
        DO 15 I=1,N1
        JJ=NELE(I)
        J1=NOD(1,I)
        J2=NOD(2,I)
        J3=NOD(3,I)
        J4=NOD(4,I)
        U41=(AH(J4)-AH(J1))/DETX
        U32=(AH(J3)-AH(J2))/DETX
        U(JJ)=(U32+U41)/2.
        V21=(AH(J2)-AH(J1))/DETY*(-1.)
        V34=(AH(J3)-AH(J4))/DETY*(-1.)
        V(JJ)=(V21+V34)/2.
 15     CONTINUE
        DO 20 I=1,N1
        WRITE(14,102)U(I),V(I)
 20     CONTINUE
 100    FORMAT(5I5)
 101    FORMAT(5E14.6)
 102    FORMAT(2X,E14.6,6X,E14.6)
        CLOSE (12)
        CLOSE (13)
        CLOSE (14)
        STOP
        END
```

RHODE ISLAND
WATER RESOURCES CENTER



FISCAL YEAR 1989 PROGRAM REPORT

WATER RESOURCES RESEARCH INSTITUTE
THE UNIVERSITY OF RHODE ISLAND
RHODE ISLAND

FISCAL YEAR 1989 PROGRAM REPORT

Rhode Island Water Resources Research Institute
University of Rhode Island
Rhode Island

Report No.
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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

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ABSTRACT

The program objective of the FY-1989 Water Resources Research Institute Program at the University of Rhode Island was to conduct studies and research of value to the New England region as well as to assist in developing solutions of water resources problems in the state of Rhode Island. Information on research results was transferred to the public and workshops/seminars/conferences were conducted to educate the public as well as to encourage their participation in many water resources related activities. Current and anticipated state and regional water problems are impacts on water quality due to the high rate of land use development in the state, discharge of chemicals from industrial and agricultural activities, slow progress in the pretreatment program leading to toxic chemical contamination of water, lack of the understanding of the impact of pricing structure on water demand, and the lack of public awareness as well as participation in water quality protection and management. The FY-1989 program addressed many of these problems. Increasing motivation and better information were believed to move water consumers from an uninformed category of behavior to ill-informed and finally to a perfectly informed category. Public information and education therefore was considered a necessary component of the whole process to increase awareness of water rates and in category choice of water consumption behavior. Analyses of lakes and reservoirs samples in Rhode Island, both stratified and non-stratified conditions, showed many publicly owned lakes eutrophic and in impairment status. The slow water movement of the eastern quarant had insignificant impact on the water quality in the main body of Scituate Reservoir(western quarant). Two organic composts yielded high levels of nitrate in soil water comparable to urea treated turf plots. Only rarely did the soil water nitrate concentration exceed 10 mg/l. Seven other composts yielded nitrate levels equal to or less than those from fertilized plots. A compact electroflotation treatment system using rock salt solution electrolysis was found successful in removing cyanide and heavy metals from industrial wastewaters and more cost-effective than a conventional treatment system. Information transfer included watershed watch, workshops on shoreline surveys, conference on groundwater protection strategies for the state, and newsletters. The Center worked closely with R.I. Department of Environmental Management, USEPA Region 1 Office, New England Water Resources Centers, Public Works and Planning Departments of many town, as well as citizen groups on program planning, research coordination, and citizen participation.

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RESEARCH PROJECT SYNOPSES

WATER PROBLEMS AND ISSUES OF RHODE ISLAND

The State of Rhode Island and the other New England States have just ended a period of a very high rate of growth due to an economic boom. In addition to the higher demand of water supply, the rapid housing and commercial development in Rhode Island presents a potential threat to the water quality in the State. Sediments, nutrients and toxic chemicals in watersheds with high development activities could be washed into streams, lakes, and reservoirs, or infiltrate into aquifers. While most municipal wastewater treatment facilities are being upgraded and pretreatment programs are being implemented in most towns and cities, the water quality in our surface water in the state still needs improvement. A sound water policy has recently been formulated to change from supply development to water management which includes water conservation. Water conservation as an important policy component and water pricing structure is a means of demand management which needs careful examination by the State and for the New England region as a whole.

In the past, State agencies and research organizations have conducted studies of water quality primarily for major rivers in the State such as Pawtuxet River and Providence River, and for the Narragansett Bay. Very little effort has been spent on water quality studies of lakes and ponds in Rhode Island. The water quality of the Scituate Reservoir, which supplies water to 60 percent of the Rhode Island population, is taken for granted. The high development activities in the recent years and the findings of unlawful dumping of toxic chemicals in the water shed (albeit sporadic in nature and small amounts) justify the need of a systematic study of the Scituate Reservoir water quality. The State of Rhode Island is required, under Section 314 (a) (1) of the Clean Water Act, to do a Lake Water Quality Assessment in order to qualify the State to participate in a federal clean Lakes Program. It is important to assess the water quality of all publicly owned lakes, ponds, and reservoirs, identifying those that have an impairment/threatened status, protecting and restoring the water quality in order to meet the requirements of the Water Quality Act of 1987.

The increased activities and performance in wastewater treatment has generated larger amounts of sludge in Rhode Island. Lacking landfills and incinerators for sludge disposal is a growing problem. Applying composted sludge to sod farms can be an alternative solution to the problem if farmers can manage high quality turf without impacting negatively on groundwater and surface water resources. Therefore, there is a need to study the nutritional value of composted sludge and its health impact on turf growth on water quality.

There is a large number of firms in Rhode Island that generate wastewater containing heavy metals and cyanides. There are 121 electroplaters and metal finishers as well as 129 companies possibly having casting operations discharging their wastewater into the Field's

Point Treatment Facility in 1987. Many large size firms have installed pretreatment facilities, removing their heavy metal and cyanide loadings to acceptable levels. However, most small firms find such treatment facilities cost prohibitive. Unless a lower cost treatment system can be developed for them, these small firms will continue to discharge their untreated wastewater into the Narragansett Bay Commission sewer system.

PROGRAM 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 Management
    - Location and extent of groundwater supplies
    - Recharge characterization
    - Rural and small town water supply systems
    - Sources of toxic materials
    - Fate and transport of chemicals

- Surface Water Management
    - Land use/hydrology interactions
    - Water reuse and conservation
    - Eutrophication
    - Acid precipitation
    - Watershed management

- Ecological and Health Relationships
    - Wetland ecology
    - Effects of chemicals in water on human health

- Institute Frameworks
    - Water Use planning and management
    - Water allocation and reallocation
    - Conflict resolution among competing users

Guided by these research needs, the Rhode Island Water Resources Center developed its program goals to meet some of these research needs as well as to transfer the information water resources research/management/education to the public. Both the State Advisory Committee and the University Water Resources Coordinating Committee for the Center were consulted to finalize the research topics for the FY-1988 program. Groundwater research remained to be an important part of the program. However, strong efforts and considerable resources were put into surface water quality and water quality control research.

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 related to surface water management and supported by the FY-1989 program met the identified research needs for the State and the region. Project 03 and S2 were two studies in one. It was a tripartite arrangement between the Rhode Island Water Resources Center, the Rhode Island Department of Environmental Management, and U.S. Environmental Protection agency, to conduct a two-year study of the water quality of publicly owned lakes and reservoirs in Rhode Island. Samples from the lakes in stratified as well as in non-stratified conditions were taken. In addition to parameters used for trophic classification, samples also were analyzed for heavy metals, nitrogen, fecal coliform, BOD, and temperature. Abundance and locations of macrophytes in the lakes were also recorded. With one year sampling and analyses completed to date, 9 out of 34 lakes and reservoirs studied showed impairment either due to low dissolved oxygen or low pH and alkalinity. Also 9 lakes were found to be eutrophic. However, there was inconsistency between the parameters of secchi disk depth, chlorophyll-a, and phosphorus in assessing the trophic status of lakes. One more year's data will help to confirm some data and eliminate some of the inconsistency.

The other project related to surface water management, Project 04, performed field investigation of the water quality and hydrology of the Scituate Reservoir, conducted mass balance analysis, identified problem areas, and managed the data base for subsequent use in a mathematical mode. Sample analyses included solids, sodium chloride, heavy metals, and nutrients. Seasonal changes of stratification were observed to be prominent. In summer, the bottom water of the reservoir showed spatial variations that included significant oxygen deficits. Although the Route 14 causeway restricted the flow from the eastern quarant of the watershed resulting in lower water quality above the causeway, the impact on the overall water quality below the causeway where waters from eastern arm and western arm mix was minimal.

Project 05 addressed groundwater management problems by studying nutrient release from composted organic wastes used as soil amendments on turf farms. Nitrate levels in soil water beneath the root zones of turf were highest in plots treated with urea. Two composts namely Sustane (turkey manure compost) and Lawn Restore (commercial organic amendment) yielded comparable levels of nitrate in soil water. Only rarely did the soil water nitrate concentration exceed 10 mg/l. Seven other composts yielded nitrate levels equal to or less than those from unfertilized plots. Nitrogen recovery by grass was positively related to the levels of nitrate in soil water. The preliminary data showed some disease and insect suppression effects of composted materials. The 1989 growing season experienced almost 15 inches of rain in excess of the long-term average. Data from a more normal season are more useful to formulate a nitrogen management strategy and to evaluate the disease/insect suppression effects of composted organic wastes.

Project 02 provided a systematic examination of alternative water pricing structures which would improve the consumers' understanding of water resources management issues by drawing on the concepts developed within the natural resources economics discipline. There exist three classes of behavior in modelling the consumers' response to water prices: the fully informed, marginal price model; the ill-informed, average price model; and the uninformed, zero response model. Increasing motivation (high potential of cost saving) and better information will move them from the uninformed category to ill-informed and finally to the perfectly informed category. Public information and education is a necessary component of the whole process to increase awareness of water rates and in category choice of water consumption behavior.

Project S1 was a research project aiming at the development of a compact, inexpensive, treatment system for the plating industry for the removal of heavy metals and cyanides in the wastewater. It was found that an electroflotation system using rock salt solution as anodelyte between two horizontally placed electrodes and the wastewater above the electrodes was successful in generating chlorine for the cyanide removal (oxidation) and producing sufficient hydroxides for the precipitation of heavy metals. The optimal operating condition included: 4 to 6 volts direct current at a current density between 10 to 24 mA/cm^2, 60 to 75 minutes of hydraulic detention time, which produce an effluent quality meeting both the federal and the local standards of the waste pretreatment program. The treatment system was most efficient when a low power input was used in conjunction with a greater depth of wastewater in the treatment system. Cost analyses showed that the electroflotation treatment system had a lower installed cost and operating cost compared to a conventional treatment system.

Sources of funding for the Rhode Island Water Resources Center included U.S. Geological Survey, U.S. Environmental Protection Agency, Rhode Island Department of Environmental Management, Providence Water Supply Board, and the University of Rhode Island. The level of funding and sources for the various projects including the information transfer activities are listed in Table 1 on the next page.

Table 1 - Sources and Levels of Finding, FY-1989

Project	Fundings* Level	Source
02 The Potential Role of Water Pricing Structure in R.I. Water Policy	$14,871 46,495	U.S. Geological Survey University of R.I.
03 Water Quality & Trophic State of Rhode Island Lakes	15,560 31,256	U.S. Geological Survey University of R.I.
04 Water Quality Assessment of the Scituate Reservoir	14,871 6,600 26,092	U.S. Geological Survey Prov. Water Supply Board University of R.I.
05 The Disposal of Composted Organic Wastes on Turf: Its Impact on Groundwater Quality & Its Value in Reducing the Incidence of Turf Diseases and Insects	14,853 34,432	U.S. Geological Survey University of R.I.
S1 Simultaneous Removal of Cyanide & Heavy Metals from Industrial Process Wasteswaters	21,806 7,395	R.I. Dept. Environ. University of R.I.
S2 Lake Water Quality Assessment in Southern Part of Rhode Island	49,435 38,992	U.S. Environmental Protection Agency University of R.I.
22 Information Transfer Activities (see description later in report)	15,000 32,480	U.S. Geological Survey University of R.I.
Center Administration (Including publication of newsletter)	29,975 51,785	U.S. Geological Survey University of R.I.

*Ending May 31, 1990

Synopsis

Project Number: 02

Start: 06/89
End: 05/90

Title: The Potential Role of Water Pricing Structures in Rhode Island Water Policy

Investigators: Opaluch, James and Wichelns, Dennis, University of Rhode Island

COWRR: 06C

Congressional District: 2

Descriptors:

Cost Allocation, Cost Sharing, Pricing/Repayment

Problem and research objectives:

Rhode Island's water policy is in the transition from an era of supply development to water management, which includes water conservation as an important policy component. An understanding of the potential of pricing as a means of demand management is an essential ingredient of appropriate water policy, as has been emphasized in the recent statement of Rhode Island's water supply policy (Division of Planning, 1988).

The objective of this project is to provide a perspective on the role of water pricing within the general Rhode Island water supply policy. The study is to provide a systematic examination of alternative water pricing structures, including those which recognize the 'resource' value of water; which provide for capital replacement and expansion; and which recognize issues related to 'both ends of the pipe'--the interrelationship between water intake and waste water disposal. It is hoped that this study will improve our understanding of these issues by drawing on the concepts developed within the natural resource economics discipline.

Methodology:

This research project used the following methods: (1) survey current research and practice in water pricing to bring in the national experience with successes and failures of water pricing, (2) explore the implications of alternative pricing structures for providing incentives for water conservation as well as the implications for the provision and stability of revenues for utilities, (3) use available estimates of demand elasticities to place a quantitative perspective on the potential role of price in encouraging conservation and (4) survey state water utilities to characterize the current situation within the state and to identify potential data for estimating demand elasticities within the state.

Principal findings and significance:

(1) Conceptual modelling of response to water prices:

Perceptions of prices by water customers appears to be the major issue with respect to the potential of water pricing as a means of encouraging water conservation. Water pricing is generally carried out by a relatively complex means of block pricing. Under a block pricing structure the price paid per thousand gallons depends on the level of water used by the household. Users typically pay a hookup charge, which includes some base amount of water for no additional charge. Beyond this level of consumption, individuals pay some price, say p_1, per unit water use up to some level of water consumption, w_1. For water use beyond this level users pay some other price, say p_2 per unit. Thus, there is no single price per unit water consumed.

Economic theory shows that the theoretically appropriate measure of price is the so-called marginal price (Taylor, 1975; Norton 1976), which is the price paid for a small increment in water used or the amount saved for a small decrement in water used. However, many individuals are not aware of the actual pricing structure of water, largely because water price is not high enough to compensate users for studying and comprehending the relatively complex pricing structure. Hence, consumers may be vaguely aware of how expensive water is, without comprehending the pricing structure, or they may not be aware that their water bill varies with the amount of water they consume. Since the success of water prices depends on individuals reactions, it the consumer's perception of water price that is critical in determining whether price will encourage conservation, not the actual price structure in use. This implies that consumer education is an important component in any attempt to use prices to encourage water conservation.

The possiblity of imperfect consumer perceptions of price implies that at least three models may be appropriate for consumer response to water prices: the fully informed, marginal price model; the ill-informed, average price model; and the uninformed, zero response model. Several empirical pieces have compared estimation under each model of price perceptions (Billings and Agthe, 1980; Chicoine, Deller and Ramamurthy, 1986; Danielson, 1979;Forster and Beattie, 1981;Howe and Linaweaver, 1967) or have suggested a more formal means of testing for the appropriate measure of price (Opaluch, 1981, 1984). Still other papers have examined the effects of simultaneity on the appropriate estimation technique (Terza and Welch, 1982; Jones and Morris, 1984; Chicoine, Deller and Ramamurthy, 1986). Hence, the block pricing structures have resulted in several empirical difficulties which must be addressed when attempting to estimate responsiveness to price.

To date water prices have generally been nominal. However, in some areas water prices have changed dramatically in recent years. Also, markets for transfer of water rights have developed in many of the western states. Pressures arising from water scarcity appear to be driving an increasing number of water systems to increase prices over time to more realistic levels.

In general, water institutions are based on two water rights doctrines: the Appropriative and the Riparian doctrines. The Appropriative doctrine allocates water according to the seniority of the claim. The earliest users of water establish a claim on water from that source. Higher priority is placed on claims established earlier. Thus, in years of insufficient rainfall, users with more junior claims lose their right to water use. Claims are maintained so long as the water is put to 'beneficial use'. This tends to lead to wasteful use of water. For example, water users do not have an incentive to reduce water use, since any saving would be inconsequential given that water prices are maintained at nominal levels. Furthermore, reducing water use relinquishes the claim to that water should the individual wish to use more water in the future.

Basing water rights sole on seniority will also tend to be wasteful, given that there is no guarantee that earlier uses have high social value. Thus, some use may arise later that has a value of water use, but that cannot be fulfilled because some lower valued use established a right at an earlier period of time. Recent moves towards establishment of markets for water rights could allow for reallocation of rights towards more highly valued uses.

(2) Empirical Estimation

Appropriate empirical methods need to recognize the three classes of behavior, discussed above, in modelling potential responsiveness of water consumption to price. In this project initial steps have been made in modelling the category of behavior as a discrete choice. That is, for individual with insufficient motivation in terms of potential cost savings, the uninformed model will be appropriate. As individuals become increasing aware of water costs, they will tend to switch from being 'uninformed' to the 'ill-informed' category, whereby they recognize that water use is costly and may respond by consuming less, but do not completely internalize the complex rate structure. Finally, given sufficient incentive, some users may learn enough about water pricing structures to switch to the 'perfectly informed' category, where they understand the full implications of block pricing structures.

Hence, any change in pricing structure may have several impacts. First, an increase in price will tend to lead to a decrease in water used for people within the 'ill-informed' and 'perfectly informed' categories. Secondly, an increase in price may tend to motivate people be learn more about water pricing structures, and hence to switch form 'uninformed' to 'ill-informed' and from 'ill-informed' to 'perfectly informed'. Public information and education represent an additional component of this process, and in some cases a necessary one. That is, dissemination of public information will tend to increase awareness of water rates and may also play an important role in the category choice problem.

Project Number: 03 and S2

Start: 6/1/89
End: 5/31/91

Title: Water Quality and Trophic State of Rhode Island Lakes

Investigators: Poon, Calvin P.C., Gold, Arthur J., and McKiel, Charles G., University of Rhode Island, Kingston, R.I. 02881

COWRR: 05A

Congressional District: 2nd, R.I.

Descriptors: Bacteria, eutrophication, heavy metals, lakes nutrients, water quality.

Problem and Research Objectives:

Under section 314 (a) (1) of the Clean Water Act, the State of Rhode Island is required to do a Lake water Quality Assessment in order to qualify the State to participate in a federal Clean Lakes Program. There are scarce and well-scattered data at various federal and state agencies as well as research institution in Rhode Island related to lake water quality in the State. The present commitments of funds and efforts by the Rhode Island Department of Environmental Management (RIDEM)) on lake water quality study are too limited. As a result, it is not likely that the lake water quality assessment for the State as required by the U.S. Environmental Protection Agency can be completed. The Water Resources Center at the University of Rhode Island enters a tripartite arrangement with the RIDEM and USEPA to participate in the Clean Lake Program. The goal is to complete the Lake Water Quality Assessment Study covering all publicly owned lakes in Rhode Island. This project is one of the tripartite in the joint effort. The study will enable the State to classify the lakes according to their trophic status, and to identify those lakes and their impairment/threatened status.

Methodology:

All together 32 lakes in Kent County and Washington County as well as 2 lakes/reservoirs in Cranston and Tiverton are studied. One composite sample from each lake/reservoir is taken for the water column to a depth of 2x secchi depth, either in the spring or in the fall. In the summer, a sample from the epilimnion (upper layer) and another from the hypolimnion (lower layer) are taken in deep lakes. Parameters analyzed for the water quality include: temperature, pH, dissolved oxygen profile, total suspended solids, turbidity, conductivity, fecal coliform (summer only), DO, BOD (summer only), chlor-a, secchi disk depth, alkalinity, total-P, ortho-P, NH_4-N, total-N (NH_3 + organic), dissolved chloride, calcium, silica, aluminum, cadmium, chromium, copper, iron, lead, and manganese. Observations of the location and abundance of macrophytes are also recorded. From data analysis, either the EPA-NES criteria or the Carlson's trophic state index are used to classify these lakes/reservoirs. Possible assessment of the status and trends of water quality in each lake can then be made. If available, land use data from the Rhode Island Geographical Information System will be used to assess the possible sources and extent of non-point source pollution for lakes which appear to be impaired based on this two-year study.

Principal Findings and Significance:

Within each of the three parameters used to assess trophic status (total-P, secchi disk depth, and chlorophyll-a), the trophic designations of a given lake are very similar using both the EPA-NES criteria and Carlson's trophic state index. However, there is more inconsistency in trophic designations between the three parameters. Only 5 of the 39 basins sampled have the same trophic designation using all three parameters, and 24 of the 39 have the same designation using two parameters. Some of the inconsistence may be the result of the limited sampling frequency used in this study (twice a year for each lake), since trophic indices are intended to be based on mean summer or mean annual values obtained from a more frequent sampling procedure. Other factors that may contribute to the inconsistency are herbicides applications in lakes, presence of suspended solids and color, as well as the presence of macrophytes.

There is insufficient background information available to assess the impairment status or trend of water quality lakes studied. If impairment is interpreted as either the lake water DO drops rapidly to hypoxic or anoxic levels at the thermocline, or a combination of pH ≤ 5.0 and total alkalinity ≤ 0.2 mg/l as $CaCO_3$, only 9 out of 34 lakes studied show impairment. Five of these 9 impaired lakes are DO impaired (Carbuncle Pond, Deep Pond, Gorton Pond, Tucker Pond, and Warwick Pond), and 4 are Ph-alk impaired (Ashville Pond, Blue Pond, Long Pond, and Moscow Pond-North basin).

Publications and Thesis:

This is a 2-year project and presently the second year sampling program has just begun. There are no publications and thesis written as a result of the first years work.

Synopsis

Project number: 04

Start: 06/89
End: 05/91

Title: Water Quality Assessment of the Scituate Reservoir

Investigators: Raymond M. Wright and Daniel W. Urish,
University of Rhode Island, Kingston, RI

COWRR: 05B

Congressional District:

Descriptors: Base Flow, Heavy Metals, Nutrients, Water Quality, Reservoir Management and Modeling

Problem and research objectives:

On the national and regional level, over the last two decades major improvements in water quality have been directly linked to improved treatment of wastewater point sources. As gross pollution is eliminated, it has become very clear that nonpoint sources of pollution can have as severe an impact on the water quality of our water resources as point sources. On the state level, a growing concern is the future ability of the Scituate Reservoir to provide sufficient water at an acceptable quality. The overall goal of this research is to provide a management tool capable of evaluating the response of and impact on water quality of the Scituate Reservoir due to the input of contaminants from incoming tributaries. This study was planned in two phases. The first phase of the research was conducted in 1989-1990. The second phase is proposed for 1990-1991. This synopsis covers the first phase of study which is the water quality assessment of the Scituate Reservoir. To accomplish this goal, the following objectives were addressed:

1) Perform intensive field investigation to characterize the water quality and hydrology of the Scituate Reservoir
2) Conduct mass balance analysis for the Reservoir
3) Identify problem area with respect to water quality
4) Develop the data base for subsequent use in the calibration of a state-of-the-art water quality/quantity mathematical model

Methodology:

To characterize the water quality of the Scituate Reservoir, a total of 7 reservoir sampling stations and 11 stream sampling stations were established during the study. The protocol for the reservoir sampling locations called for two samples to be taken; one 5 feet below the surface and the other 5 feet above the bottom. Profiles of temperature, dissolved oxygen, and specific conductance were taken at 5 foot intervals throughout the vertical distance. The sampling was performed on a monthly basis, commencing July 1989 and ending October 1989.

Total suspended solids, volatile suspended solids, sodium, chloride, cadmium, chromium, copper, lead, nickel, nitrate and orthophosphate were the constituents analyzed.

Principal findings and significance:

The results of the water quality analysis to date are preliminary in nature. The dissolved oxygen concentrations of the surface of the reservoir ranged between 8 to 10 mg/L. The bottom water of the reservoir showed seasonal and spatial variations that included significant oxygen deficits in both July and August. Particularly, during the August survey, the dissolved oxygen concentration of bottom water above the Route 14 causeway approached zero.

Temperature profiles provide insight to thermal stratification, which enables one to understand the general conditions of impounded water bodies. The thermocline (metalimnion), where the sudden shifts occur with regard to water quality, was observed at depths between 20 and 40 feet. Seasonal changes of stratification were also prominent, i.e. well stratified profiles of July and August surveys, and uniformly mixed quality of the two October surveys.

The most important observation to date, is the importance of the Route 14 causeway in both the flow of water from the eastern quadrant of the watershed and the impact on water quality. From preliminary evaluation the restriction of flow at the Route 14 causeway appears to be significant. Since the water quality above the causeway is generally lower than that of the eastern or main sections of the reservoir, one expects to see an impact as the western and eastern arms mix below the causeway. This is not obvious with the data to date. The water quality below the causeway is similar to that of the western arm of the reservoir essentially showing very little movement of water from the eastern arm of the reservoir through the causeway.

<u>Publications and professional presentations</u>:

<u>M.S. thesis</u>:

<u>Ph.D. dissertations</u>: Watershed Wide Modeling of the Scituate Reservoir and Pawtuxet River in Rhode Island, Young-Soo Lee, University of Rhode Island, Kingston (expected completion 1991)

SYNOPSIS

Project Number: 05

Start: 6/1/89
End: 5/31/91

Title: The Disposal of Composted Organic Wastes on Turf: Its Impact on Ground Water Quality and Its Value in Reducing the Incidence of Turf Diseases and Insects.

Investigators: Jackson, Noel and Hull, Richard J., Plant Sciences Department, University of Rhode Island, Kingston, RI 02881

COWWR: 05B, 05G **Congressional District:** 2nd, R. I.

Descriptors: Ground water pollution, Turfgrasses, Sludge disposal, Land application, Nitrates, Organic Wastes, Plant diseases, Aquifer management

Problem and Research Objectives:

Ground water resources constitute a primary potable water supply for Rhode Island and the urban Northeast. Increasingly the quality of this water is being threatened by the growing intensity of land use: agricultural, domestic and industrial. At the same time, the quantities of various organic wastes generated at sewage treatment plants and from agricultural and industrial operations are increasing. Strategies for protecting the quality of ground water resources have concentrated on regulating land uses and restricting the land application of substances which have the potential for leaching through the soil to ground water. Landscaped areas with large expanses of turf have received special scrutiny because of the relatively large amounts of fertilizer, pesticides and water used in their maintenance. Most contemporary research has failed to detect significant transport of these substances from turf and concludes that urban land areas covered with grass sod are less likely to contribute pollutants to ground water than most alternative land covers. Because turfgrasses have a nutritional need for many of the elements contained in sludges and organic wastes, and because turfgrasses are not used as food for humans or feed for livestock, it has been proposed that such areas might constitute environmentally sound sites for the land disposal of these waste materials.

A number of soil amendments derived from composted organic wastes are being marketed for use on turf and landscape plantings. The agronomic value of these materials has been established but their potential for releasing nitrates which may leach to ground water and depositing heavy metals in the soil which may be absorbed by plants is less well understood. Before composted sludges can be recommended for use on turf these potentially negative environmental effects must be quantified.

Plant pathologists have long known that the addition of organic matter to soil can have a suppressive effect on plant pathogenic fungi and reduce the incidence and severity of turfgrass diseases. Anecdotal evidence suggests that some organic composts, when applied to turf, can suppress disease and reduce the need for fungicides. It is even conceivable that these organic materials may reduce the number of root and shoot eating insects thereby reducing the use of insecticides.

The objectives of this study are: (1) to evaluate the agronomic value of several commercially available composts when applied to established turf (2) to measure the nitrate leaching from turf receiving composts (3) to monitor the accumulation of heavy metals in the soil and plants from compost treated turf and (4) to evaluate the effect of compost applications on the incidence and severity of disease and insect injury.

Methodology:

Most of the research conducted during the 1989-90 season involved the application of composted wastes to field plots of established Kentucky bluegrass (*Poa pratentis* L.), Perennial ryegrass (*Lolium perenne* L.) and creeping bentgrass (*Agrostis palustris* Huds.). Composted materials were applied at a rate of two pounds of nitrogen per 1000 sq-ft. during mid-June, late July and early November. Similar applications had been made to the same plots during the 1988 growing season. Suction lysimeters were installed to a depth of two feet in plots of the Kentucky bluegrass test and soil water samples were collected following each significant rain event. All grasses were mowed each week and clippings were collected from a standard area of the Kentucky bluegrass plots. Clippings were dried, weighed, ground to pass a 40 mesh screen and analyzed for total nitrogen. From these data, yearly nitrogen losses due to leaching and clipping removal were determined.

All plots were scored for turfgrass quality once each month and separate disease and insect injury ratings were recorded whenever they were observed. Grub numbers were determined in Kentucky bluegrass plots on 31 October 1989. Diseases of special interest included dollar spot, red thread, necrotic ring spot and brown patch.

Principal Findings and Significance:

The 1989 growing season was characterized by heavy rainfall; the June through November season having an excess above normal of 14.8 inches. This probably contributed to the relatively high nitrate levels in soil water beneath the root zones of most treatments. The highest nitrate levels were detected in water from plots treated with urea, Sustane (turkey manure compost), and Lawn Restore (commercial organic amendment). Only rarely did the soil water nitrate concentration exceed 10 mg/L. Between January and March 1990, the same three materials provided the highest soil water nitrate levels although no material on any date averaged more than 10 mg/L. All other composts yielded soil water nitrate levels equal to or less than those from unfertilized plots.

Nitrogen recovery in clippings during the 1989 season was greatest from plots fertilized with urea, Lawn Restore and the fine grade of Sustane. More nitrogen was recovered in clippings from all compost treated plots than from unfertilized controls. Nitrogen recovery by grass was positively related to the levels of nitrate in soil water.

Only preliminary results on disease suppression can be reported at this time. Necrotic ring stop was less destructive on Kentucky bluegrass plots fertilized with Sustane, Milorganite, Lawn Restore and Clandosan (commercial chitin-based product). Rhizoctonia brown patch was more prevalent on compost treated turf. The incidence of red thread was reduced in all perennial ryegrass plots receiving compost probably due to the nitrogen stimulated leaf growth. Insect injury generally was light and no treatment effects were detected.

Publications and Professional Presentations:

Cisar, J.L., R.J. Hull and D.T. Duff. 1989. Ion uptake kinetics of cool season turfgrasses. p. 233-235. In H. Ide and H. Takatoh (Eds.). Proc. Seventh Inter. Turfgrass Res. Conf., Tokyo, July 31 - August 4, 1989.

Gold, A.J., W.M. Sullivan and R.J. Hull. 1989. Influence of fertilization and irrigation practices on waterborne nitrogen losses from turf. p. 143-152. In A.R. Leslie and R.L. Metcalf (Eds.). Integrated Pest Management for Turfgrass and Ornamentals. USEPA, Off. of Pesticide Programs. August 1989.

Hull, R.J. 1990. Minimizing nitrate leaching from turf to groundwater. p. 39-40. Conference Proc., 61st Inter. Golf Course Conf. & Show, Feb. 19-26, Orlando, Florida.

Hull, R.J., H. Liu and H.J. Brown. 1989. The use efficiency of fall-applied nitrogen by turf. Agronomy Abstracts 81:159.

Thesis: One graduate student, H. Liu, is contributing to this project as part of his doctoral dissertation research. No students have written their thesis or dissertation based on this study.

SYNOPSIS

Project Number: S1

Title: Simultaneous Removal of Cyanide and Heavy Metals from Industrial Process Wastewaters

Investigators: Poon, Calvin P.C., University of Rhode Island

COWRR: 05D Congressional District: 2nd

Descriptors: Heavy Metals, Industrial Waste Water, Wastewater Treatment

Problem and Research Objectives:

The industrial pretreatment program of the Narragansett Bay Commission has identified total metal loadings to their Field's Point Wastewater Treatment Facility to be 363,645 pounds and total cyanide loadings to be 27,043 pounds in 1987. The industrial contribution of these metals was calculated to be between 60 to 90% of the total metal load to the treatment facility but only 7% of the total flow. The three largest loadings of metals were zinc, copper, and nickel which together made up more than 91% of the total metal loadings. Within the Narragansett Bay Commission district, there are 121 electroplaters and metal finishers as well as 129 companies identified as possibly having casting operations, all contributing in part to the total metal and cyanide loadings.

The objectives of the research have been to demonstrate the feasibility of a physical-chemical treatment process, using brine solution electrolysis, in simultaneous removal of cyanide, nickel, copper, and zinc.

Methodology:

A compact reactor was built with a platinated columbium anode and a stainless steel cathode. The space between the horizontally laid anode screen and cathode screen was filled with a rock salt solution as the anodelyte. The wastewater containing heavy metal and cyanide was introduced on top of the rock salt solution layer. The electrolysis of the rock salt solution generated chlorine to destroy cyanide and hydroxides to precipitate the heavy metal. Gas bubbles carried the precipitated metal to the top to form a scum layer. The scum layer was collected and acid dissolved to form a high concentrated metal solution from which the metal could be plated out or disposed of. A field testing of the unit in a metal plating firm will be conducted to demonstrate the applicability of the system.

Principal Findings and Significance:

By applying a direct current from 4 to 6 volts and a current density in a range from 10 to 24 mA/cm^2, experimental results indicated successful removal of nickel, copper and cyanide, lead and zinc to levels meeting the pretreatment standards. Effluents of 0.35 ppm Ni, 0.28 ppm Cu, 0.16 ppm total CN, 0.43 ppm Zn, and 0.34 Pb could be achieved in a continuous flow process. The hydraulic detention time for Ni was 60 minutes, and 75 minutes for Cu-CN, and 75 minutes for Zn-Pb.

Only two control variables were deemed important in the process: power supply and depth of wastewater in the electroflotation unit above the electrodes. A multiple linear regression analysis of data in all experiments showed that a lower power supply together with a greater depth of wastewater above the electrodes was the optimal operational condition that yielded the highest treatment effectiveness in terms of mass of metal or cyanide removal per unit kwh power consumption.

The electroflotation treatment system in this study comprised of an elctroflotation reactor and a sand filter. This system replaces the normal practice of conventional treatment using a cyanide chlorination (oxidation) tank, alkaline precipitation tank, flocculation tank, and a clarifier. The compact size of the electroflotation system has a lower start-up cost along with advantages of simpler operation and less chemical requirement. Prototype electroflotation treatment system of 10 gal/min capacity would cost $39,500 as opposed to $62,000 for a conventional treatment system. The operating costs for the electroflotation system and for the conventional system are respectively $7,600/yr and $13,680/yr by estimation.

Recovery of metal was shown to be impractical by direct plating out of the acidified scum solution from the electroflotation treatment. The percentage of recovery for copper was only 76.1%. In addition the recovered copper contained impurities of Ca 0.23%, Mg 1.4% and Na 2.17%. The laboratory unit of the electroflotation treatment system is being converted to a portable unit which will be shipped to some metal plating firms for field testing.

INFORMATION TRANSFER ACTIVITIES

Project No.: 22 Information Transfer Activities

Title: Environmental Education: Water Protection, Management, and Conservation

Investigators: William R. Wright, Ph.D.
Department of Natural Resource Science, URI

Calvin P. C. Poon, Ph.D.
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Problem and Research Objectives:

Two major sources of drinking water, surface and groundwater, exist in Rhode Island. The Scituate Reservoir serves approximately 60 percent of the state, with a safe yield capacity of 78 million gallons per day (MGD). The southern part of the state is dependent on a large aquifer network. On December 1, 1987, a petition for Environmental Protection Agency designation for the Pawcatuck Basin Aquifer as a Sole Source Aquifer was submitted. The concern lies in the pressures of increased water demand and water degradation caused by accelerated urban development. Research conducted by the Rhode Island Department of Environmental Management (DEM) presented in The Groundwater Protection Strategy cites a growing number of contaminated drinking water wells throughout the state. Such nonpoint sources as agricultural and urban runoff add to pollution loading. Protection of these sole-source water supplies is critical to meet future demands for potable water. Important forces in accomplishing this protection are informed decision makers and an educated public. A comprehensive Technology Transfer Program can target key groups and disseminate information on planning strategies for effective land use and water protection.

Methodology:

To ensure that water resource management occurs in a way which both maintains areas of high water quality and improves degraded areas, people entrusted with executing planning decisions must have technical information accessible. The University of Rhode Island can implement programs of technology transfer.

As a strong research base committed to water resource issues, the University can generate technical information. The University can integrate and support existing related water quality programs at state and local levels. The University also can increase scientific information on surface water quality in Rhode Island by compiling background water quality data against which present conditions can be measured and evaluated. This Technology Transfer Program proposes to continue and to broaden the following programs initiated in FY 1987:

1. Printing of written materials, aimed at municipal decision makers and the general public on such topics as storm water management, fertilizers, buffer zones, and surface and groundwater quality;
2. Sponsoring of workshops on groundwater issues particularly addressing state and local strategies for groundwater protection;
3. Monitoring program for Watershed Watch, a citizen-based monitoring program for surface waters within the Pawcatuck Watershed, to be expanded to include the northern part of Rhode Island.

There are many benefits to the above programs. 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, the University can offer technical assistance and strengthen existing water quality programs. A good example of this is the cooperative surface water monitoring program, Watershed Watch, which increases DEM's surface water quality data-base. On the local level, university assistance can serve to galvanize the public on key water quality issues.

Principal Activities and Significance:

A. Watershed Watch, a citizen-based monitoring program for surface waters with the Pawcatuck Watershed, was expanded to include the northern part of the state. Training materials were developed as part of a four-session training workshop in lake and river management which was held at the University of Rhode Island from June 1-22, 1989. The training consisted of three classroom sessions and one Saturday morning field exercise. Topics addressed at the workshop included:

1. Physical, chemical, and biological characteristics of RI surface waters.
2. Factors affecting surface water quality, including pollution sources, natural characteristics, and man-made alterations.
3. Conducting shoreline surveys to develop an inventory of natural characteristics and pollution sources.
4. Steps that individuals and organizations can take to protect water quality.

In 1989 both the number of monitoring locations was increased by the addition of more monitoring locations in the Pawcatuck watershed, including several locations in North Stonington, CT. We also welcomed the addition of the Town of North Kingstown and the North Kingstown Land Conservancy who worked together to initiate monitoring on locations in the Annaquatucket and Upper Pettaquamscutt watersheds. In 1989 twenty-six locations were monitored by 55 volunteers.

In 1989, the scope of the program was also enlarged by supplementing the in-water monitoring with the development of a short course on

"Understanding and Managing Rhode Island Lakes and Streams" and by training volunteers to conduct detailed shoreline surveys.

B. Shoreline Surveys. The general goal of the shoreline survey program was to encourage citizens to take an active role in managing RI lakes and rivers through their local watershed associations, Conservation Commissions or other volunteer organizations and to provide these groups with technical support in management of non-point sources. The specific objectives were to offer a series of training workshops on watershed management that would: 1) provide volunteers with basic information on water quality characteristics of freshwaters; 2) promote a watershed perspective in assessing water quality; 3) train volunteers to conduct shoreline surveys; and 4) equip volunteer associations to undertake management of non-point sources of pollution based on the shoreline survey findings, with technical support from Watershed Watch. A total of 21 locations were surveyed in mid-summer 1989 by about 28 volunteers.

Additionally, a number of workshops were presented to various groups including Girl Scouts. A travelling exhibit entitled "What is a Watershed" was circulated among local libraries in conjunction with Coastweeks '89.

This year (1990) approximately 90 volunteers are monitoring 34 locations. The scope of water quality monitoring has expanded to include sampling and laboratory analysis of the major tributaries to the ponds being monitored. A pilot study of bacterial monitoring will commence in July. The Shoreline Survey and non-point source management segment of the program has also expanded. It is now being offered to groups not yet participating in water quality monitoring in addition to those who are. A number of fact sheets pertaining to water quality are also being planned for 1990. They will include such topics as septic system management, lakeside greenbelts, and home-based water quality improvements.

C. A Conference on the Role of Citizens in Watershed Management. A statewide conference was held on March 5, 1990 at the Whispering Pines Conference Center on the URI W. Alton Jones Campus. The focus of this conference was to present approaches to watershed management, drawing on successful programs in Rhode Island and across the country. In addition, tools for developing a water quality monitoring program were presented. The workshop was attended by 75 people including municipal and state officials, public water supply managers, representatives from watershed associations, environmental organizations, and educators.

The objectives of this one day program were to allow participants to:

1. gain insight into watershed management strategies;
2. learn about models for developing a water quality monitoring program with a volunteer organization or within a classroom;
3. increase their knowledge of local, regional, and national watershed protection efforts; and
4. network with professionals in the field.

The conference accomplished all of its stated objectives. Additionally, participants received a resource notebook.

A resource room was set up and open throughout the day in which many groups and organizations involved in water quality monitoring and protection issues displayed informational materials and answered questions. Those involved in the resource room included:

1. URI Watershed Watch
2. Wood-Pawcatuck Watershed Association
3. USDA Soil Conservation Service
4. Rhode Island Resource Conservation and Development Area, Inc.
5. Riverways Program, Adopt-A-Stream, Massachusetts
6. Tip of the Mitt Watershed Council, Michigan
7. River Watch Network, Vermont
8. The Interactive Rouge River Water Quality Project, Michigan
9. Governor's Water Conservation Program
10. The Land Management Project, Rhode Island

A copy of the conference brochure is included.

D. When to Water: A Guide to Watering Your Lawn. Irrigation scheduling models now used in the agricultural sector are being adapted for use on home lawns. A computer model is being developed which uses climatic data from the state weather station in Warwick, RI and calculates a soil water deficit for a typical Rhode Island sandy and silty soil. Weekly estimates of required water applications for these two soil types will be calculated and reported to the public through the media. After determining their sprinkler output, homeowners will apply the appropriate amount of water to their lawn based on this deficit using a simple chart.

A brochure is being developed to explain the importance and benefits of home lawn irrigation scheduling and how to determine soil type and sprinkler output. A draft copy of this brochure is included.

This program is being co-sponsored by the URI Water Resources Center, URI Department of Natural Resources Science, the Cooperative Extension Education Center, and the Governor's Water Conservation Program.

E. Newletters. Newsletters, published on September 1 and December 1, 1988, and on March 1, and June 1, 1989 by this Center were distributed to the public as well as to water agencies and the research community in Rhode Island, and all other 53 Water Resources Research Institutes. Items covered in the newsletter included research works, planning activities of this Center, announcements of other water resources related activities, as well as discussions on water related environmental issues relevant to Rhode Island and other states such as hazardous waste market, cost of environmental crime, bioremediation/biotreatment of hazardous wastes, and environmental protection advocate.

COOPERATIVE ARRANGEMENTS

The Center has two advisory committees, the State Advisory Committee and the University Water Resource 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
Alfred L. Hawkes, Director of the Audubon Society of R.I.

University Water Resources Coordinating Committee

Pei Wen Chang, Animal Pathology
Frank DeLuise, Mechanical Engineering
Reinhard K. Frohlich, Geology
Scott W. Nixon, Oceanography & Sea Grant Coordinator
James Opaluch, Resource Economics
Calvin P.C. Poon, Environmental Engineering
Leonard Worthen, Pharmacognosy

As in the past year, both committee have contributed significantly to the development and direction of the Center's program.

In Project 03 and Project S2 studying the water quality of Rhode Island lakes, there was a close cooperation between the Project principal investigators with the Water Resources Division of the R.I. Department of Environmental Management and USEPA Regional I Office at the planning stage. The project investigators were also assisted by engineers or planners of various towns where these lakes/reservoirs were located. Their guidance and information on land use practice/planning are important to these two projects.

The investigators in Project 04 received help from the Providence Water Supply Board who provided boats and manpower for field sampling. A water quality model incorporating the Scituate Reservoir water quality data will provide the PWSB a management tool to forecast impacts of watershed pollutant loadings to the reservoir.

Project 05 worked closely with U.S. Department of Agriculture, Soil Conservation Service.

Project S1 received assistant from the jewelry industry and worked closely with the Division of Environmental Coordination of the R.I. Dept. of Environmental Management, as well as the Association of Jewelry and Silversmiths of Rhode Island to develop the project objective and work scopes.

The project on information transfer worked with various groups and organizations in various phases of the project, including:

Pawcatuck Watershed Association
Town of North Kingstown
North Kingstown Land Conservancy
Girl Scouts
R.I. Dept. of Environmental Management
USEPA, Region 1 Office
Resources Conservational Development
USDA Soil Conservation Service
Narragansett Bay Project of R.I.
Rural New England
New England Interstate Water Pollution Control Commission
Connecticut Dept. of Environmental Protection
U.S. Geological Survey, Providence District Office

The Center also participated in the third year program of the 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	Undergraduate	Master's degree	Ph.D. degree	Post Ph.D.	Total
	Academic Level				
Engineering					
Environmental		2	1		3
Chemical		1			1
Plant & Soil Sci.	1	2			3
Resources Economics		1			1
	1	6	1		8

INCINERATOR ASH AND ITS LEACHATE CHARACTERISTICS IN A SIMULATED LANDFILL CONDITION

prepared for

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1 INTRODUCTION

According to the Statewide Resources Recovery System Development plan prepared by the Rhode Island Solid Waste Management Corporation (RISWMC), the Central Landfill in Johnston, R.I. will provide disposal capability for municipal and commercial waste disposal in the State, and will also provide disposal capability for the disposal of the residue from three resources recovery facilities currently being developed by the RISWMC. At the time this report is being prepared, the State may reach an agreement with the town of Johnston to continue the municipal and commercial waste landfill for five (5) more years as long as other acceptable sites can be found and be permitted elsewhere in Rhode Island. The residue of the resources recovery facilities, including the incinerator residue and ash, however, will be continually disposed of at the Central Landfill. Wehran Engineering Corporation has completed a study on the "EVALUATION OF DISPOSAL OF RESOURCES RECOVERY RESIDUE AT THE CENTRAL LANDFILL, TOWN OF JOHNSTON, RHODE ISLAND"-1987 in which different disposal alternatives were developed. Six of the seven alternatives include residue disposal until the year 2010, ranging from 5 to 20 years of service.

A literature review of residue and residue leachate characteristics was conducted by Wehran Engineering Corp. In their report, RESOURCES RECOVERY RESIDUE CHARACTERIZATION AND DISPOSAL EVALUATION, August 1986, they present the results of an analysis of published reports, studies, and other available data on the characteristics of resources recovery facility residue and residue leachate. One problem of concern is addressed in this Wehran Engineering Corp. report which pertains to the properties of incinerator bottom ash and fly ash. Incinerator bottom ash and fly ash, which comprise the largest portion of the residues, may constitute a hazardous waste requiring disposal pursuant to the requirements set forth in 40 CFR 264 "Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities," and the Rhode Island Rules and Regulations for Hazardous Waste Generation, Transportation, Treatment, Storage and Disposal. The report indicates that some incinerators produced non-hazardous fly ash and bottom ash while others produced hazardous fly ash or combined mixture of fly ash and bottom ash, e.g. the combined mixture of fly ash and bottom ash of the Saugus RESCO facility in Massachusetts is consistently found to be hazardous in terms of the lead (Pb) and cadmium (Cd) content pursuant to current EPA criteria.

Recently the United States Environmental Protection Agency (USEPA) has proposed a rule amendment to the leaching procedure "Extraction Procedure Toxicity Characteristic" (EPTC) by using a more rigorous leaching protocol called "Toxicity Characteristic Leaching Procedure" (TCLP). The newly proposed TCLP protocol uses a more acidic leaching medium 0.1N pH 2.9 acetic acid solution for moderate to high alkaline wastes which include incinerator ash. The TCLP protocol therefore has a potential of extracting more heavy metals and other chemicals from incinerator ash than the existing EPTC method. When higher heavy metals are extracted, the potential exists for the ash residue generated by resources recovery facilities to be classified as a hazardous waste. Such a classification, if adopted for nationwide application, would have significant implications for both operating and future resources recovery projects, particularly in terms of residue disposal requirements.

Leachate generation is primarily the result of infiltration of precipitation water on the landfill. Since precipitations in Rhode Island are known to be acidic, more chemicals can be expected in the leachate from landfills in the State. According to the report "ACID PRECIPITATION: SOURCE IDENTIFICATION AND ITS EFFECTS ON WATER QUALITY" By Poon, Wright and North, the pH of precipitations in Rhode Island in 1983-1984, varied from 3.81 to 5.50. Major acid components in the precipitations, include strong acids (sulfuric and nitric) up to 1.59×10^{-4} N, and week acids (H_2CO_3 and HCO^-_3) up to 4.6×10^{-4} N. These inorganic acids react with ash residue in landfill differently from organic acids such as acetic acid. Both the EPA leaching procedures (EPTC and TCLP), using acetic acid as the leaching medium, are based on a disposal model which assumes the co-disposal of residue with municipal solid waste (MSW). The acetic acid produced from MSW biodegradation enhances the solubility of heavy metals by lowering the pH while at the same time could form organo-metal complexes resulting in an increase of the metal mobility. For a ash-residue monofill scenario, i.e., landfill of ash-residue alone without MSW, it is not know if and how much acetic acid would be generated from the leachate. The acetic acid generation, if any, should depend on the organic content of the ash-residue which in turn depends on the combustion efficiency of the incinerator.

The sulfate content of the ash-residue and the sulfate content of the acid precipitation could be reduced to sulfide under the anaerobic condition in a landfill. Sulfide could form sulfide-metal complex which reduces the metal mobility.

To assist landfill designers, operators/owners, and regulators, the US Army Corps of Engineers at the Waterways Experiment Station, Mississippi has developed for EPA a computer model "Hydrologic Evaluation of Landfill Performance Model" (HELP). Climatologic, soil, and facility design data are used to compute daily, monthly, and yearly estimates of water movements across, into, through and out of landfills. By changing some of the characteristics of the designed layers, e.g., material, thickness, compaction, etc, the computer simulation is able to generate information from which it is possible to identify the optimal condition most cost effective for the design of the landfill.

2 OBJECTIVES

Before a landfill is designed, it is useful to know the physical and chemical nature of the material to be landfilled, the quantity as well as the quality of the leachate to be generated. The design engineer will be able to use the information for different design alternatives so that a cost-effective design can be selected while meeting both the federal and state regulations. Specifically the objectives of this study are:

a) To compare the lead (Pb) and cadmium (Cd) content of an incinerator ash-residue using modified EPTC and TCLP protocols.

b) To determine the physical and chemical characteristics of ash-residue and municipal solid waste used in this study, as well as their hydraulic characteristics in packed columns simulating landfills.

c) To perform quantitative and qualitative studies of leachate generation from a simulated ash-residue monofill with a Rhode Island acid precipitation condition.

d) To perform qualitative and quantitative studies of leachate generation from simulated landfills with as-residue and MSW co-disposal under the Rhode Island acid precipitation condition.

e) To calibrate the HELP Model with data obtained from the simulated landfill studies in order to use the Model to predict short term and long term leachate generations for various landfill design alternatives, including incinerator ash-residue monofil, co-disposal of the mixture of ash-residue and MSW, and co-disposal of ash-residue on top of MSW in a stratified condition.

3 HEAVY METALS IN INCINERATOR ASH-RESIDUE AND MUNICIPAL SOLIDWASTE

3-1 GENERAL

Early on in this study, it is decided to examine if or not an incinerator ash-residue can be identified as hazardous waste by an extraction procedure EPTC currently used by USEPA. An incinerator ash-residue is defined here as the mixture of residue, bottom ash, and fly ash from a resource recovery incinerator using the mass-burn technology. Under the present EPA regulation, a mixture of bottom ash, fly ash, and residue could be classified as non-hazardous if it does not exceed the EPTC limits, even if one of the ash-residue components, by itself, exhibits the characteristic of EP toxicity.

The Hazardous and Solid Waste Amendments, 1984, to the Resources Conservation and Recovery Act (RCRA) directed EPA to make changes in the EPTC to insure a more accurate prediction of leachate potential as well as identification of additional toxic characteristics of hazardous waste. The "second generation" leaching procedure, TCLP, as proposed by EPA is used to compare the results obtained from the EPTC extraction in this study.

3.2 SOURCE OF MATERIAL

The ash-residue from a mass-burn incinerator is obtained for this study. This incinerator is similar in design and in operation to the incinerator to be built in Rhode Island for RISWMC. The incinerator is equipped with acid gas air pollution control devices, using lime for neutralization purposes, making the ash-residue a highly alkaline waste. The newly proposed TCLP method calls for an additional pH adjustment step for moderate to highly alkaline wastes. The two barrels of ash-residue as received are emptied out onto a newly built wooden platform measured 8 ft. x 8 ft. The ash-residue are well hand-mixed on the platform. Four sub-samples are collected from different locations on the platform which are subsequently mixed together. This final sample is equally divided into several portions for extraction procedure, physical and hydraulic characteristic determinations. The remaining ash-residue is used for column studies with the left-over put back into the two barrels for storage.

The municipal solid waste sample is obtained by taking a core from the Central Landfill, mixed, and shipped in a barrel. The MSW as received is hand-mixed, and eight (8) sub-samples from different locations are collected. These sub-samples, each weighs approximately two pounds, are mixed together before a final sample is taken. The final sample weighs 2.92 pounds.

3.3 MODIFIED EPTC AND TCLP PROCEDURES

The EPA procedures of EPTC and TCLP are strictly followed, with one modification. In this study, large objects in either the ash-residue or the MSW sample are broken by hand. Subsequently, any material larger than one-inch in diameter is discarded before the sub-samples are taken. Grinding is carried out but structural integrity procedure is not used. All other steps such as leaching media, liquid/solid separation, use of specific extraction vessel, agitation, extraction time, and quality control requirements follow the EPTC and TCLP procedures with no change. It is safe to assume that a sample divided into two parts, extracted by the modified EPTC and TCLP procedures respectively, will be able to detect the difference in the toxicity characteristic as if both EPTC and TCLP without modification were followed.

3.4 HEAVY METAL EXTRACTION RESULTS

In addition to the modified EPTC and TCLP procedures, another extraction using de-ionized water (pH=4.95) is also carried out. The result of various heavy metals extraction from the ash-residue is presented in Table 3.1.

The result in Table 3.1 shows that of all the heavy metals analyzed, both Cd (1.20 mg/l) and Pb (11.0 mg/l) extracted by the TCLP procedure exceed their respective hazardous limits of 1.0 mg/l and 5.0 mg/l. However, the EPTC extract shows only Cd=0.85 mg/l and Pb=6.5 mg/l. While the Pb concentration still exceeds the 5.0 mg/l hazardous limit, Cd is below the limit. This result indicates that the ash-residue contains sufficient Pb in it to be classified as hazardous waste regardless which extraction protocol, EPTC or TCLP, is used. The ash-residue, however, is considered hazardous in terms of its Cd content, only if the newly proposed TCLP extraction procedure is used. It is interesting to note that the result of this study is consistent with those of other studies cited by Wehran Engineering Corp's report "RESOURCES RECOVERY RESIDUE CHARACTERIZATION AND DISPOSAL EVALUATION", August 1986 in that only Cd and Pb among other heavy metals are found in ash-residues of incinerators likely to exceed the hazardous limits.

Table 3.1 also shows the extraction results using de-ionized water. By comparison it can be seen that none of the heavy metal extract exceeds their respective hazardous limits. Although the de-ionized water has a pH of 4.95 which is equivalent to the acetic acid leaching medium of pH=5.0 in the EPTC protocol, the fact that EPTC consistently extracts more metals indicates that organic acid, i.e., acetic acid, in the leaching medium is much more efficient that the weak inorganic acids in de-ionized water. This has a strong implication on the importance of anaerobic biodegradation in a landfill, producing acetic acid and other low molecular weight organic acids which enhance the mobility of heavy metals better than the inorganic acids in acid precipitations can do to the same landfill.

EPTC and TCLP extractions are also applied to the Central Landfill MSW sample. Table 3.2 presents the Cd and Pb concentrations in MSW extracts as well as in ash-residue extracts for comparison. As expected, there are much less Cd and Pb found in the MSW sample.

4 COLUMN DESIGN AND CHARACTERIZATION OF PACKED MATERIAL

4.1 GENERAL

The main task in the present study is to apply synthetic acid precipitations into columns packed with ash-residue or acid-residue and MSW simulating landfill conditions and to characterize the leachate collected from these columns. It is the purpose of this chapter to present the column design, packed material in the columns, physical and hydraulic characteristics of the packed material. Although the column simulation of landfills is of laboratory scale only and leachate collection/analysis covers a period shorter than one year, the information on leachate amount and characteristics can be used for the calibration of a landfill performance of a landfill with different design alternatives.

4.2 COLUMN DESIGN

Three columns are used in this study. The first column simulating the ash-residue landfill consists of a plexiglass column of 5 1/2-inch inside diameter. A drainage pipe, on a 5-degree slope, is laid at the bottom under 2 feet of sand. A four foot three inch (4'-3') layer of ash-residue is packed on top of the sand layer. This column is depicted in Figure 4.1. Two other columns are built for landfill simulation of ash-residue/MSW co-disposal. Both columns are of the same construction, each made of a PVC pipe of 8-inch inside diameter equipped with a 5-degree slope drainage pipe at the bottom of a 2-ft. deep sand layer,. On top of the sand layer, each column is packed with a 4-ft.-1-inch of ash-residue/MSW. In the mixed packing column, 25 pounds of ash-residue are mixed with 75 pounds of MSW on a wooden platform 4 ft. x 8 ft. After well mixed by hand, the mixture is packed to 4 ft.-1-inch in 7 individual packings, totaling 92.06 lbs. In the stratified packing column, 69.05 lbs. of MSW are packed on top of the sand layer to a depth of 40.2-inches in 5 individual packings while 23.02 olb. of ash-residue are packed to a depth of 8.8-inches above the MSW layer in 2 individual packings. Figure 2 shows one of these two columns, with a 1/2-inch-ID PVC pipe vertically imbedded throughout the entire depth of the ash-residue/MSW layer for gas collection.

Unlike the design of the future ash-residue landfill for RISWMC, all three columns do not have the necessary double composite layers below the sand drainage layer. It is impractical to install the composite layers in columns because no leachate will be expected below these impermeable layers for a short term study. The bottom of each of these three columns therefore represents a perfect impermeable layer for the duration of the study.

4.3 CHARACTERISTICS OF PACKED MATERIAL

Before packing, the sand particles, and ash-residue are analyzed for their size and size distribution, and the MSW for its components. The results are presented in Tables 4.1, 4.2, and 4.3.

It is important to obtain accurate information on the physical and hydraulic characteristics of the packing materials in all three columns so that the computer model for landfill performance can be calibrated. These physical and hydraulic characteristics are packing density, porosity, hydraulic conductivity, water holding capacity and field capacity, as packed in each of the three columns. Porosity of the packed material in a column is measured by the water displacement method. Hydraulic conductivity is measured by a falling head method. Both water holding capacity and field capacity are measured by gravity drainage. Tables 4.4, 4.5, and 4.6 list the results respectively for columns 1, 2, and 3 representing the ash-residue column, ash-residue/MSW mixed column, and ash-residue/MSW stratified column.

The ash-residue in column 1 is packed to a density of 74.41 lb/ft^3, or 2009 lb/yd^3, in an attempt to achieve the design packing density in Wehran Engineering Corp's design. Likewise, the packing density of the MSW (46.77 lb/ft^3 or 1400 lb/yd^3) is also the result attempting to duplicate what is to be expected in the field in co-disposal. By comparison (tables 4.4, 4.5, and 4.6), the result shows that the ash-residue has a slightly higher porosity and a sightly higher hydraulic conductivity than the ash-residue/MSW mixture. It follows that the water holding capacity for the ash-residue in column 1 is less than the water holding capacity for columns 2 and 3 with ash-residue/MSW combined, by 25%.

5 EXPERIMENTS

5.1 ACID RAIN COMPOSITION

The nature of acid precipitation in Rhode Island has been studied and reported in "ACID PRECIPITATION: SOURCE IDENTIFICATION AND ITS EFFECTS ON WATER QUALITY" by Poon, Wright, and North. Based on this study, the amounts and various acid components as well as the pH of the precipitations are identified. For this study, an acid rain of a similar nature is synthesized in the laboratory. Equal amounts of nitric acid HNO_3 at 7 x10^{-5} N concentration and sulfuric acid H_2SO_4 at 7 x 10^{-5} N are mixed together. Various quantities of sodium bicarbonate $NaHCO_3$ in the concentration range of 1 x 10^{-5} N to 1 x 10^{-4} N are added to the HNO_3-H_2SO_4 acids mixture to obtain final acid rain solutions of pH 3.8 to 5.5. The synthetic acid rains are prepared fresh before the application of each acid rain event.

5.2 ACID RAIN APPLICATION

There are all together 30 separate acid rain applications to column 1 (ash-residue), and 27 separate applications to columns 2 (ash-residue/MSW mixture) and 3 (ash-residue/MSW stratified). Table 5.1 lists the dates and quantities of acid rain applications for all columns. The quantity applied is expressed in inches, varying from 0.5 to 4.0, representing light to heavy rainfalls. Each acid rainfall is applied to the column uniformly over a period of 6 hours.

5.3 START OF EXPERIMENT

Prior to the first acid rain application, each column is saturated with deionized water. Porosity and hydraulic conductivity of the different packing material in each column are determined. Subsequently, the water in the column is drained by gravity, from which the water holding capacity and field capacity are measured. The gravity drained leachate from each column is collected for analysis. The first acid rain event is then applied one day after the completion of the gravity drain. Thereafter the schedule of acid rain applications follows that listed in Table 5.1.

Leachates are collected from the three columns periodically. All leachate volumes are measured, and they are stored at 4°C for later analysis.

5.4 SAMPLING AND ANALYSIS

Only leachate samples are collected for this study. The leachates are analyzed for the following parameters:

pH
Alkalinity, mg/l, as $CaCO_3$
SO_4^{-2}, mg/l
Total sulfides, mg/l
Chloride, mg/l
Dissolved solids, mg/l
Conductivity, uhmos/cm
Chemical Oxygen Demand (COD), mg/l
Redox Potential (Eh), mV
Formate, mg/l
Acetate, mg/l
Metal: Total lead acidified (pH 2.0), ug/l (PPb)
    Total lead non-acidified ug/l
    Free lead ug/l
    Complexed lead ug/l

    Total cadmium acidified pH 2.0 ug/l
    Total cadmium non-acidified ug/l
    Free cadmium ug/l
    Complexed cadmium ug/l

The analyses of SO_4^{-2}, sulfides, and Eh indicate the degree of aerobic or anaerobic condition in the columns. Acetate and formate are the dominant low molecular weight volatile organic acids produced in the columns in the anaerobic decomposition of organic compounds in the MSW and the combustible fraction of the ash-residue. Sulfide can combine with either lead or cadmium to form complexes and therefore immobilizes the metals. On the other hand acetic acid and formic acid forming complexes with lead or cadmium increase the metal solubility and therefore enhance the metal mobility. Free metals are measurements of the metals without forming the complexes in the column.

6 EXPERIMENTAL RESULTS AND DISCUSSIONS

6.1 ASH-RESIDUE COLUMN

The ash column simulates an ash monofil condition. The results of the chemical analyses of all leachates from the ash column are presented in Table 6.1. One important characteristic of the ash leachate is that it contains large quantities of chloride and other dissolved chemicals, much more so than MSW does. This characteristic is reflected in the high concentrations of chloride, dissolved solids and conductivity found in ash leachates. By comparison, the concentrations of chloride at 24,000 to 25,000 mg/l, and dissolved solids at 43,000 to 45,000 mg/l are one order of magnitude to several times higher than the typical MSW leachate chloride concentration (25,00 mg/l) and dissolved solid concentration (2,000 to 9,000 mg/l). As a result the conductivity value in the leachate is very high. Even after 308 days, the leachate still contains high concentrations of chloride at 6,590 mg/l, dissolved solids at 13,290 mg/l and conductivity at 14,100 uhmos/cm.

The initial leachate (gravity drained leachate before the first acid rain application) has a pH of 11.02, showing the highly alkaline nature of the ash-residue with lime scrubbing removal of flue gas acid. However, the acid nature of the rainfall events quickly lowers the leachate pH. After 53 days the pH of the leachate is stabilized to 6.86 and remains relatively constant thereafter. As more acids from rainfall events and acids generated from within the ash-residue due to anaerobic biological decomposition reduce more of the alkalinity in the ash-residue, further lowering of the leachate pH is expected, but at a very slow rate.

The main concern of this study is the quantity of heavy metals, lead and cadmium, leached from an ash-residue monofil. As expected, the initial leachate before the experiment starts contains the highest amount of both Pb and Cd. The Pb content of 4,920 ug/l or 4.92 mg/l is close to but still below the 5.0 mg/l level which is the threshold limit of hazardous waste for Pb. Similarily, the Cd content in the initial leachate is 9.77 ug/l which is far below the 1.0 mg/l threshold limit of hazardous waste for Cd. Soon after the experiment starts, both the Pb and Cd contents in the leachate drop gradually. It appears that after 180 days, the Pb and Cd contents in the leachate have leveled off. Figure 6-1 depicts the change of Pb and Cd concentrations in the leachate throughout the study. It is reasonable to expect that leachate Pb concentration will remain at approximately 3.0 ug/l and Cd at 0.56 ug/l with insignificant variations over a long period of time.

The samples that are not acidified before filtration prior to analysis obviously contain less metal because some metal in the particulate form or some metal attached to particulates in the sample will be filtered out. The difference of the concentration values between C_T' (with acidification before filtration) and C_t (without acidification before filtration) therefore represents the particulate form of metal and C_t represents the dissolved form of metal. The data show that in most cases (7 out of 9 leachates) the dissolved form of Pb is 66.4% or higher (average 77.7%) of total Pb. Similarily, the dissolved form of Cd is estimated to be 91% of total Cd.

The free ionic form of Pb or Cd is determined by analyzing the metal concentration after passing the sample through a Sep-Pak column. The column removes all organic forms, assuming that the metal and acid (acetate and formate) complexes could be effectively removed by this separation technique. By comparing the C_f or concentration of the free ionic form and the C_t or concentration of the dissolved form of metals, it can be seen from Table 6.1 that the free ionic form of metal constitutes a very high percentage of the total dissolved metal. In the case of Pb the percentage is on the average of 87.6% and Cd 90.3%.

The result therefore indicates that the organo-metal complex form if exists, constitutes a very small fraction of the total dissolved form of both Pb and Cd and therefore a very small fraction of the total form of both Pb and Cd also. In fact, the complex form in most cases (sample purged from the Sep-Pak columns using an organic solvent) is undetectable. In other words both Pb and Cd in the leachate are primarily dissolved and free inonic form which should move freely once they reach the aquifer. Also the organic-metal complex forms of Pb and Cd are insignificant in quantity in the ash-residue leachate.

It is useful to examine the SO_4^{-2}, total sulfides, Eh, acetate, and formate values all together. Sulfates as SO_4^{-2} could a component of the ash-residue. The synthetic acid rain also contains SO_4^{-2}. In the anaerobic condition, sulfates are converted to sulfides. The leachate samples show the presence of sulfides from 0.82 to 2.89 mg/l. The Eh values throughout the experiment of 308 days remain to be positive varying from +16.8 to +242 mV, indicating only a slight anoxic to aerobic condition. Only insignificant amount of conversion from sulfate to sulfides can be expected in the ash-residue column. The low concentration values of acetate and formate found in the leachate throughout the experimental period also bear out this face that a strong reducing environment has not been established. Figures 6.2, 6.3, 6.4 show the histograms of parameter values of the experiment. The leachate COD decreases from 2,300 mg/l to 293 mg/l. The significant reduction COD is not reflected in the acetic and formic acid generation. This is another indirect evidence of weak anoxic condition in the column. Unless a saturated condition prevails and is maintained in the column, a strong anoxic condition can not be expected in the ash-residue monofil.

6.2 ASH-RESIDUE/MSW MIXED COLUMN

This column simulates a co-disposal condition where ash-residue and MSW are mixed and disposed of in the landfill. The mass ratio of ash-residue to MSW is 1 to 3. The results of the chemical analyses of all leachates from this column are presented in Table 6.2. It is noted that large quantitives of chloride, dissolved solids and therefore high conductivity values are found in the leachates from this column. However, by comparison with the ash column, these values are much smaller in the ash-residue/MSW column. In general only 20% to 50% of chloride, dissolved solids and conductivity values are found in the ash-residue/MSW mixed column compared to those found in the ash-residue column.

With a mass ratio of 1 to 3 of ash-residue to MSW. the pH remains stable within the range of 6.53 to 7.02, which is comparable to the leachate pH of the ash-residue column.

Since MSW contains much less Pb and Cd than ash-residue does in this study (Table 3.2), the leachate from the ash-residue/MSW mixed column also contains much less Pb and Cd throughout the experiment. By comparing Figure 6-5 and Figure 6-1, it can be seen that initially the leachate of the ash-residue/MSW mixed column contains only 88 to 167 ppb of Pb which is only 2 to 4% approximately of the Pb content of the leachate of the ash-residue column. Notice that there is a delay in the amount of Pb leached out in this column as the data show that the 21-day leachate contains 167 ppb of Pb while the initial leachate contains only 88 ppb of Pb. The Pb content in the leachate is gradually reduced to 1.2 to 1.5 ppb near the end of the experiment which is consistently lower than the 3.0 to 8.5 ppb concentration in the ash-residue column leachate. The delayed leaching action of Cd is not noticed in this column. After 150 days, the Cd concentration is near 0.1 ppb or none detectable. The data also show that insignificant amount of organo-metal complex form of Pb and Cd exists in the leachates.

The SO_4^{-2} and total sulfides results in Table 6.2 are not stable. However, the Eh values indicate that the column has established a strong anaerobic condition. There is more organic matter in this column reflected by the higher COD values in the leachates. Coupled with the strong anaerobic condition established in the column, more organic acids, i.e., formate and acetate, are produced. For the leachate samples that are analyzed for formate and acetate contents, the data show consistently higher concentrations of these two acids than that in the ash-residue column leachates. Despite the higher acetate and formate concentrations, organo-metal complex form of Pb and Cd is almost non-existent. It appears that some other factors that may initiate the organo-metal complex formation such as the presence of a catalyst may be lacking.

6.3 ASH-RESIDUE/MSW STRATIFIED COLUMN

This column simulates a co-disposal condition where ash-residue is disposed of on top of MSW layers in the landfill, assuming the final disposal constitutes a mass ratio of ash-residue to MSW of 1 to 3. The results of the chemical analyses of all leachates from this column are presented in Table 6.3.

Although this column contains the same amounts of ash-residue and MSW as in the ash-residue/MSW mixed column, the fact that the ash-residue is a separate layer on top of the MSW layer crates a different scenario resulting in different leachate characteristics. It is apparent from the data that there is a delayed purge of chloride and dissolved solids from the ash-residue and MSW by the leachates. It has been established that the ash-residue material contains more chloride and dissolved solids. The MSW layer below acts as a buffer zone that withholds the leached chloride and dissolved solids for a period of more than 107 days before the breakthrough occurs (Figure 6-12). The breakthrough of chloride and dissolved solids concurs with the increase of the conductivity value as shown in Table 6.3.

The redox potential, Eh, drops from +183 mV to -20.7 mV in the 46-day leachate and remains negative throughout the entire experiment. Obviously the column is highly anaerobic, at least in the MSW layer. However, only low sulfide content is found in the leachates. It is possible that metal sulfides precipitates are formed inside the column, immobilizing Pb and Cd and consuming sulfide at the same time. Consequently, very low sulfide content is detected in the leachate. The metal sulfide precipitates may be retained inside the column, but part of these precipitates may leave the column with the leachate. The leachates from this column do contain higher total-Pb and total-Cd relative to their respective soluble form when compared with results of the ash-residue/MSW mixed column, indicating more particulate form of Pb and Cd in the leachate. No attempt has been made, however, to identify and to quantify metal sulfides in the particulates of the leachates.

7 CONCLUSIONS

The leachate from the ash-residue column simulating an ash-residue monofil is relatively clear and odorless. It unexpectedly contains high concentration of organics in the form of COD and some low molecular weight volatile organic acids such as acetate and formate. The result indicates that the incinerator from which the ash-residue is obtained is not very efficient in the combustion of organic matter. The residue, while in storage, decomposes and produces the organic acids. The high chloride and dissolved solid contents and the COD concentration indicate that the leachate over the 308 days of study is similar in nature to a septic domestic sewage. Even in this adverse condition, the initial leachate does not contain sufficient Pb and Cd to be classified as hazardous waste. Leachates collected at later stages show significant reduction of the Pb and Cd contents. No attempt has been made to analyze the leachate for other hazardous substances such as phenol, chlorobenzene, xylene, acrylonitrile, and nitroaniline, etc.

The leachate from the ash-residue/MSW column, mixed packing and stratified packing, show similar characteristics. Because of the lesser amount of ash-residue, the leachates contain lower concentration of chemicals such as chloride, dissolved solids, and sulfate except COD. Overall the leachates are similar or stronger in organic content than a domestic sewage. The leachates are septic, colored, and odorous, more so in the stratified packing column. The Pb and Cd contents in the leachates of these two columns are lower than those found in the ash-residue column. However, other hazardous substances have not been analyzed. Therefore, the potential of finding hazardous substances from the leachate of the ash-residue/MSW co-disposal is not ascertained.

8 COMPUTER SIMULATION

8.1 OBJECTIVE

Assuming that the "Hydrologic Evaluation of Landfill Performance Model" (HELP) developed by US Army Corps of Engineers for USEPA is applicable to most landfills including the Central Landfill in Rhode Island, it is the objective to use the experimental data obtain from this study to calibrate the model followed by using the calibrated model to predict the performance of the Central Landfill for various design alternatives. Once a landfill is designed with the number and characteristics of various layers determined, the runoff, infiltration, and drainage rates can be predicted by the computer model. The landfill design engineer can select the best design, among the design alternatives, to meet his specific design objective.

8.2 CALIBRATION OF THE HELP MODEL

Since the HELP model is developed for general application to landfills anywhere, its suitability for application to a specific site depends on the availability of site specific information required as input to the model. By using columns to simulate three different landfill conditions, many physical and hydraulic characteristics of the simulated landfills are developed. By applying synthetic rainfalls simulating the Rhode Island condition and by measuring the leachate drainage rates, the HELP model is then applied to each case (column) and information such as evaporation, and runoff (SCS curve number) can be developed. Thus calibrated, the HELP model is ready for use to predict the performance of various Central Landfill design alternatives.

(1) Apply known values

Ash top layer as waste layer,	51 inches
Porosity	56.27%
Field Capacity	0.375
Wilting Point	0.24 (measured at 15 bars pressure)
Hydraulic Conductivity	272.1 inch/hr.
Evaporative Coefficien	3.3 (mm/day)$^{0.5}$

Sand layer	24 inches
Porosity	0.363
Field Capacity	0.193
Wilting Point	0.107 (measured at 15 bars pressure)
Hydraulic conductivity	43.937 inch/hr.
Evaporative Coefficien	3.3 (mm/day) 0,5

Drainage pipe at 5° or 8.75% slope

Impermeable layer (clay) 24 inches
Default values
With no leakage allowed as in the simulation column

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(2) Selected values for calibration

Soil Conservation Service (SCS) curve number CN= 70, 80, 85, 90
Solar radiation, 1617, 237 langley/day (RI min. and average)
Potential runoff Pe=Precipitation-0.2 [(1000/CN)-10]
Evaporative zone 6, 12, 18, 24, 25, 30, 34, 35, and 36 inches

(3) Monitored values

Amount of rainfall applied to column 40 inches
(amount applied is equivalent to precipitation minus runoff as there is no runoff in the column study)
Amount of drainage (leachate) collected 36.49 inches
Soil moisture contents before and after experiment, 21.83, 23.47 inches (for calculation of soil water storage before and after the calibration period)
Ambient air temperature (laboratory) 78°F

(4) Various combinations of selected values in step (2) are used, and together with information from steps (1) and (3), enter into HELP model to generate reasonable values of runoff and evaporation, resulting in obtaining the objective values of 40 inches of infiltration to the column and collecting 31 inches of drainage from the bottom of the sand layer.

The HELP model is successfully calibrated, after several trials, with the data from the ash-residue column study as follows:

> Use all known values in (1), aforementioned and select CN=85, solar radiation equals to 237 langley/day for 10 months (duration of experiment), evaporative zone=25 inches, precipitation=44 inches in 10 months, substitute the 1983 precipitation data in the program with the actual aplications of synethic precipitations (see table 5-1, schedule of Acid Rain), the HELP model generates the result shown in the computer printout-ash column. The printout shows projected results which compare vary closely with the monitored experimental results shown in Table 8.1.

Table 8.1 Comparison of HELP Model Projected Results with Monitored Experimental Results in Model Calibration, Simulated Ash-Residue Landfill

	Experiment Monitored Values	HELP Model Projected Value
Infiltration	40-in applied to column	44-in minus 4.169-in R/o =39.83-in
Soil Water Difference before & After Experiment	-1.64-in	32.77-in minus 34.40-in =-1.63-in
Drainage from Sand Layer	36.49-in	36.383-in
Evapotranspiration	40-(-1.64)-36.49=5.15-in	39.83-(-1.63)-36.38=5.08-in

Similarily, the calibration of the HELP MODEL with the Ash-Residue/MSW Mixed Column and with the Ash-Residue/MSW Stratified Column have been carried out. The results are shown in Computer Printout-Ash-Residue/MSW Mixed Column, and Computer Printout-Ash-Residue/MSW Stratified Column. Comparisons of the HELP Model projected results with the monitored experimental results in model calibration of these two columns are shown in Tables 8.2 and 8.3 respectively.

Tabel 8.2 Comparison of HELP MODEL Projected Results with monitored Experimental Results in Model Calibration, Simulated Ash-Residue/MSW Mixed Landfill

	Experiment Monitored Values	HELP MODEL Projected Values
Infiltration	36-in applied to column	38.99-in minus 3.03-in=35.96-in
Soil Water Difference Before & After Experiment	0.96-in	28.50-in minus 29.46-in=0.96-in
Drainage From Sand Layer	32.25-in	32.245
Evapotranspiration	36-0.96-32.25=2.79-in	35.96-0.96-32.245=2.76-in

Tabel 8.3 Comparison of HELP MODEL Projected Results with monitored Experimental Results in Model Calibration, Simulated Ash-Residue/MSW Stratified Landfill

	Experiment Monitored Values	HELP MODEL Projected Values
Infiltration	36-in applied to column	38.99-in minus 2.96-in=36.03-in
Soil Water Difference Before & After Experiment	0.94-in	30.10-in minus 29.16-in=0.94-in
Drainage From Sand Layer	33.02-in	32.33-in
Evapotranspiration	36-0.94-33.02=2.04-in	36.03-0.94-32.33=2.76-in

FISCAL YEAR 1991 PROGRAM REPORT

CALVIN P.C. POON, DIRECTOR

WATER RESOURCES RESEARCH INSTITUTE
THE UNIVERSITY OF RHODE ISLAND

FISCAL YEAR 1991 PROGRAM REPORT

Rhode Island Water Resources Research Institute
University of Rhode Island
Rhode Island

FISCAL YEAR 1991 PROGRAM REPORT
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by

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University of Rhode Island
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Calvin P.C. Poon, Director

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ABSTRACT

The objectives of the FY-1991 Rhode Island Water Research Institute Program are to identify policy issues and management problems of water resources in the State as well as in the New England region; to conduct research that is useful to address the issues; to obtain solutions to the problems; to transfer the information to potential users throughout the State and New England region; to educate the public about water protection, management and conservation; and to train graduate as well as undergraduate students in water resources research. Current and anticipated state and regional water problems are managing and protecting the groundwater resources from non-point pollution such as nitrate, insecticides used in farming; increase the groundwater recharge in areas where groundwater is the only source of public and private drinking water supply, particularly in the sole-source aquifer areas; understanding the chemical reactions that control the composition and quality of groundwater; and the lack of information dissemination on water quality, potential fertilizer and insecticide contamination problems, proper management approach, land use, and water conservation.

The FY-1991 program addressed many of these problems. A comprehensive nitrogen budget study in turfgrasses farming using different species, different nitrogen sources, and various applications revealed low soil water nitrate levels in the winter-spring season but much higher during the summer and fall. Hard fescue and Kentucky bluegrass exhibited highest soil nitrate and greatest leaching potential. Type of nitrogen sources also affected the soil water nitrate significantly. Potential insecticide leaching study showed that a typical turf farm may find high leaching rates of aldicarb, methamidophos, carbofuran, moderate

leaching rates of methomyl, atrazine, and very low leaching rate of pendimethalin. Indeed, aldicarb was found in community wells near turf farms in the mid-1980s. The geochemical evolution of groundwater in the Pawcatuck River Basin was characterized. Based on a laboratory evaluation of Water-rock interactions, it was found that the leachate from Narragansett Pier Granite yielded a sodium/calcium ration of 6.5 representing the early phase of weathering, and later dropped to 2.0, indicating the chemical weathering of parent material and formation of reaction products. Bicarbonate, a by product of weathering reactions, was found the dominant anion, as a result of the reaction of the interaction between carbonic acid with alumino-silicate minerals. Groundwater simulation in the proposed Big River area indicted high groundwater levels in wet season in the upland till area due to low hydraulic conductivity. However, in the stratified drift area, the flood water was drained by the Big River system resulting in low groundwater level rises. On the other hand, the decrease of groundwater level in the stratified drift area was about double of the decrease in the upland area in an extended dry season. The construction of a recharge reservoir would greatly improve the groundwater supply in the area surrounding the reservoir during a dry season. Information transfer activities include the publication of newletters, a series of research briefs (technology transfer notes), a series of seminar focusing on the application of nutrients and pesticides on agricultural lands, and the completion of a water resources curricular for high school students. The Center also worked with Rhode Island Department of Environmental Management to complete a draft of a booklet on electroflotation technology for plating waste treatment. Throughout the year, the Center worked closely with all state and federal agencies dealing with water resources in

Rhode Island, as well as New England Water Resources Center directors, the Natural Resources Science Department at the University of Rhode Island, and citizens groups on program planning, research coordination, and citizen participation.

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WATER PROBLEMS AND ISSUES OF RHODE ISLAND

The State of Rhode Island and other New England states have in the past concentrated their efforts in point source pollution control. Recently the emphasis has ben changed to the study and curbing of non-point sources of pollution. Although point sources of pollution have not been under control completely, as evidenced by the recent decision of expanding the treatment capability of three treatment plants along the Pawtuxet River in Rhode Island to include nitrogen and phosphorus removal, the state is responding to the federal directive and the availability of federal funds in channeling its efforts in non-point source pollution management, e.g. combined sewer overflow (CSO) studies, well-head protection program, and Narragansett Bay studies. CSO is a urban pollution problem while protection of drinking water supply wells in Rhode Island is principally a suburban and rural area pollution problem. Agricultural activities and land development in suburban and rural areas are causes of concern in non-point pollution.

Turf farming is extensive in the northeast, throughout all New England states. Important to the groundwater quality protection in rural areas are three issues: (1) how to manage high quality turf without impacting negatively on groundwater resources; (2) how best to utilize municipal and industrial organic wastes in turfgrass management without compromising groundwater quality; (3) how to evaluate the potential of insecticide leaching from farm land to groundwater. Since the large sod farms and recreational turf areas in southern New England require substantial quantities of fertilizer nutrients and pesticides to establish and maintain quality turf, the potential contamination and best management practice of fertilizer/insecticide applications are important issues and problems facing Rhode Island.

The Pawcatuck River Basin is classified by the U.S. Environmental Protection Agency as a sole-source aquifer. This designation underscores the importance of developing sound management and protection strategies in this area. However, without a complete understanding of the groundwater hydrology, the effectiveness of current and proposed strategies (i.e., wellhead protection areas, zoning laws, etc.) is unknown. There is a need to study and to provide information about the chemical reactions that control the composition of groundwater in the Pawcatuck River Basin aquifer.

The demands for quality water in Rhode Island puts more emphasis on groundwater supply. Withdrawals of groundwater for public use nearly doubled from 1960 to 1980. A Big River Reservoir has been proposed to augment the Situate Reservoir supply for Rhode Island but the project was canceled. However, a smaller Big River Reservoir, without taking away much wetland in the area, can be of great value for the following benefits: (1) recharging the groundwater aquifer during extended periods of low precipitation, (2) recharge the aquifer in order to attain higher pumping rates as the demand for quality water increases, (3) provide a backup system for emergency cases when other primary surface water systems cannot meet the water demands of the state. Such information will be needed by the planning decision making agencies of Rhode Island for water management in the state.

There is a large number of firms in Rhode Island that generate wastewater containing heavy metals and cyanide. Most small plating firms find metal recovery or other treatment methods used by large size firms cost prohibitive. The information of a low cost treatment system made available to the plating industry will by very useful.

PROGRAMS GOALS AND PRIORITIES

The research needs on water resources in Rhode Island and in the New England region as identified by the State Advisory Committee and the University Water Resources Coordinating Committee in October 1991 have been:

Groundwater Management

1. Economic Impact analysis of artificial recharge
2. Assessment of aquifer contaminant cleanup by geophysical or geochemical methods
3. Study of geology of Rhode Island aquifers and their effects on groundwater flow, yield, and contaminant transport
4. Development of models for highway run-off and surface water-groundwater interaction
5. Evaluation of viruses in saturated and unsaturated zones

Surface Water Management

1. Control of algae blooms by bioaugmentation (ecological engineering)
2. Cost-benefit analysis on consolidation of small water supply systems
3. Impact of water withdrawal from surface water and groundwater on wetland and streams in Rhode Island
4. Wastewater treatment: paint and powder coating removal from water, low-cost and energy efficient method for recycling of non-contact cooling water
5. Methods of recycling effluents from industrial wastewater treatment systems.

Institutional Frameworks

1. Water right concept and conflict resolution among competing water users in Rhode Island
2. Land use regulation and other watershed management practices in non-point pollution control

Technology Transfer

Water Coacervation, water resources atlas for the state of Rhode Island, and seminars of water resources research.

Guided by these research needs, the Rhode Island Water Resources Center developed its program goals to meet some of these research needs as well as to transfer the information water resources research/management/eduction to the public. Based on the quality of the proposals submitted, it was decided to concentrate the effort of research in the area of management of groundwater quality and quantity. In addition to relevance of research needs and technical competency, a reasonable budget was also a criterium in selecting the projects for FY-1991 program support.

The first project, Project 02, entitled Minimizing Nitrate Contamination of Groundwater Following Fall Fertilization of Turf, was the first year of a two-year study. Four turfgass species and five nitrogen sources were used for fall application. Clippings were collected for nitrogen analysis. Soil water nitrate was determined every two weeks and a hydrological mass balance model was used to determine nitrate leaching throughout the year. Denitrification as also determined from six-inch soil cores from each plot. Glass bell jars were used to collect and measure ammonia volatilization. Soil water nitrate levels were low in the winter-spring season but increased in the summer and fall. Clippings produces 1.15 to 1.45 g/m^2 day of dry matter with very little difference in nitrogen recovery. Water amended cores evidenced low levels of denitrification (3.9 g N/ha-day) in June but higher levels in fall (25.9 to 65.3 g N/ha-day). If turf was irrigated soon after fertilizer application, little nitrogen would be lost to ammonia volatility.

The second project, Project 03, entitled Potential Pesticide Contamination of Groundwater and Surface Water in Rhode Island, identified all community wells in Rhode Island located in areas near farm lands. Crops and pesticide application data were collected.

Soil data were provided by Rhode Island Soil Survey and amended with SESOIL soil database. Chemical parameters of target pesticides were obtained from USEPA one-liner database, NPURG database, Handbook of Chemical Property Estimation Methods, and The Pesticide Manual. Weather data for Kingston in monthly formats were created from daily weather records of the Kingston Weather Station whereas the average monthly data for Providence were included in the PCGEMS database. Model simulations showed that in the Kingston area, the leaching rates of aldicarb, methamidophos, carbofuran were high, while methomyl, atrazine had moderate leachate rates and pendimethalin was practically immobile in soil.

The third project, Project 04, entitled Geochemical Controls on Groundwater Chemistry in the Pawcatuck River Basin of Southern Rhode Island, used rock leaching experiments using both batch and column tests. The mass balance and reaction path modeling of the chemical reactions were carried out with the computer models BALANCE and PHREEQE. Results indicated that in the early phase of weathering, sodium was the dominant cation, with only minor contributions of calcium, magnesium, and potassium. The variable distribution of cations as a function of time was consistent with chemical weathering of parent material and formation of reaction products.

The fourth project, Project 05, entitled Potential Groundwater Yield of the Big River Area Including the Recharge from a Big River Reservoir, used a computer model MODFLOW and the entire Big River watershed as the boundary to simulate groundwater levels in the area. In wet season, the upland till area groundwater level would rise significantly and in dry season the stratified drift area would experience a significant decrease of groundwater level. A small reservoir in the area would greatly improve the groundwater supply in the area during the dry season.

The southern part of Rhode Island is dependent on a large aquifer network. A major concern lies in the increasing water demand and water quality degradation caused by land development, agricultural activities, and transient tourists population. There is a growing number of contaminated drinking water wells throughout the state. Important forces in establishing policy and guidelines of protection of our water resources are informed decision makers and an educated public. Research briefs, seminars, and a water resources curriculum developed for high school students were the major components of a comprehensive technology transfer program designed for disseminating information on planning strategies for water quality protection.

Sources of funding for the Rhode Island Water Reouces Center included U.S. Geological Survey, Rhode Island Department of Environmental Management, and the University of Rhode Island. The level of funding and sources for the various projects including the information transfer activities are listed in Table 1 on the following page.

Table 1 Sources and Levels of Funding
FY-1991

Project	Level	Source of Funding ending May 31, 1992
02 Minimizing Nitrate Contamination of Groundwater Following Fall Fertilization of Turf (1st yr)	$15,327	U.S. Geological Survey
	36,091	University of Rhode Island
03 Potential Pesticide Contamination of Groundwater and Surface Water in Rhode Island (1st yr)	15,685	U.S. Geolgical Survey
	27,173	University of Rhode Island
04 Geochemical Control on Groundwater Chemistry in the Pawcatuck River Basin of Southern Rhode Island (1st yr)	14,350	U.S. Geological Survey
	33,965	University of Rhode Island
05 Potential Groundwater Yield of the Big River Area Including the Recharge from a Big River Reservoir	15,660	U.S. Geological Survey
	32,032	University of Rhode Island
22a Information Transfer Activities	15,000	U.S. Geological Survey
	31,779	University of Rhode Island
22b Information Transfer Activities	1,500	Dept. of Environmental Management
01 Center Administration (including Publication of Newsletter)	28,552	U.S. Geological Survey
	58,263	University of Rhode Island
FY-1991 Total Funding:		
U.S. Geological Survey	$104,574	
University of Rhode Island	219,303	
R.I. Department of Environmental Management	1,500	

SYNOPSIS

Project Number: 02 **Start:** 06/91
End: 06/92

Title: Minimizing Nitrate Contamination of Ground Water Following Fall Fertilization of Turf

Investigators: Richard J. Hull, Plant Sciences Dept., University of Rhode Island, Kingston, RI 02881

Peter M. Groffman, The New York Botanical Garden, Institute of Ecosystem Studies, Box AB, Millbrook, NY 12545-0129

COWRR: 05B, 05G **Congressional District:** 2nd, R. I.

Descriptors: Ground water pollution, Turfgrasses, Sludge disposal, Land application, Nitrates, Organic Wastes, Aquifer, Fertilizers

Problem and Research Objectives:

Two major water quality problems in the suburban Northeast are being addressed by this research. First, how to manage high quality turf without impacting negatively on ground water resources. Second, how best to utilize municipal and industrial organic wastes in turfgrass management without compromising ground water quality. The large sod farms and recreational turf areas in southern New England require substantial quantities of fertilizer nutrients and pesticides to establish and maintain quality turf. At the same time, near-by municipal sewage treatment facilities and various industrial and agricultural enterprises produce large quantities of nutrient rich sludges or organic wastes. These wastes, when composted to destroy pathogens and generate an easily handled material, can be utilized to meet the nutritional needs of turfgrasses. In this way, a waste disposal problem and a turfgrass management need are resolved together.

For several sound agronomic reasons, most nitrogen fertilizer is applied to turf during late summer and fall. Several researchers have demonstrated that fertilizer nitrogen is most likely to leach as nitrate into ground water when applied to turf in the fall. Organic nitrogen sources generally are less likely to promote nitrate leaching, however, during heavy precipitation in the fall they too can allow nitrate to leach from turf. Long established turf areas tend to accumulate nitrogen in the plant-soil complex and when nitrogen mineralization exceeds absorption by roots, nitrate accumulates in the soil solution and substantial leaching can occur. This is most likely to happen in the fall. To resolve this problem, comprehensive nitrogen budgets must be determined for several turfgrasses managed with fall applied nitrogen comparing several nitrogen sources and times of application.

The primary objective of this research is to evaluate the relative impact of several turf management variables on the potential for nitrate leaching to ground water. Variables being considered include, turfgrass species (4), nitrogen sources (6) and times of fall application (2). Secondary objectives include constructing comprehensive nitrogen budgets for each combination of management variables (48). Factored into these budgets will be quantitative estimates of nitrogen losses due to nitrate leaching, ammonia volatilization, denitrification, and clipping removal. Nitrogen accumulation within the turf-soil system will also be determined as will estimates of nitrogen additions in rainfall.

Methodology:

Field plots used for this study were seeded on June 20, 1985 and consisted of four turfgrass species: 'Georgetown' Kentucky bluegrass, 'Jamestown' Chewings red fescue, 'Repell' perennial ryegrass, and 'Scaldis' hard fescue. Prior to 1990, these plots received minimal fertilization, were never irrigated and received a spring herbicide application to control broadleaved weeds. The six nitrogen sources compared in this study are summarized below:

Nitrogen Source	Analysis	Type of Material
	% N-P_2O_5-K_2O	
Coron	28-0-0	Soluble methylene urea
Earthgro lawn food*	8-2-4	Composted manures and leaves
IBDU	31-0-0	Slow-release urea based polymers
Milorganite	6-2-0	Digested municipal sewage sludge
S-coated urea**	44-0-0	Urea made less soluble in S coating
Urea	46-0-0	Readily available soluble N source

* Applied to plots that received Sustane the previous fall.

** Replaced by Earthgro cow manure compost (2-1-1) in spring 1992

These materials were applied at 2.5 lbs. N/1000 sq-ft on September 3 or November 19, 1991. Some had been applied at the same rate in early or late November, 1990. To maintain turf of good quality, plots received the same materials at 1.0 lb N/1000 sq-ft on June 11, 1991 and June 15, 1992.

Clippings were collected from a standard area of each plot prior to every fourth mowing. The clippings were dried, weighed, ground in a Wiley mill, and analyzed for total nitrogen using a micro-Kjeldahl procedure. From these values, total nitrogen removal in clippings was estimated. Soil water nitrate was determined every two weeks from water samples recovered in suction cup lysimeters placed two feet in the soil in all plots of two replications (96 plots). Using a hydrologic mass balance model, water percolation through the turf was determined and based on soil water nitrate levels, nitrate leaching was estimated. Leaching was estimated throughout the year. Denitrification was measured following fertilizer applications in 1991 and 1992. Six-inch soil cores were removed from each plot, incubated in an acetylene atmosphere and assayed for nitrous oxide, N_2O. The same cores were incubated with acetylene in water or water containing 100 ppm NO_3-N. N_2O production was assayed to estimate denitrification potential under ambient or elevated nitrate levels.

Beginning in June 1992, ammonia volatilization was measured 24 hours after fertilizer application. Six-inch diameter circles of turf were enclosed in glass bell jars and the atmosphere within the bar circulated through a 0.1 M boric acid solution to trap all ammonia released from the turf. Previous studies have shown that maximum ammonia volatility is observed 24 hours after applying nitrogen fertilizers. Also commencing in 1992, turf quality scores were taken from all plots each month between April and October.

Principal Findings and Significance:

Soil water nitrate levels were <1.0 ppm under all turfgrasses during the winter-spring season of 1991 but increased during the summer and fall. Hard fescue and Kentucky bluegrass exhibited highest soil nitrate and greatest leaching potential. Soil water nitrate was greatest under turf fertilized with the Earthgro lawn food, sulfur-coated urea (SCU) and urea. IBDU, milorganite and methylene urea resulted in lower soil water nitrate levels and were less promotive of nitrate leaching. Early September applications resulted in significantly greater nitrate leaching potential than late November fertilization.

During the 1991 growing season, hard fescue produced clipping dry matter at a rate of 1.45 $g/m^2/day$ which was significantly greater than 1.15 $g/m^2/day$ of the least productive perennial ryegrass. There were no significant differences in the nitrogen recovery rates of the four grasses. Urea and SCU promoted greater clipping yields than the other four nitrogen sources while IBDU produced the least clippings but not significantly different from Earthgro Lawn Food or Coron methylene urea. Clippings recovered significantly more nitrogen from urea and SCU than from the other four materials. The major differences among nitrogen sources occurred during April and May harvests.

Denitrification measured one week after the June, September and November fertilizations, was very low in unamended soil cores. Water amended cores evidenced low levels of denitrification (3.9 g N/ha/day) in June but higher levels in September and November (65.3 and 25.9 g N/ha/day respectively). Water plus nitrate amended cores exhibited ten-fold greater denitrification rates in September than in June or November. Elevated soil water nitrate in late summer along with a favorable soil environment may explain the greater potential for denitrification at that time. Turfgrass species and nitrogen source did not significantly influence denitrification rates at any time.

Ammonia volatilization measured 24 hours after fertilizer application on June 15, 1992 was highly variable and ranged from 4.5 to 0.7% of the nitrogen applied. Milorganite and urea exhibited the greatest ammonia loss with Earthgro Lawn Food and IBDU the least. Perennial ryegrass tended to lose more nitrogen to ammonia volatility while Chewings fescue lost the least. High variability among observations rendered these differences non-significant at the 5% level. A high degree of patchiness in ammonia release from turf thatch may account for this variability. It appears that, if turf is irrigated soon after fertilizer application, little nitrogen will be lost to ammonia volatility.

SYNOPSIS

Project Number: 03

Title: Potential Pesticide Contamination of Groundwater and Surface Water in Rhode Island

Investigators:
Calvin P.C. Poon, University of Rhode Island, Kingston, R.I.
Wm. Michael Sullivan, University of Rhode Island, Kingston, R.I.

COWRR: 05-B Sources and Fate of Pollution

Congressional District: Second

Discriptors: Pesticides, Fate of Pollutants, Model Studies, Farms

Problems and Research Objectives:

Non-point sources of pollution have become a major concern of water quality problems in Rhode Island as well as in the Northeast region. The magnitude of non-point pollution and its effects on groundwater and surface water have not studied to the same extent as in point source pollution. Other than the conventional pollutants such as organics, suspended solids, and coliforms, very little information is available on non-point source toxic substances.

Pesticides are used extensively in agricultural lands to control annual grasses, broadleaf and sedge weeds, fungus, on crops and for wood or soil treatment. They are used on non-cropped industrial land and on lawns as well. Runoffs and leachate can carry pesticides to surface water and groundwater. The recent national survey of sampling in many states revealed pesticide contamination of groundwater. Because of the large numbers of drinking water wells in Rhode Island, an extensive sampling analysis program could be cost prohibitive. The objective of this project is to use a predictive model to screen the community drinking water wells throughout the State. The model can be applied to scenarios or areas where particular combinations of pesticide applications, climate, water management, and soil characteristics so that the potential hazard to groundwater contamination can be ascertained. The use of this approach can result in a more effective sampling program where efforts of sampling can be directed to wells with the greatest potential hazards.

Methodology:

The project selected PCGEMS as the principal computer model for predicting the potential hazard areas of groundwater with pesticide contamination. Long-term projection of pesticide migration in soil, and three-dimensional transport of pesticide once it reached the groundwater, were simulated for different pesticides and their application rates under different site-specific soil and climate conditions. Soil data were obtained from Rhode Island Soil Survey, NPURG, and built-in SESOIL database. Sources of chemical data included USEPA one-liner data base of some eight hundred pesticides; NPURG database; Handbook of Chemical Property Estimation Methods; and the Pesticide Manual. Monthly weather data according to the input formate required by the SESOIL program for Kingston were created from the daily weather data in Kingston while Providence climate data for other areas were obtained from the PCGEMS weather database. Pesticides used and historical application rates for Kingston for the past twenty years were reconstructed from information given by the University of Rhode Island Agricultural Extension Service. The wellhead protection program of the Rhode Island Department of Environmental Management provided the location and size of aquifers of the community drinking wells. All necessary input files were then constructed for simulation.

Accomplishment to date:

The work in the first year of a two-year project resulted in large quantity of data collected on soil characteristics of areas with community drinking wells and nearby farm lands, crop type, pesticides used and application schedule, chemical characteristics, weather data.

The first group of community drinking wells studied was the University of Rhode Island field K5 with Enfield silt loam. A history of 17 years of pesticide application was reconstructed, with a variety of crops rotated over the years. A total of 12 different pesticides were used but only 7 pesticides had complete data necessary to enter the simulation program. Of these 7 pesticides, only 5 of them had any potential of leaching into the soil column below the organic layer (64-cm depth) and further migration to groundwater below. The result is presented in the following table:

Table 1: Pesticide and Its Peak Concentration in Soil Water Below 64 cm Depth

Pesticide	Peak Conc.in Soil Water ug/ml	Time (month)
Aldicarb	6.49	6
Methamidophos	0.481	2
Methomyl	0.198	12
Carbofuran	0.141	4
Atrazine	0.0130	6

The data in Table 1 indicates that Alicarb was the most mobile of the pesticides found in the simulation study. Methamidophos and Methomyl also had relatively high migration rates while Carbofuran and Atrazine had only moderate rate of leaching into the soil column below the organic soil. Pendimethlain (not listed in Table 1) was not found at all under the organic soil layer, indicating that it was extremely immobile.

The next step in assessing the potential hazard of these fast migrating pesticides in contaminating drinking water wells is to use the AT123D model to simulate the transport of pesticides towards the wells from the location they enter the aquifer. Comparing the potential concentration in well water and the drinking water standards will give a clear picture of pesticide contamination in various locations in Rhode Island.

SYNOPSIS

Project Number: 04

Start: 06/91
End: 06/92

Title: Geochemical Controls on Ground-Water Chemistry in the Pawcatuck River Basin of Southern Rhode Island

Investigators: Anne I. Veeger, University of Rhode Island, Kingston
O. Don Hermes, University of Rhode Island, Kingston

COWRR: 02 K Chemical Processes

Congressional District: Second

Descriptors: Groundwater, geochemistry, chemical reactions, water quality, metals, computer models

Problem and research objectives:

This study provides information about the chemical reactions that control the composition of ground water in the Pawcatuck River Basin ground-water reservoir. These data are useful for describing ground-water flow paths, identifying recharge areas and the degree of interaction between surficial and bedrock aquifers, and for predicting the impact of chemical and physical stresses on the system. In effect, a more accurate description of the aquifer system will be obtained by coupling these hydrochemical data with the available hydrologic data.

The chemical composition of ground water is a function of the origin and history of the aqueous solution. Solutes in recharge water may be derived from numerous sources, including salts in rainwater, dry fallout, organic reactions in the soil zone, and anthropogenic inputs. Following recharge, however, the chemical evolution of ground water is the result of water-rock interactions. Because the composition of an aqueous solution moves toward chemical equilibrium with the surrounding materials, it is possible to use changes in the chemical composition of ground water to delineate general flow patterns and identify the mixing of waters from different sources. The use of these hydrochemical data to supplement hydrologic information can lead to a more complete understanding of flow dynamics in an aquifer.

This approach is particularly useful in complex and heterogeneous aquifers such as those found in Rhode Island. The stratified glacial deposits that form the major ground-water reservoirs in the State are complex layered deposits with both lateral and vertical heterogeneity. Although water level measurements can be used to determine the direction of the hydraulic gradient, the presence of confining or semi-confining layers may deflect ground-water flow. Similarly, ground-water in the underlying crystalline bedrock is restricted to flow along fractures, which may not be parallel to the hydraulic gradient. In addition, glacial aquifers, which receive natural recharge along their length, may be affected by induced surface-water infiltration near high-volume wells or seasonal recharge-discharge variations. In these settings, physical measurements may be inadequate for a complete description of the system, but chemical data can provide the additional information necessary for evaluating the dynamics of the aquifer system.

In this study we characterize the geochemical evolution of ground water in the Pawcatuck River Basin. This research is being accomplished over a two year period. This synopsis covers the first phase of research in which the laboratory evaluation of water-rock interactions is being completed. To accomplish this, the following objectives were pursued:

1) Characterization of the solutes derived from water-rock interactions involving the major bedrock units in the Pawcatuck River Basin: Hope Valley Alaskite Gneiss, Narragansett Pier Granite, Scituate Granite and Ten Rod Granite Gneiss.

2) Characterization of the solutes derived from unconsolidated stratified glacial deposits in the Pawcatuck River Basin.

3) Development of mass-balance and reaction path models to simulate the chemical evolution of ground water in the river basin.

The second phase of research will focus on the field application of these results.

Methodology:

Sample Preparation and Experimental Set-up

Samples of rock were collected from outcrops of each of the major rock units in the river basin as stated above. Samples of unconsolidated glacial material were collected from sand and gravel quarries. The mineralogical composition of each sample was determined by standard microscopic analysis of thin sections and the chemical composition was determined in the Department of Geology's geochemistry laboratory by x-ray fluorescence (Kevex 0700 XRF).

Following mineralogical identification, each rock sample was crushed into 1 to 2 mm grains and split into 2 equivalent portions. One portion was sorted into its mineral components while the other was preserved as a whole-rock sample. Each of these samples was then crushed into 125-250 micron size particles for use in rock leaching experiments. The crushed samples were wet filtered with acetone to remove the fraction finer than 125 microns.

The chemistry of water in contact with the crushed samples was monitored over time in both batch and column experiments. Batch experiments were completed in 1 liter polypropylene bottles with a water-rock mass ratio of 1:50. Column experiments were conducted in liquid chromatography columns packed with crushed rock. Water circulation was maintained with a peristaltic pump using the same volume of water as the batch experiment. Both experimental setups were conducted at 25°C and at equilibrium with atmospheric carbon dioxide.

The concentration of solutes, pH and conductivity was monitored throughout the course of each experiment. 10 ml alequots of water were collected at increasing time intervals until pH has stabilized (approximately 2000 hours). Each sample was analyzed for calcium, magnesium, sodium, potassium, chloride, and sulfate. Alternate samples were analyzed for alkalinity and silica because of the greater volume requirement for these analyses.

Numerical Modeling

Mass-balance and reaction path modeling of the chemical reactions will be completed with the computer models BALANCE (Parkhurst et al., 1982) and PHREEQE (Parkhurst et al., 1980). BALANCE is used to determine the amount of reactants and/or products that must dissolve and/or precipitate to account for the observed water chemistry. Chemical analysis of the mineral constituents provides the data for the reactant phases. The chemical composition of the products may be determined analytically if present in sufficient quantities, but usually must be surmised from the composition of the reactants and the resulting water chemistry. Because the chemistry of both the reactants and the aqueous solution are known, BALANCE can be used to calculate the stoichiometry of the weathering product.

PHREEQE is an ion speciation model that can simulate the reaction between water and specified solid phases, the mixing of water from different sources or simply calculate the saturation indices of a water with respect to a suite of minerals. In this phase of the proposed research, PHREEQE will be used to verify the thermodynamic validity of the mass-balance calculations.

Principal finding and significance:

The column experiments for each of the rock types have been completed, and the batch experiment for the Narragansett Pier Granite has been completed.

Chemical analyses of these leachates is ongoing and will be completed along with the chemical modeling over the summer of 1992. Data obtained to date from the Narragansett Pier Granite indicates that in the early phase of weathering, sodium is the dominant cation, with only minor contributions of calcium, magnesium, and potassium. The leachate produced during this early phase is characterized by a sodium to calcium ratio in excess of 6.5. The sodium is probably attributable to reactions occurring on the surface of easily weathered sodic feldspars. At late time however, preferential release of sodium diminishes producing a leachate with a sodium to calcium ratio of 2.0. The variable distribution of cations as a function of time is consistent with chemical weathering of parent material and formation of reaction products. Bicarbonate, a byproduct of weathering reactions, was the dominant anion in all but the earliest samples collected. This finding is consistent with weathering reactions occurring as a result of the interaction between carbonic acid with alumino-silicate minerals. These early findings suggest that the laboratory microcosms are able to simulate weathering reactions that may be occurring in the bedrock and glacial aquifers of Rhode Island. Completion of the chemical modeling will provide the foundation needed in the second phase of this study for the interpretation of the chemical composition of ground water collected from both glacial and bedrock aquifers in the Pawcatuck River Basin.

PROJECT SYNOPSIS

Project Number: 05 Start: 06/91

End: 06/92

Title:

Potential Groundwater Yield of the Big River Area Including the Recharge from a Big River Reservoir.

Investigators:

George Tsiatas and Sau-Lon James Hu, University of Rhode Island, Kingston, RI.

COWRR: 04B Congressional District: Second

Descriptors:

Groundwater, Groundwater Recharge, Reservoirs, Reservoir Yield, Numerical Analysis, Recharge Basin

Problem and Research Objectives:

The Big River watershed, with an approximate area of 30 square miles is located primarily in the Town of West Greenwich, Rhode Island. This area was a long time candidate for a surface reservoir which was expected to provide a supplemental water supply for the Providence Metropolitan area as well as for the surrounding communities. Following a lengthy investigation on the suitability and environmental impact of such a reservoir, the project was abandoned. However, the possibility of a smaller reservoir to be used for recharging the groundwater supplies in the area is still viable. The objectives of this study are to investigate the ground-water yield in the Big River area and to explore the effect of a reservoir recharging the groundwater using a numerical model verified through field data. The effects of a flood season, a drought season, pumping withdrawal and different sizes of the Big River Reservoir on the ground-water levels are investigated.

Methodology:

The powerful computer program MODFLOW is used to model the groundwater level in the Big River area. The Big River watershed is chosen to be the boundary of the model. It is approximately 40,000 ft long in the east-west direction and 39,000 ft long in the north-south direction. The area is divided into a rectangular grid with a grid distance of 1000 ft. Since the glacial deposits overlying the bedrock are thin and due to lack of detailed material profile information, a one layer horizontal two-dimensional model is used to simulate the physical problem. Parameters used in the model, such as hydraulic conductivity, bedrock elevation and recharge rate, are all estimated from measured data. The numerical model is first calibrated to a steady-state solution by the field data of ground-water levels under natural conditions. By using the steady-state solution as the initial hydraulic heads, a series of ground-water development alternatives are investigated regarding to the effects of wet season, dry season, pumping wells, construction of a reservoir and the size of the reservoir.

Principal Findings and Significance:

The simulation results of the ground-water levels in the Big River area can be concluded as follows:

- The long-term steady-state ground-water levels are of acceptable accuracy compared with the field data.

- During a wet season, the ground-water levels increase quite a lot in the upland till area due to the low hydraulic conductivity while in the stratified drift area, the ground-water levels do not increase much because the flood water is drained by the river system. Hence, the ground-water supply in the upland till area is mainly provided by precipitation recharge.
- In an extended dry season, due to the reduced storage of the river system, the decrease of ground-water level in the stratified drift area is about double of the decrease in the upland area where the hydraulic conductivity is low. It can be inferred that the river system in the Big River area is very important for to the ground-water yield.
- The hypothetical pumping wells mainly affect the ground-water levels of the surrounding cells. Pumping wells located in areas of low hydraulic conductivity may cause the ground-water to dry easily.
- The construction of a reservoir will improve the condition of ground-water supply in the area surrounding the reservoir, especially during a dry season. The results show that the size of the reservoir is an important factor to the local ground-water system. Since the thickness of the aquifer is very thin and bedrock elevations are higher than the water surface of the reservoir in most of the surrounding area, the reservoir does not influence much the ground-water system in the upland area.

INFORMATION TRANSFER ACTIVITIES

Technology Transfer Project
Synopsis

Project No.: 22 Information Transfer Activities

Title: Technology Transfer: Water Protection, Management, and Conservation

Investigators:
Thomas P. Husband, Ph.D., Department of Natural Resources Science, URI
Alyson McCann, Department of Natural Resources Science, URI
Calvin P.C. Poon, Ph.D., Department of Environmental Engineering, URI

COWWR: 10-B,C,D

Congressional District: 2nd, RI

Key Words: Nonpoint Pollution Sources, Land Use, Ground Water Pollution, Water Quality, Water Use, Watershed Management

Problem and Research Objectives:

Two major sources of drinking water, surface and groundwater, exist in Rhode Island. The Scituate Reservoir serves approximately 60 percent of the state, with a safe yield capacity of 78 million gallons per day (MGD). The southern part of the state is dependent on a large aquifer network. A major concern lies in the pressures of increased water demand and water degradation caused by accelerated urban development. Research conducted by the Rhode Island Department of Environmental Management (DEM) presented in The Groundwater Protection Strategy cites a growing number of contaminated drinking water wells throughout the state. Such nonpoint sources, such as agricultural and urban runoff, add to pollution loading. Protection of these sole-source water supplies is critical to meet future demands for potable water. Important forces in accomplishing this protection are informed decision makers and an educated public. A comprehensive Technology Transfer Program can target key groups and disseminate information on planning strategies for effective land use and water protection.

The specific objectives of the 1991-1992 information transfer activities were to produce: 1. a series of research briefs (Technology Transfer Notes); 2. the completion of a water resources curriculum; and 3. a series of lectures focusing on the application of nutrients and pesticides to agricultural lands. The synopses for each of these activities follow:

1. Technology Transfer Notes:

Three Technology Transfer Notes were published through the Department of Natural Resources Science. The titles of these publications are: Minimizing Nitrate Leaching from Turf by Richard Hull; Feasibility Study of the Use of Composted Municipal Sewage Sludge as a Landfill Cover Material by Leon T. Thiem, George E. Veyera and Daniel R. Wise; and Southern Rhode Island Lake Quality Assessment Program; 1989-1990 by Arthur J. Gold, Bonnie Lamb, Calvin P.C. Poon, and Christopher Deacutis. In addition, further water resources information was disseminated through the publication of a fact sheet, Water Conservation In and Around the Home by Alyson McCann and Thomas P. Husband. This fact sheet is being used as a center piece for a workshop on water conservation which will be conducted this summer. A press release indicating the availability of this fact sheet has been sent to all newspaper in the state. In addition, all fact sheets and technology transfer notes have been distributed to district offices of the RI Cooperative Extension Service for further dissemination to the public.

2. Water Resources Curriculum:

A prototypic computer program for students in grades 5-9 entitled "Water, Our Irreplaceable Resource" was developed and completed. The computer program and its accompanying materials reflected current technology and information gained through the research activities of the URI Water Resources Center. Teacher training workshops, including the Narraganset Bay Classroom, were conducted. An extensive teachers' manual also was developed, published, and distributed to the participants of the workshops, as well as to professional educators at the RI Cooperative Extension and the W. Alton Jones Campus. The curriculum is slated for future workshops and is being adopted by several schools in Rhode Island; schools in other states have also indicated that they will adopt the curriculum.

3. Public Informational Lectures:

A series of lectures on water quality issues were presented by the Department of Natural Resources Science. Lectures included: Rhode Islands Future Water Supply by Mr. Christopher Modisette of the Providence Water Supply Board; Toward Nutrient Self-sufficiency in Turfgrass Management by Dr. Richard Hull of the Department of Plant Science at the University of Rhode Island; and Assessing Natural Resource Damages from Oil Spills by Dr. James Opaluch of the Department of Resource Development at the University of Rhode Island. The last two speakers were PI's on grants with the URI Water Resources Center, and used these lectures to disseminate information gained in their research activities. All lectures were advertised broadly and certain professionals in RI were targeted through a mailing.

In addition to the activities aforementioned, the information transfer effort included the publication of a newsletter four times a year reporting and discussing some relevant water resources issues of Rhode Island and other regions as well as other parts of the world. Also included in the information transfer project was the comletion of a draft of a booklet entitled "Electroflotation" targetting state regulating agencies, Providence chamber of Commerce and the electroplating industry who could use the information concerning a low cost treatment technology suitable for small plating firms in the area. It is anticipated that the booklet, once the approval of Rhode Island Department of Environmental Management is secured, can be published for wide distribution.

COOPERATIVE ARRANGEMENTS

The Water Resources Center at the University of Rhode Island has two advisory committees, namely the State Advisory Committee and the University Water Resources Coordinating Committee. The membership has been changed in the past year, reflecting the recent interest and availability of water resources experts in Rhode Island.

State Advisory Committee

Falcone, William	Water Resources Board
Greiner, Ellen	League of Women Voters
Hawkes, Alfred L.	Audubon Society of Rhode Island
DeLima, Virginia	U.S. Geological Survey
Meyer, Henry	Kingston Fire District
Miller, Scott	Office of System Planning, Dept. of Administration
Rose, Vincent	Save the Bay
Salomon, Erich W.	Armbrust Chain Co.
Scott, Elizabeth	Office of Environmental Coordination
Stuart, Kristine	U.S. Dept. of Agriculture
Varin, Daniel W.	Dept. of Administration

The state advisory Committee is consisted of leading water resources officials of the state and federal agencies as well as representatives from prominent citizen groups and manufacturers.

The other committee is the University Coordinating Committee, consisting of faculty members of the University of Rhode Island from various colleges and the director of the Sea Grant program. Each member has a significant contribution to academic and research programs related to water the resources area.

University Coordinating Committee

Cain, J. Allen	Professor and Head of the State Geologist Office
DeLuise, Frank	Professor, Mechanical Engineering
Frohlich, Reinhard K.,	Professor, Geology
Gold, Arthur	Associate Professor
Miller, Robert H.	Dean, College of Resources Development
Nixon, Scott	Professor, Coordinator of Sea Grant Program
Calvin P.C. Poon	Professor, Environmental Engineering

The two committees met and discussed water resources issues and research priorities for the FY-1992 State Water Research Institute Program on October 30, 1991. As a result of the discussion and suggestions from the committee members, the research priorities were established as listed on page 3 of this report. Both committees also reviewed and ranked research proposals, made comments and suggestions of proposal alterations. They also served as points of contact to collect and to disseminate information to various groups of audience.

Project 02 worked closely with U.S. Department of Agriculture, Soil conservation Service and with the Cooperative Extension Service at the University of Massachusetts, as well as the commercial turf producers and landscaper managers in Rhode Island.

Project 03, by nature of its work, had close cooperation with the Agricultural Stabilization and Conservation Service, Soil Conservation Service, the GIS group and the Groundwater/ISDS Division of the R.I. Department of Environmental Management, as well as the agricultural extension service at the University of Rhode Island.

Project 04 worked closely with USGS subdistrict office at the project development stage, and **Project 05** with the Water Resources Board of Rhode Island.

The project on information transfer worked with high school teachers for a water resources curriculum development as well as a teacher's manual.

PUBLICATIONS

1. Dissertations	Field of Study	Supporting Project #
Liu,Haibou, 1992, Evaluating Three Turf Grasses for N, P, and K Nutrient Uptake Efficiency, Ph.D. thesis University of Rhode Island Plant Science, Kingston, R.I.	Plant Science	02 (FY-85) 02 (FY-86) 03 (FY-88)
2. Conference Presentations		
Poon, C.P.C. et al., 1991, Efficient Water Use: A Key Factor in Rate Structure Design of a Wastewater Management System. Seminario Internacional Sobre Uso Eficiente del Agua, Mexico City, Oct., 1991	Civil/Environmental Engineering	06 (FY-84) 06 (FY-85) (partially supported)
Hull, R.J., N. Jackson, et al., 1991 Organic Nitrogen Sources for Turf: Nitrate Leaching & Disease Suppression Am. Soc. Agronomy Conf., Denver, Oct. 27, 1991.	Plant Science	02 (FY-1991)
Lin, H., R.J. Hull, et al., 1991 Comparative Nitrate-N Leaching from Cultivars of Three Cool-Season Turfgrasses, Am. Soc. Agronomy Conf. Denver, Oct. 27, 1991.	Plant Science	02 (FY-1991)
Liu, R.J., H. Liu, et al., 1991 Nitrogen Use Efficiency of Turfgrasses, Am. Soc. Agronomy Conf. Oct. 27, 1991.	Plant Science	02 (FY-1991)
3. Other Publications		
Tsiatas, G. and J. Hu, 1992, Potential Groundwater Yield of the Big River Area Including the Recharge from a Big River Reservoir, Completion Report, R.I. Water Resources Center, University of R.I., Kingston, R.I.	Civil/Environmental Engineering	05 (FY-1991)

Poon, Calvin P.C., 1991, Fiscal Year Year 1991 Program Report, R.I. Water Resources Research Center, URI Kingston, R. I.	Water Resources	01 (FY-1991)
Hull, R.J., 1992, Minimizing Nitrate Leaching from Turf, Turf Notes 2(6):1-4	Plant Science	02 (FY-1991)
Feasibility Study of the Use of Composted Municipal Sewage Sludge as a Landfill Cover Material, Technology Transfer Notes, No.92-3	Civil/Environmental Engineering	22 (FY-1991)
Southern Rhode Island Lake Quality Assessment Program, 1989-1990, Technology Transfer Notes, No.92-1	Natural Resources Science/Water Resources	22 (FY-1991)
Minimizing Nitrate Leaching from Turf, Technology Transfer Notes, No. 92-2	Plant Science	22 (FY-1991)
Water Conservation in and Around the Home, Natural Resources Facts, Fact Sheet No. 91-2	Natural Resources Science	22 (FY-1991)
Walsh, T.J. et al., Water, Our Irreplaceable Resource, A Computer-Based Curriculum for Grades 5-9 with an attached software, 1992.	Natural Resources Science/Water Resources	22 (FY-1991)
Poon, C.P.C. and E. Pepper, Electro-flotation, An Attractive Alternative of Wastewater Treatment for the Plating Industry, 1992	Civil/Environmental Engineering	22 (FY-1991) S1 (FY-1990)

TRAINING ACCOMPLISHMENTS

	Academic Level				
Field of Study	Undergraduate	Master's Degree	Ph.D. Degree	Post-Ph.D.	Total
Engineering					
Environmental		2			2
Ocean		1			1
Geology		1			1
Plant Science	2		1		3
Natural Resources Science		1			1
	2	5	1		8

COMPLETION REPORT FY-1992 PROGRAM

TOXIC ORGANIC CHEMICALS IN RHODE ISLAND GROUNDWATER: CONTAMINANT FATE & TRANSPORT

Amy P. Gamerdinger

1892

WATER RESOURCES RESEARCH INSTITUTE
THE UNIVERSITY OF RHODE ISLAND

Final Report

Project Number: 05

Start: June 1, 1992
End: May 31, 1993

Title: *TOXIC ORGANIC CHEMICALS IN RHODE ISLAND GROUNDWATER: CONTAMINANT FATE AND TRANSPORT*

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Focus Categories: TS

Congressional District: Second

Descriptors: Fate of Pollutants, Organic Compounds, Contamination, Toxic Wastes, Groundwater Pollution, Groundwater Quality

Research Objectives:

The primary objective of this two-year project is to describe the fate and transport of organic pollutants in the presence of organic solvents and natural organic material that is present in the soil-solution. Secondary objectives include modifying mechanistic process descriptions which are used to characterize environmental fate processes and providing a means for incorporating these descriptions into currently existing environmental fate models. Results of the initial experiments are presented here and will be expanded upon in the final project report.

Relevance:

An estimated 24% of Rhode Island's population obtain their drinking water supply from groundwater, thus, preserving groundwater quality is important for human and environmental health. Organic chemicals are among the principal contaminants, from a variety of sources, which are found in Rhode Island groundwater.

An understanding of the fate and transport of organic chemicals in soils and groundwater sediments is necessary for addressing several groundwater quality issues such as: estimating the travel time of potential groundwater pollutants from the point of release to drinking water supply wells, the amount or concentration of the contaminant that will ultimately be present in the wells, and contaminant removal rates from soil and groundwater when cleanup and remediation strategies are employed.

Most of our current understanding of organic contaminant behavior in soil and groundwater is based on studies conducted for a single chemical in a completely aqueous system. In the environment, we often have complex mixtures of chemical contaminants in aqueous systems where organic solvents are also likely to be present. We know that the fate and transport of an organic chemical will be influenced by the presence of other organic chemicals and solvents. In order to properly assess organic pollutant fate and transport from waste sites or leaking fuel storage tanks, we need to consider contaminant behavior in the presence of other chemicals, such as organic solvents, which are known to influence fate and transport.

We consider the fate and transport of hydrophobic organic chemicals (HOCs) in the presence of organic solvents and natural organic material that is present in the aqueous phase. We examine the effects on processes which control distribution between phases, retardation and transport, and biodegradation. Retardation slows the movement of the pollutant through the sediment and results from contaminant-sediment interactions (sorption).

Literature Review:

The need for understanding the fate and transport of toxic organic chemicals in order to maintain groundwater quality is apparent; the need to determine the potential for exposure to these chemicals (via surface and groundwater) in evaluating environmental health risks is obvious [Kimbrough, 1990]. Environmental fate models provide an efficient means for predicting exposure, however, the execution of such models requires mechanistic descriptions of the relevant processes (e.g., retardation and attenuation) which govern chemical fate and transport. These mechanistic process descriptions require specific input parameters.

The descriptions and parameters which are available for describing contaminant fate and transport have generally been determined for a single chemical in an aqueous (100% water) system. However, the situations which pose the greatest threat to groundwater commonly involve complex chemical mixtures which contain organic solvents in addition to other chemicals and natural organic chemicals.

Our project considers the fate and transport of HOCs in the presence of synthetic organic solvents and natural organic material, which are known to modify pollutant behavior. We consider HOC distribution among three phases: soil, water, solvent; the effect of selected organic solvents on distribution and biodegradation; and the effect of soil organic matter (OM) on biodegradation potential. Sorption, or the partitioning of an organic contaminant between the solution and solid phase, acts to slow or retard HOC movement through soil or groundwater. Partitioning between the aqueous phase and an organic solvent will have the same effect. It is well-documented that the equilibrium partitioning of HOCs in soil or groundwater systems can be described by the following equation:

$$S_T = K_p \, C \qquad [1]$$

where S_T is the concentration which is sorbed to sediment (sorbent), K_p is the equilibrium sorption constant, and C is the equilibrium concentration of the sorbate in solution [Chiou et al., 1979; Rao 1990]. Similarly, HOC distribution between the solvent-water phase is described by a solvent-water partition coefficient (analogous to the oft-used octanol-water partition coefficient:

$$K = C_{i,\ \mathrm{solvent}} / C_{i,\ \mathrm{water}} \qquad [2]$$

The value of K_p can be determined from the retardation factor, R,

$$R = 1 + \rho K_p / \theta \qquad [3]$$

where ρ and θ are the bulk density and volumetric water content of the porous media, respectively. R is calculated from the breakthrough curve (BTC) which is generated with miscible displacement techniques (below).

Greater microbial activity, and therefore biodegradation potential, has traditionally been associated with higher OM soils. Recently, several researchers have reported that sorption in high OM soils decreases bioavailability of 2,4-D and therefore the biodegradation potential [Ogram et al., 1985; Greer and Shelton, 1992]. Another factor that has received less attention is the effect of natural organic matter (present in the aqueous phase as dissolved or colloidal material) on biodegradation.

There are few studies to date on HOC biodegradation in the presence of organic solvents. Recent work by Efroymson and Alexander [1991] considers the biodegradation of hydrocarbons which are partitioned into an organic solvent; this is one of the few studies in an environmentally relevant system. As mentioned above, bio- and chemical process engineers have found that biologically mediated enzymatic reactions are catalyzed in bi-phasic (organic and aqueous) systems [Lilly et al., 1987; Carrea 1987; Halling 1990]. As more research on the behavior of nonaqueous phase liquids in the environment is conducted, our understanding of how organic solvents affect pollutant attenuation will become apparent.

Methodology:

General.

^{14}C naphthalene (Sigma Chemical Co.) was used in combination with non-labeled naphthalene in mineralization studies to obtain the desired activity and concentration of naphthalene. Liquid scintillation counting (Packard Tri-Carb, Packard Instrument Co., Downers Grove, IL) and HPLC with UV detection (HP 1050) were used to determine naphthalene activity and concentration, respectively.

Optical density (Klett-Summerson Photoelectric colorimeter, Klett MFG. Co., Inc., NY) was used as an indicator of bacterial number and growth. Standard techniques were used to plate bacterial cultures and inocula for verification of microbial number and culture purity.

Soil and aquifer material were obtained locally (Kingston, RI): aquifer material from the C-horizon, Peckham Farm; Merrimac from the B-horizon, Great Swamp Management area; and a muck soil from the A-horizon, URI Northwoods. For "washed soil" experiments, the A and B horizon soils were treated with a water-methanol solution to remove water soluble and/or leachable organic matter from the soil. Experiments were conducted with "washed" and untreated soils to determine the effect of natural organic matter (present in the aqueous phase) on biodegradation.

Naphthalene sorption and partitioning.

Naphthalene sorption onto aquifer material, glacial outwash, and muck soils was measured using the miscible displacement technique in a laboratory soil column [Zhong et al., 1986; Lee et al., 1988; Gamerdinger et al., 1990, 1991]. The soil-water partition coefficient (K_p) was calculated from the retardation factor ($R = 1 + \rho K_p / \theta$) which was determined through mathematical moment analysis [Valocchi, 1985].

Naphthalene partitioning between each of the solvents was measured in two- phase solvent-water, and three-phase soil-solvent-water systems (in progress). A known concentration and activity of ^{14}C naphthalene in acetone was added to 1 ml of each solvent followed by 7 mls of D.I. water. The vials were tightly sealed with teflon lined caps, equilibrated for 6 days, and centrifuged prior to sampling and analysis of each phase.

Bacterial isolation and growth.

A bacterium that was able to use naphthalene as a carbon source was isolated from soil collected in the vicinity of an underground oil storage tank; characterization is in progress. Standard isolation techniques were used; glycerol stocks were prepared and stored at -20°C.

Pure culture inocula for use in mineralization studies were prepared as follows. A flask containing M-9 mineral media and excess crystalline naphthalene was inoculated with bacteria from a frozen glycerol stock and placed on an incubator/shaker until the late log-phase of growth was reached (3-5 days). The culture was then centrifuged at 5000 rpm for 15 minutes, the supernatant was discarded, and the pellet was resuspended in M-9 media. This procedure was repeated twice. The final resuspension was diluted to a predetermined optical density and used as the inoculum in mineralization studies.

Mineralization experiments.

Sterilized soil, M-9, the solvent treatment, naphthalene in acetone, ^{14}C-labeled naphthalene in acetone, and the inoculum were added to each 250 ml flask, depending upon the treatment. The total acetone in each flask did not exceed 0.2%, a concentration which was shown to have no effect on bacterial growth [Bauer and Capone, 1985].

An inlet to each flask was connected to an air pump; the outlet was connected to 3 CO_2 traps in series, which contained a 4:1 methanol:ethanolamine solution [Zhou and Traxler, 1992]. The flasks were closed except during sampling and were placed on a shaking water bath at a temperature of 27 +/- 1 °C throughout the experiment.

The CO_2 traps were changed at discrete time intervals following a ten minute aeration period; a 0.3 ml sample was taken and $^{14}CO_2$ was measured by liquid scintillation counting. Microbial number of the inoculum was estimated from optical density and subsequently verified by plating of a dilution series using standard techniques.

Results and Discussion:

Naphthalene sorption and mineralization in 3 soils.

Results of miscible displacement studies of naphthalene transport in each of the 3 soils (aquifer material, outwash, and muck) are presented in Figures 1-3. As anticipated, greater retardation and sorption to soil was observed with increasing organic carbon content.

Results of the mineralization studies (complete conversion of naphthalene to CO_2) in each of the three soils and in "washed" soils are shown in figures 4-6. In untreated soil, mineralization increased with increasing organic carbon content of the soil (Figure 4). Because sorption is thought to decrease bioavailability, we were surprised with this result. To explore the controlling mechanism, the experiments were repeated on "washed" soil with water soluble organic matter removed. Mineralization decreased in these treatments (Figures 5 and 6), but the results are not clear because biological activity (as measured in the control treatment) was different for the two experiments. These experiments will be repeated.

Naphthalene partitioning and mineralization in solvent-water systems.

Solvent-water partition coefficients were similar and on the order of 500-600 for naphthalene distribution between a solvent (hexane, octane, decane, dodecane, and hexadecane) and aqueous phase. Experiments in 3-phase (aquifer material, solvent, water) are not yet complete.

Mineralization of naphthalene was enhanced in some solvent-water systems (Figures 7-8). Activity is correlated with solvent hydrophobicity as reported by others [Laane et a., 1987]. The effect of organic solvents on biodegradation was systematically evaluated by comparing mineralization of naphthalene in the presence of hexane, octane, decane, dodecane, and hexadecane in 2-phase solvent water and 3-phase soil-solvent-water systems. Analysis of these experiments is not yet complete, but it appears that activity is higher in the longer chain, more hydrophobic solvents.

***Principle Findings and Conclusions*:**

Complete degradation of naphthalene in the presence of 3 soils (A horizon muck, B horizon outwash, and aquifer material) was measured. The extent of degradation was positively correlated with the organic carbon content of the soil, suggesting that organic matter from the soil enhanced degradation. Degradation was reduced when water-soluble organic matter was removed from the two surface soils. These results suggest that enhanced degradation is positively correlated with the amount of organic carbon available via the aqueous phase. This could result from increased substrate availability due to the cosolvency effect of the water soluble fraction of the soil organic matter, or, due to growth of the bacteria on this water-soluble fraction of organic matter. Further experimentation and evaluation is required to understand the mechanism and under what conditions enhancement will be observed.

Complete degradation of naphthalene in the presence of 5 organic nonaqueous phase liquids (hexane, octane, decane, dodecane, hexadecane) was evaluated. The extent of degradation was enhanced in the presence of the more hydrophobic organic solvents. This could be due to a direct effect on the microorganism, or due to indirect effects such as increasing substrate availability to the bacteria. We suspect that degradation will be diminished in the presence of more hydrophilic solvents. Further experimentation is required to establish the relationship between solvent properties and their effect on biodegradation.

Bacteria which degrade PAHs were present in hydrocarbon contaminated soil. The bacterial population was viable in the presence of hydrophobic organic solvents (alkanes with chain length of 8 or greater). These solvents are also classified as L-NAPLs (nonaqueous phase liquids which are less dense than water). The overall extent of naphthalene degradation to CO_2 was enhanced in the presence of selected organic solvents, although the initial rate was slower. This suggests that contaminant degradation is a function of the mixture of contaminants that may be present on-site. Understanding the controlling mechanisms is important for predicting contaminant fate and for optimizing bioremediation strategies.

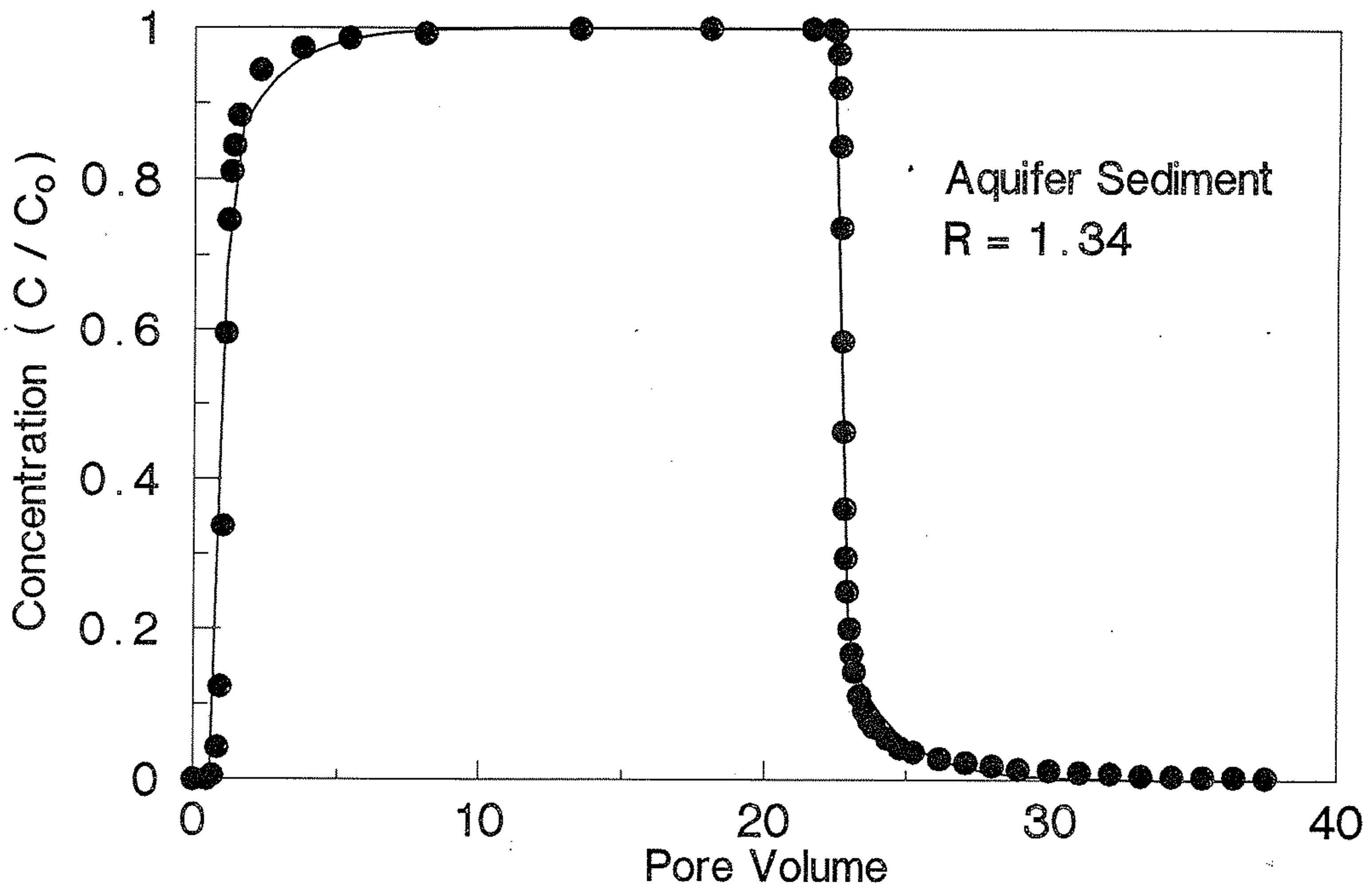

Figure 1. Naphthalene Sorption/Retardation in Aquifer Material.

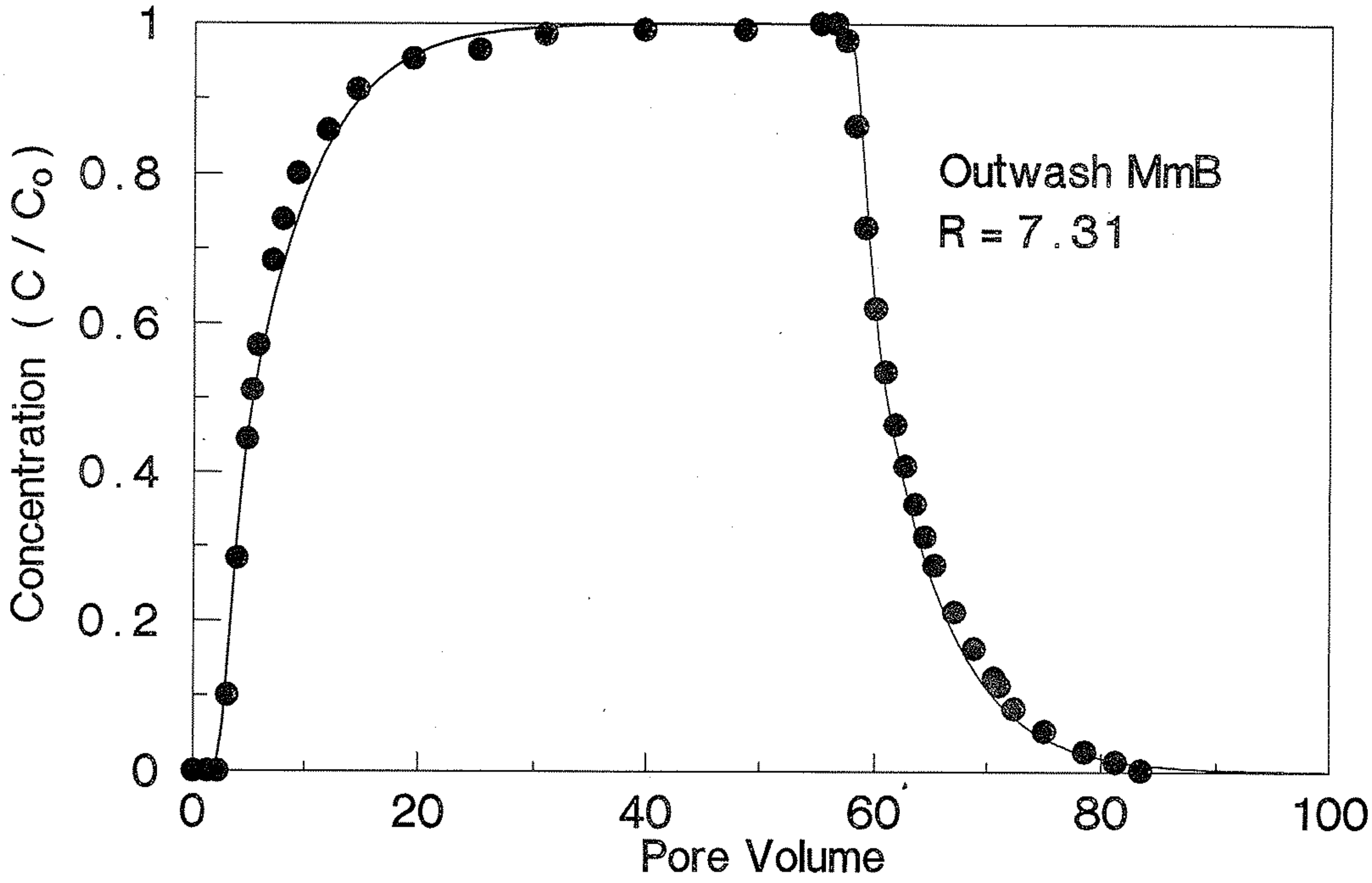

Figure 2. Naphthalene Sorption/Retardation in Outwash.

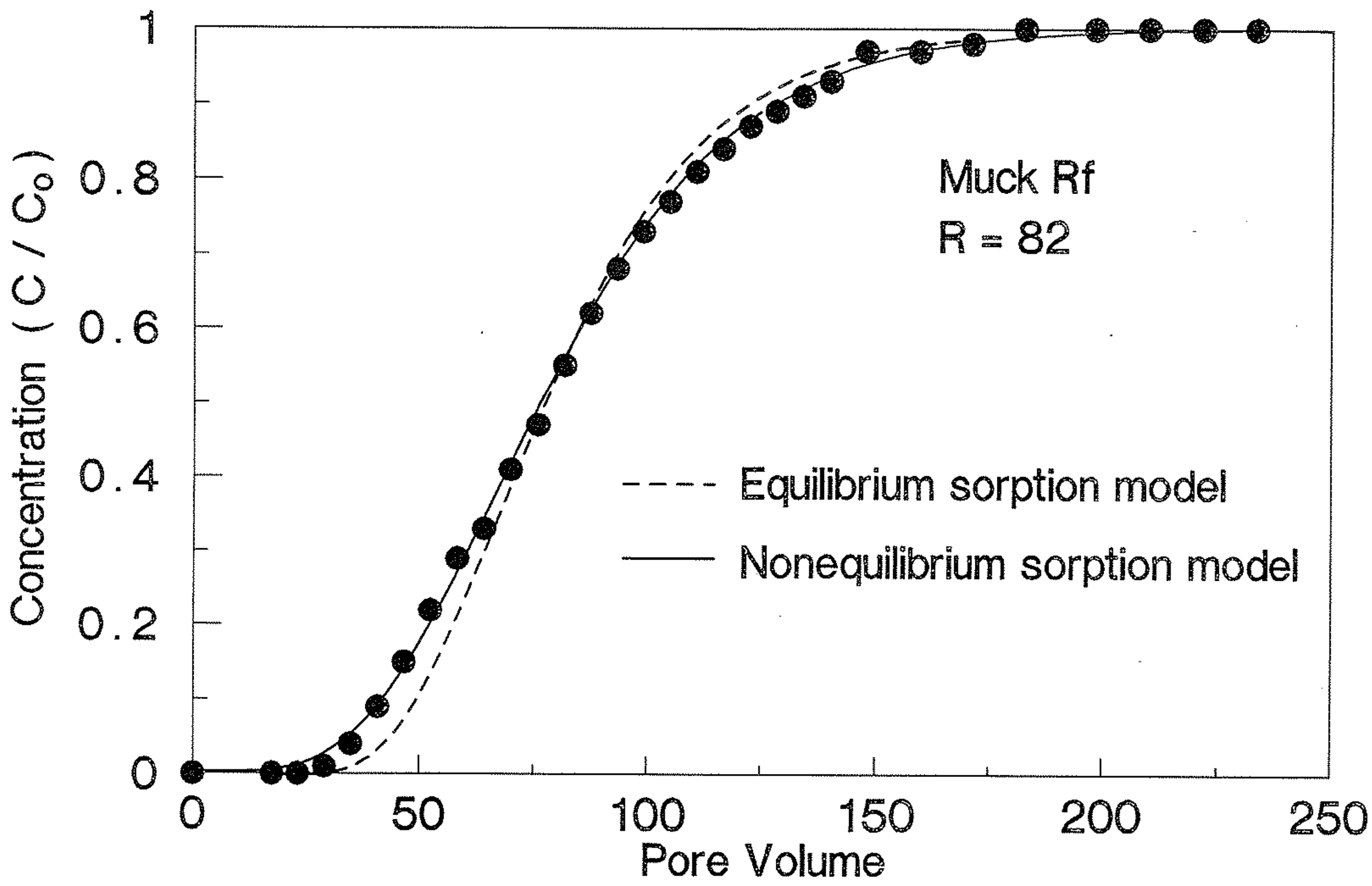

Figure 3. Naphthalene Sorption/Retardation in Outwash.

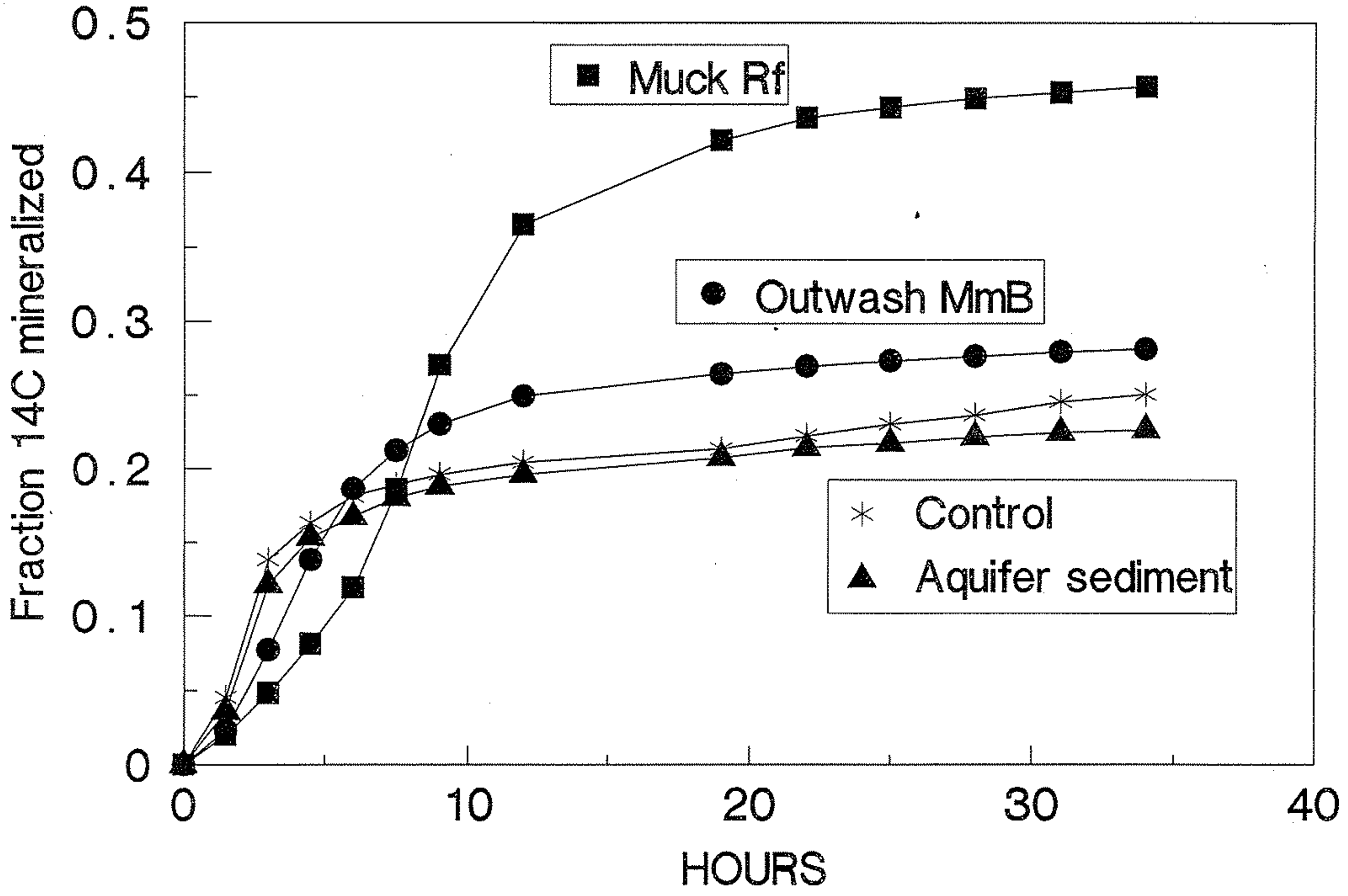

Figure 4. Naphthalene Biodegradation in 3 Soils.

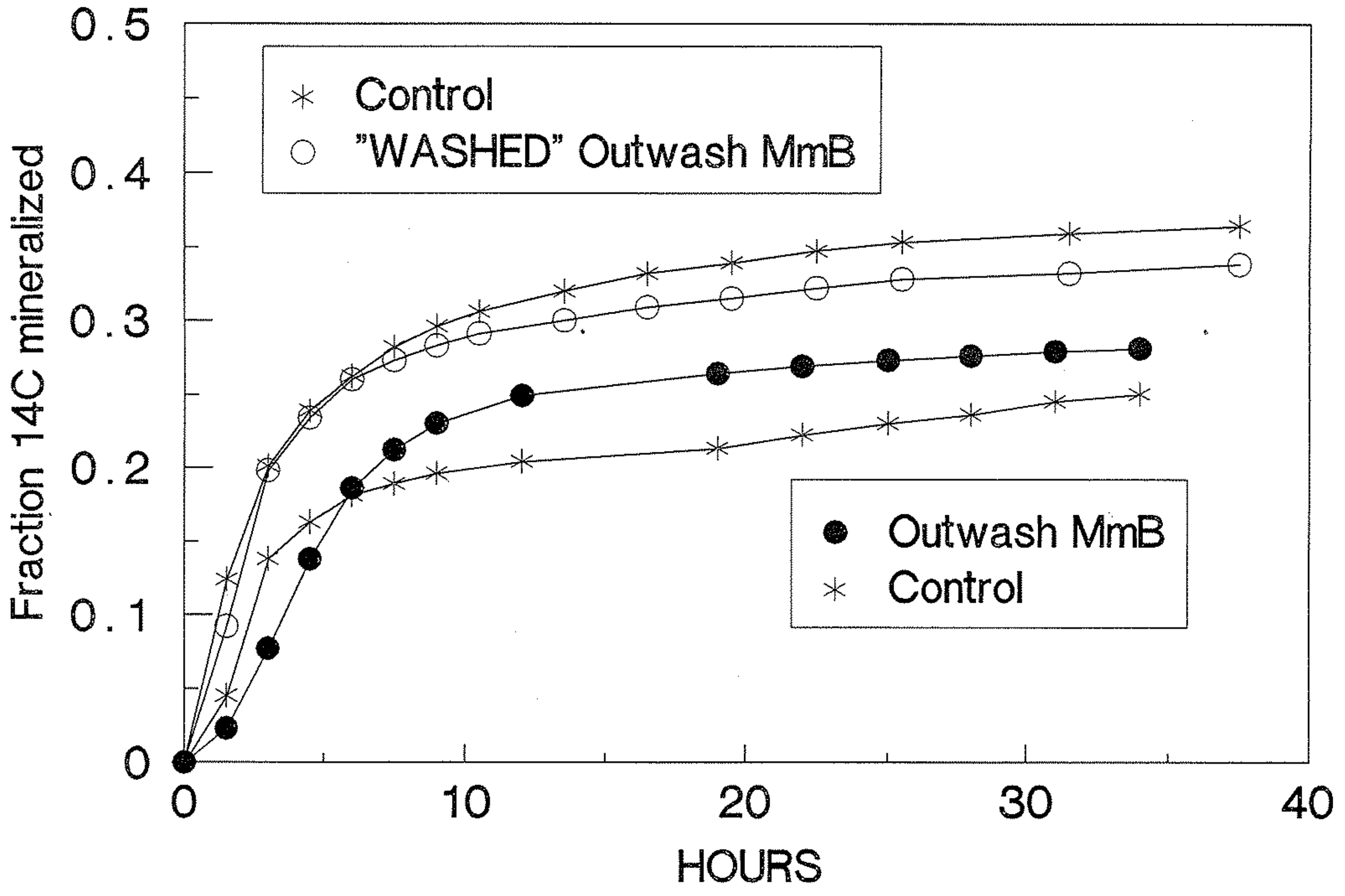

Figure 5. Decrease in Biodegradation in "Washed" Soil.

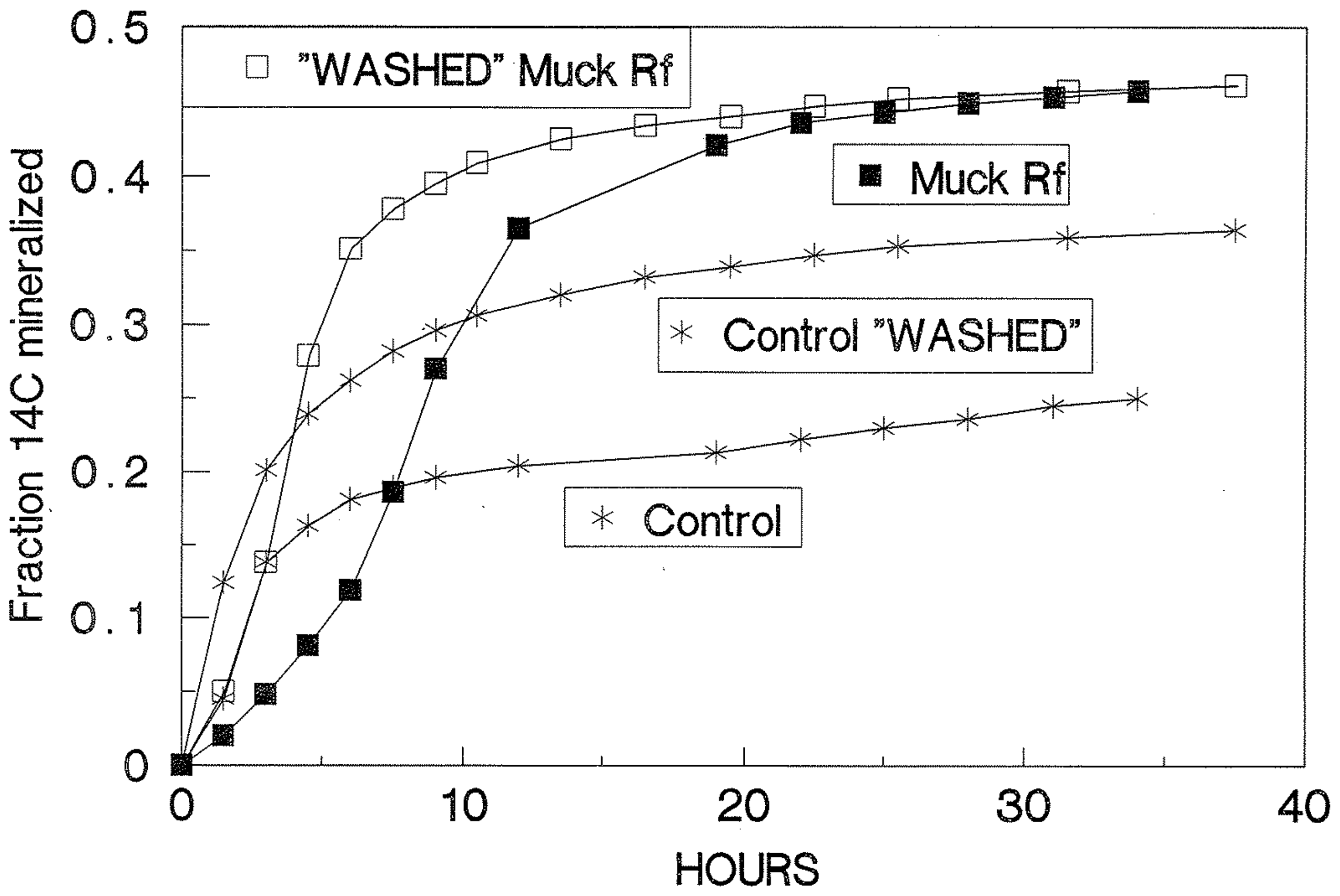

Figure 6. Decrease in Biodegradation in "Washed" Soil.

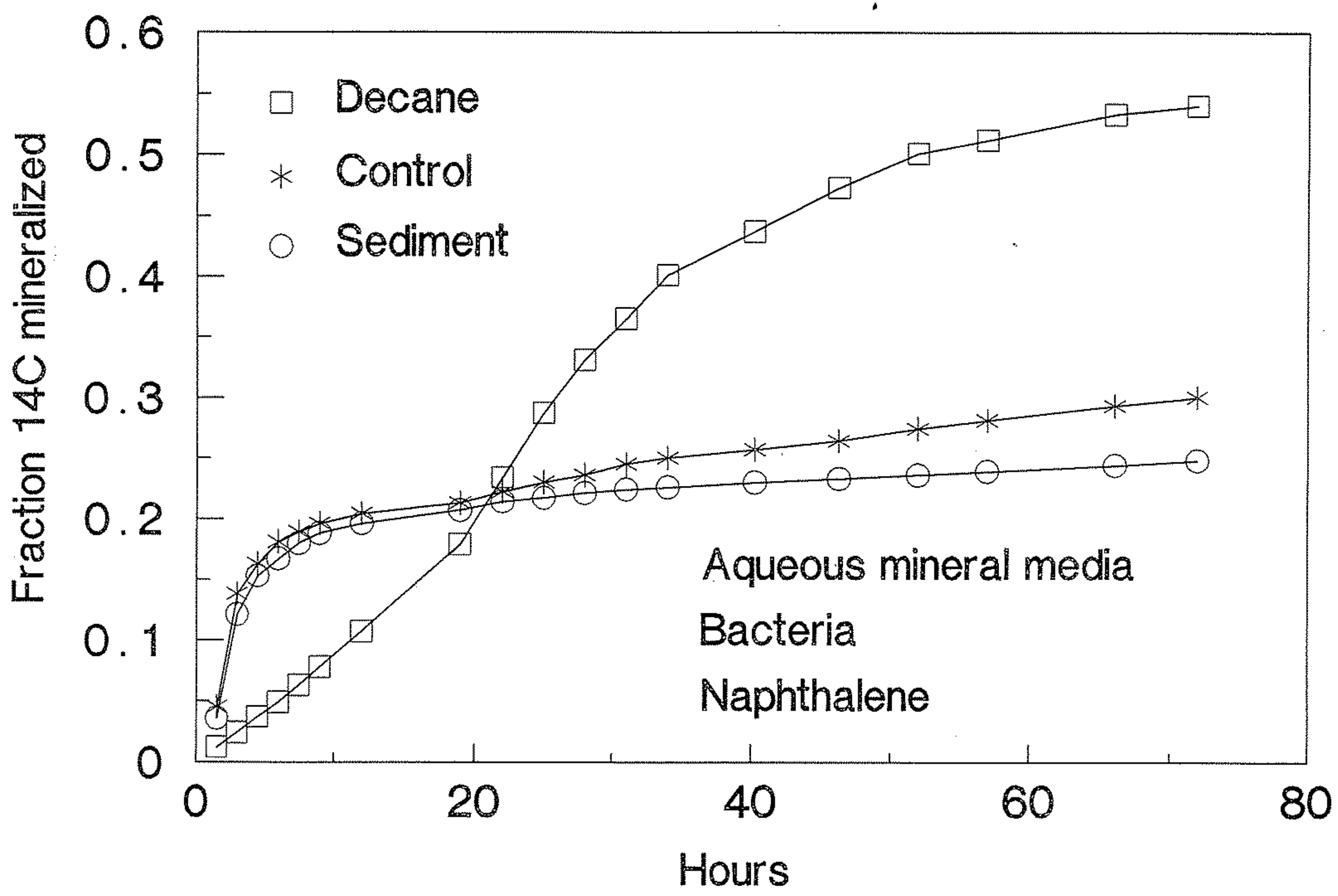

Figure 7. Biodegradation in Solvent-water and Soil-water systems.

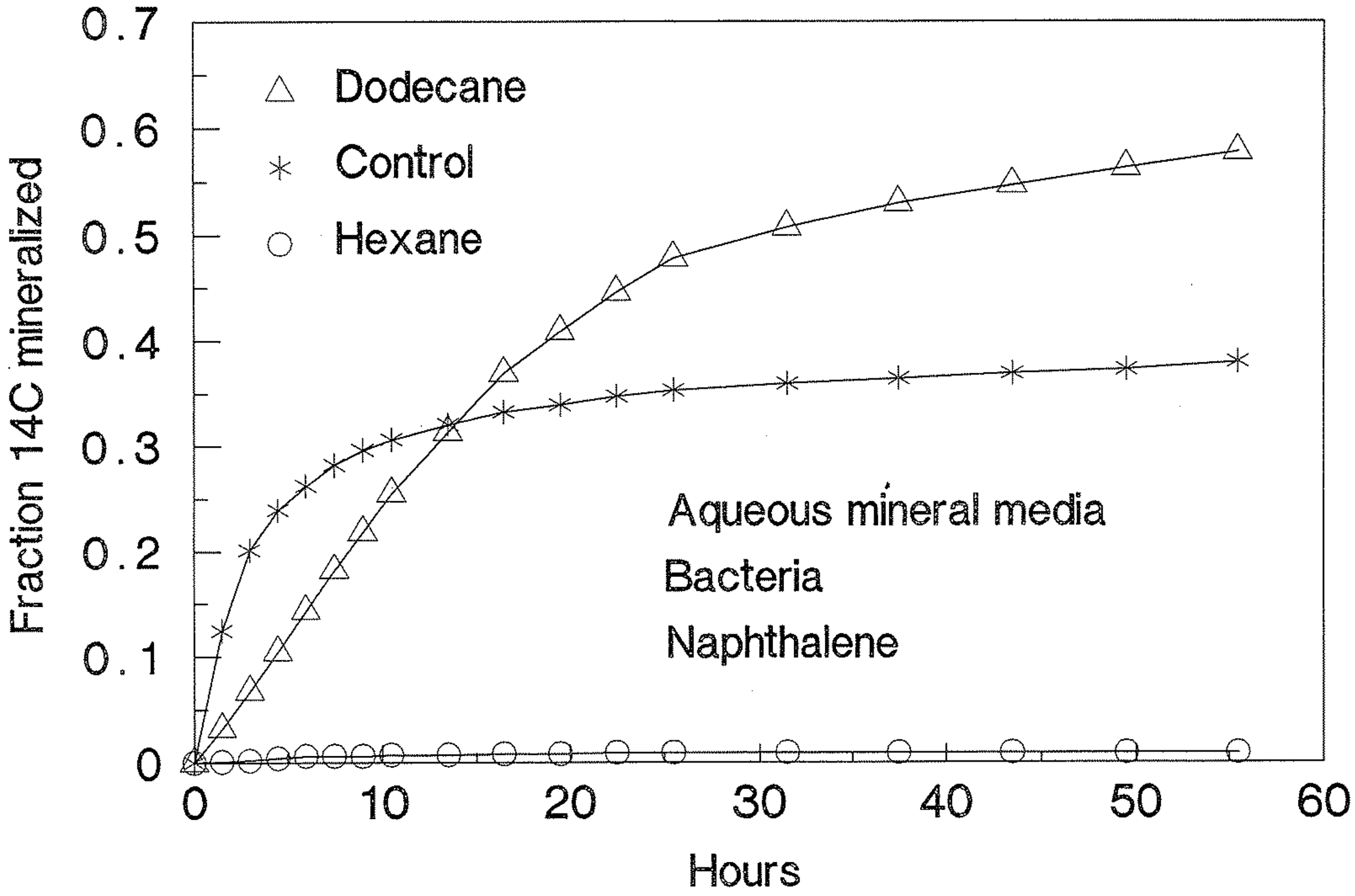

Figure 8. Biodegradation in Solvent-Water Systems.

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FISCAL YEAR 1992 PROGRAM REPORT

CALVIN P.C. POON, DIRECTOR

1892

WATER RESOURCES RESEARCH INSTITUTE
THE UNIVERSITY OF RHODE ISLAND

FISCAL YEAR 1992 PROGRAM REPORT

Rhode Island Water Resources Research Institute
University of Rhode Island
Rhode Island

ABSTRACT

The objectives of the FY-1992 Rhode Island Water Research Institute Program are to identify policy issues and management problems of water resources in the State as well as in the New England region; to conduct research that is useful to address the issues; to obtain solutions to the problems; to transfer the information to potential users throughout the State and New England region; to educate the public about water protection, management and conservation; and to train graduate as well as undergraduate students in water resources research. Current and anticipated state and regional water problems are managing and protecting the groundwater resources from non-point pollution such as nitrate, insecticides used in farming; competition of high quality water supply by various communities in the state, understanding the chemical reactions that control the composition and quality of groundwater as well as the fate and transport of taxic organic chemicals; and the lack of information dissemination on water quality, potential fertilizer and insecticide contamination problems, proper management approach, land use, and water conservation.

The FY-1992 program addressed many of these problems. A comprehensive nitrogen budget study in turfgrasses farming using different species, different nitrogen sources, and various applications revealed low soil water nitrate levels in the winter-spring season but much higher during the summer and fall. Hard fescue and Kentucky bluegrass exhibited highest soil nitrate and greatest leaching potential. Type of nitrogen sources also affected the soil water nitrate significantly. Ammonia volatilization following fertilizer application was greatest in September and lowest in June, but nitrogen loss in either case accounted for about or less than 2% of that applied as fertilizer. Denitrification in unamended soil cores was very low but was

ten times faster in water plus nitrate amended soil cores. Potential insecticide leaching study showed that farmland may find high leaching rates of aldicarb, methamidophos, carbofuran, moderate leaching rates of methomyl, atrazine, and very low leaching rate of pendimethalin. Indeed, aldicarb was found in community wells near turf farms in the mid-1980s. The geochemical evolution of groundwater in the Pawcatuck River Basin was characterized. Based on a laboratory evaluation of Water-rock interactions, it was found that the leachate from Narragansett Pier Granite yielded a sodium/calcium ration of 6.5 representing the early phase of weathering, and later dropped to 2.0, indicating the chemical weathering of parent material and formation of reaction products. Bicarbonate, a by product of weathering reactions, was found the dominant anion, as a result of the reaction of the interaction between carbonic acid with alumino-silicate minerals. Information transfer activities include the publication of newletters, a series of seminar focusing on the application of nutrients and pesticides on agricultural lands and topics on groundwater, landfill, and environmental education and the effort of compiling a water resources directory in Rhode Island. The Center also worked with Rhode Island Department of Environmental Management to publish a booklet on electroflotation technology for plating waste treatment. Throughout the year, the Center worked closely with all state and federal agencies dealing with water resources in Rhode Island, as well as New England Water Resources Center directors, the Natural Resources Science Department at the University of Rhode Island, and citizens groups on program planning, research coordination, and citizen participation.

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RESEARCH PROJECT SYNOPSES

WATER PROBLEMS AND ISSUES OF RHODE ISLAND

The State of Rhode Island and other New England states have in the past concentrated their efforts in point source pollution control. Recently the emphasis has ben changed to the study and curbing of non-point sources of pollution. Although point sources of pollution have not been under control completely, as evidenced by the recent decision of expanding the treatment capability of three treatment plants along the Pawtuxet River in Rhode Island to include nitrogen and phosphorus removal, the state is responding to the federal directive and the availability of federal funds in channeling its efforts in non-point source pollution management, e.g. combined sewer overflow (CSO) studies, well-head protection program, and Narragansett Bay studies. CSO is a urban pollution problem while protection of drinking water supply wells in Rhode Island is principally a suburban and rural area pollution problem. Agricultural activities and land development in suburban and rural areas are causes of concern in non-point pollution. Other potential sources of groundwter contaminants include waste disposal sites, underground fuel storage tanks, septic systems and cesspools, and oil and chemical spills.

Turf farming is extensive in the northeast, throughout all New England states. Important to the groundwater quality protection in rural areas are three issues: (1) how to manage high quality turf without impacting negatively on groundwater resources; (2) how best to utilize municipal and industrial organic wastes in turfgrass management without compromising groundwater quality; (3) how to evaluate the potential of insecticide leaching from farm land to groundwater. Since the large sod farms and recreational turf areas in southern New England require substantial quantities of fertilizer nutrients and pesticides to establish and maintain quality turf, the potential contamination and best management practice of fertilizer/insecticide applications are important issues and problems facing Rhode Island.

The Pawcatuck River Basin is classified by the U.S. Environmental Protection Agency as a sole-source aquifer. This designation underscores the importance of developing sound management and protection strategies in this area. However, without a complete understanding of the groundwater hydrology, the effectiveness of current and proposed strategies (i.e., wellhead protection areas, zoning laws, etc.) is unknown. There is a need to study and to provide information about the chemical reactions that control the composition of groundwater in the Pawcatuck River Basin aquifer.

Many community wells in Rhode Island have been found to contain toxic chemicals including solvents and pesticides which led to the closure of these wells for service. Many of the major community well systems are near farm land. Consequently, the potential of pesticide and fertilizer contamination of these wells exists. Instead of conducting a comprehensive sampling program of the water quality of these wells, it is possible to use chemical fate model to predict the chemical concentration in groundwater. The model simulation study can, therefore, be used as a screening tool to identify the high risk areas so that a selective sampling program can be devised.

The presence of organic solvents will modify the pollutant behavoir and its fate and transport in soil. Two most important processes, retardation and attenuation, influence pollutant fate and transport. A study of these processes will yield process descriptions and parameters which can be incorporated into currently existing environmental fate models.

PROGRAMS GOALS AND PRIORITIES

The research needs on water resources in Rhode Island and in the New England region as identified by the State Advisory Committee and the University Water Resources Coordinating Committee have been:

Groundwater Management

1. Economic Impact analysis of artificial recharge
2. Assessment of aquifer contaminant cleanup by geophysical or geochemical methods
3. Study of geology of Rhode Island aquifers and their effects on groundwater flow, yield, and contaminant transport
4. Development of models for highway run-off and surface water-groundwater interaction
5. Evaluation of viruses in saturated and unsaturated zones

Surface Water Management

1. Control of algae blooms by bioaugmentation (ecological engineering)
2. Cost-benefit analysis on consolidation of small water supply systems
3. Impact of water withdrawal from surface water and groundwater on wetland and streams in Rhode Island
4. Wastewater treatment: paint and powder coating removal from water, low-cost and energy efficient method for recycling of non-contact cooling water
5. Methods of recycling effluents from industrial wastewater treatment systems.

Institutional Frameworks

1. Water right concept and conflict resolution among competing water users in Rhode Island
2. Land use regulation and other watershed management practices in non-point pollution control

Technology Transfer

Water Conservation, water resources research briefs and seminars of water resources research.

Guided by these research needs, the Rhode Island Water Resources Center developed its program goals to meet some of these research needs as well as to transfer the information water resources research/management/eduction to the public. Based on the quality of the proposals submitted, it was decided to concentrate the effort of research in the area of management of groundwater quality and quantity. In addition to relevance of research needs and technical competency, a reasonable budget was also a criterium in selecting the projects for FY-1992 program support.

The first project, Project 02, entitled *Minimizing Nitrate Contamination of Groundwater Following Fall Fertilization of Turf*, was in the second year of a two-year study. Four turfgass species and five nitrogen sources were used for fall application. Clippings were collected for nitrogen analysis. Soil water nitrate was determined every two weeks and a hydrological mass balance model was used to determine nitrate leaching throughout the year. Denitrification was also determined from six-inch soil cores from each plot. Glass bell jars were used to collect and measure ammonia volatilization. Most organic nitrogen sources applied in the fall and mid-June lost less than 5% of their nitrogen to nitrate leaching. Late fall application of organic fertilizers was found to be a better practice since less mineralization occured and resulted in less opportunity for nitrate leaching during the winter. Ammonia volatilization and denitrification resulted in annual nitrogen losses equivalent to 2% and 4% of that applied as fertilizer, which was not a major loss of nitrogen from the turf-soil ecosystem. Results also indicate that denitrification rates were influenced by the frequency of soil saturating episodes (precipitation) more than by variations in soil water nitrate concentrations. Grass clippings contained nitrogen equivalent to 65% of that applied as fertilizer. If clippings are retained on turf, typical nitrogen losses due to nitrate leaching, ammonia volatilization, or denitrification account for less than

15% of the 3.5 lbs. N/1000 sq.ft. applied during the growing season. The effect on nitrate leaching by the long term accumulation of nitrogen within the turf-soil system is not known.

The second project, Project 03, entitled *Potential Pesticide Contamination of Groundwater and Surface Water in Rhode Island,* identified all community wells in Rhode Island located in areas near farm lands. Crops and pesticide application data were collected. Soil data were provided by Rhode Island Soil Survey and amended with SESOIL soil database. Chemical parameters of target pesticides were obtained from USEPA one-liner database, NPURG database, Handbook of Chemical Property Estimation Methods, and The Pesticide Manual. Weather data in monthly formats were created from authentic daily weather records or generated from the a synthetic weather generator. Using the SESOIL and AT-123D programs, long term insecticide migration was simulated. Simulated results were compared with the sampling records of insecticide concentration of some of these community drinking wells.

The third project, Project 04, entitled *Field Assessment of Geochemical Controls on Groundwater Chemistry in the Pawcatuck River Basin of Southern Rhode Island,* studied the chemistry of groundwater in the Chipuxet, Queen-Usquepaugh, and Upper Wood aquifer. The gross mineralogy of all the rock types was found to be similar, with sodic plagioclase, potassium feldspar, and quartz. Assessory minerals, however, have a profound impact on the water chemistry providing a useful indicatio or reaction with a particular rock type. The absence of fluoride in Queen-Usquepaugh groundwater is attributed to the absence of apatite in the Hope Valley Alaskite Gneiss. High fluoride concentrations in the Upper Wood may be indicative of flow from the Scituate Granite Gneiss to the north. The groundwater chemistry compared favorably to the water chemistry produced in the water-rock interaction experiments in phase one of this study.

The fourth research project, project 05, entitled *Toxic Organic Chemicals in Rhode Island Groundwater: Contaminant Fate and Transport,* used standard enrichment culture techniques to isolate a bacterium from local soil in the vicinity of an underground oil storage tank which was abel to use several polycyclic aromatic hydrocarbons, PAHs, as substrate for growth. The bacterial population was viable in the presence of hydrophobic organic solvents. The overall extent of naphthalene degradation CO_2 was enhanced in the presence of selected organic solvents. This suggests that contaminant degradation is a function of the mixture of contaminants that may be present on-site.

The level of funding and sources for the various projects including the information transfer activities are listed in Table 1 on the following page.

Table 1 Sources and Levels of Funding
FY-1992

Project	Level	Source of Funding ending May 31, 1992
02 Minimizing Nitrate Contamination of Groundwater Following Fall Fertilization of Turf (2nd yr)	$14,940 40,949 7,500	U.S. Geological Survey University of Rhode Island Earthgo, Inc. and coron
03 Potential Pesticide Contamination of Groundwater and Surface Water in Rhode Island (2nd yr)	15, 765 30,356	U.S. Geological Survey University of Rhode Island
04 Field Assessment of Geochemical Control on Groundwater Chemistry in the Pawcatuck River Basin of Souther Rhode Island (2nd yr)	15,300 31,893	U.S. Geological Survey University of Rhode Island
05 Toxic Organic Chemicals in Rhode Island Groundwater: Contaminant Fate and Transport	14,040 29,900	U.S. Geological Survey University of Rhode Island
22a Information Transfer Activities	14,804 32,437	U.S. Geological Survey University of Rhode Island
22b Information Transfer Activities	1,500	R.I. Dept. of Environmental Management
01 Center Administration (including Publication of Newletter)	26,532 57,203	U.S. Geological Survey University of Rhode Island
FY-1991 Total Funding: U.S. Geological Survey	104,574	
University of Rhode Island	222,738	
R.I. Department of Environmental Management	1,500	

SYNOPSIS

PROJECT NUMBER: 02

START: June 1, 1992
END: May 31, 1993

TITLE: Minimizing Nitrate Contamination of Ground Water Following Fall Fertilization of Turf

INVESTIGATORS: Richard J. Hull, Plant Sciences Dept., University of Rhode Island, Kingston, RI 02881

Peter M. Groffman, The New York Botanical Garden, Institute of Ecosystem Studies, Box AB, Millbrook, NY 12545-0129

FOCUS CATEGORIES: GW, NC, NPP, NU, WQL

CONGRESSIONAL DISTRICT: 2nd, R. I.

DESCRIPTORS: Ground water pollution, Turfgrasses, Sludge disposal, Land application, Nitrates, Organic Wastes, Aquifer, Fertilizers

PROBLEMS AND RESEARCH OBJECTIVES:

Two major water quality problems in the suburban Northeast are being addressed by this research. First, how to manage high quality turf without impacting negatively on ground water resources. Second, how best to utilize municipal and agricultural organic wastes in turfgrass management without compromising ground water quality. The large sod farms and recreational turf areas in southern New England require substantial quantities of fertilizer nutrients and pesticides to establish and maintain quality turf. At the same time, near-by municipal sewage treatment facilities and various agricultural enterprises produce large quantities of nutrient rich sludges or organic wastes. These wastes, when composted to destroy pathogens and generate an easily handled material, can be utilized to meet the nutritional needs of turfgrasses. In this way, a waste disposal problem and a turfgrass management need are addressed together.

For several sound agronomic reasons, most nitrogen fertilizer is applied to turf during late summer and fall. Several researchers have demonstrated that fertilizer nitrogen is most likely to leach as nitrate into ground water when applied to turf in the fall. Organic nitrogen sources generally are less likely to promote nitrate leaching, however, during heavy precipitation in the fall they too can allow nitrate to leach from turf. Long established turf areas tend to accumulate nitrogen in the plant-soil complex and when nitrogen mineralization exceeds absorption by roots, nitrate accumulates in the soil solution and substantial leaching can occur. This is most likely to happen in the fall. To resolve this problem, comprehensive nitrogen budgets must be determined for several turfgrasses managed with fall applied nitrogen comparing several nitrogen sources and times of application.

The primary objective of this research is to evaluate the relative impact of several turf management variables on the potential for nitrate leaching to ground water. Variables being considered include, turfgrass species (4), nitrogen sources (6) and times of fall application (2). Secondary objectives include constructing comprehensive nitrogen budgets for each combination of management variables (48). Factored into these budgets will be quantitative estimates of nitrogen losses due to nitrate leaching, ammonia volatilization, denitrification, and clipping removal.

METHODOLOGY:

Field plots used for this study were seeded on June 20, 1985 and consisted of four turfgrass species: 'Georgetown' Kentucky bluegrass, 'Jamestown' Chewings red fescue, 'Repell' perennial ryegrass, and 'Scaldis' hard fescue. Prior to 1990, these plots received minimal fertilization, were never irrigated and received a spring herbicide application to control broadleaved weeds. The six nitrogen sources compared in this study are summarized below:

Nitrogen Source	Analysis % N-P_2O_5-K_2O	Type of Material
Coron	28-0-0	Soluble methylene urea
Earthgro lawn food*	8-2-4	Composted manures and leaves
IBDU	31-0-0	Slow-release urea based polymers
Milorganite	6-2-0	Digested municipal sewage sludge
S-coated urea**	44-0-0	Urea made less soluble in S coating
Urea	46-0-0	Readily available soluble N source

* Applied to plots that received Sustane the previous fall.

** Replaced by Earthgro cow manure compost (2-1-1) in spring 1992

These materials were applied at 2.5 lbs. N/1000 sq-ft on September 3 or November 19, 1991 and September 1 or November 19, 1992. Some had been applied at the same rate in early or late November, 1990. To maintain turf of good quality, plots received the same materials at 1.0 lb N/1000 sq-ft on June 11, 1991 and June 15, 1992.

Clippings were collected from a standard area of each plot prior to every fourth mowing. The clippings were dried, weighed, ground in a Wiley mill, and analyzed for total nitrogen using a micro-Kjeldahl procedure. From these values, total nitrogen removal in clippings was estimated. Soil water nitrate was determined every two weeks from water samples recovered in suction cup lysimeters placed two feet in the soil in all plots of two replications (96 plots). Using a hydrologic mass balance model, water percolation through the turf was estimated and based on soil water nitrate levels, nitrate leaching was determined. Leaching was estimated throughout the year. Denitrification was measured following fertilizer applications in 1991 and 1992. Six-inch soil cores were removed from each plot, incubated in an acetylene atmosphere and assayed for nitrous oxide, N_2O. The same cores were incubated with acetylene in water or water containing 100 ppm NO_3-N. N_2O production was assayed to estimate denitrification potential under ambient or elevated nitrate levels.

Beginning in June 1992, ammonia volatilization was measured 24 hours after fertilizer application. Six-inch diameter circles of turf were enclosed in glass bell jars and the atmosphere within the bar circulated through a 0.1 M boric acid solution to trap all ammonia released from the turf. Previous studies have shown that maximum ammonia volatility is observed 24 hours after applying nitrogen fertilizers.

PRINCIPAL FINDINGS AND SIGNIFICANCE:

Soil water nitrate levels were <1.0 ppm under all turfgrasses during the winter-spring season of 1991 and 1992 but increased during the summer and fall. Kentucky bluegrass consistently exhibited elevated soil water nitrate concentrations and the greatest leaching potential. Soil water nitrate was greatest under turf fertilized with the Earthgro lawn food, sulfur-coated urea (SCU) and urea. IBDU, milorganite and methylene urea (Coron) resulted in lower soil water nitrate levels and were less promotive of nitrate leaching. Early September applications resulted in significantly greater nitrate leaching potential during the fall and winter than late November fertilization. However, late fall applications resulted in higher soil nitrate concentrations in early spring which if accompanied by heavy precipitation, resulted in nitrate leaching.

During the 1991 growing season, fine-leaved fescues produced clipping dry matter at a greater rate than perennial ryegrass with Kentucky bluegrass being intermediate. There were no significant differences in the nitrogen recovery rates of the four grasses during either year. Urea and SCU promoted greater clipping yields in 1991 while Earthgro Lawn Food, IBDU and urea did so in 1992. Clippings recovered from plots receiving the same materials also contained more nitrogen than from the other materials.

Ammonia volatilization following fertilizer application was greatest in September and lowest in June. Nitrogen loss via this route accounted for about 2% of that applied as fertilizer. Neither turfgrass species nor nitrogen source influenced ammonia volatilization.

Denitrification measured one week after the June, September and November fertilizations, was very low in unamended soil cores. Water amended cores evidenced low levels of denitrification in June and December 1991 and December 1992 but higher levels in September 1991 and July and September 1992. Water plus nitrate amended cores often exhibited ten-fold greater denitrification rates during most times tested. Elevated soil water nitrate was less responsibile for greater denitrification than frequency of saturating conditions during the growing season. Turfgrass species and nitrogen source did not significantly influence denitrification rates at any time.

If clippings are retained on turf (their removal can withdraw the equivalent of 65% of nitrogen applied as fertilizer) nitrate leaching and gaseous losses can account for the equivalent of 15% of nitrogen applied. Consequently considerable accumulation of nitrogen must be occurring within the turf-soil ecosystem. This loading of the turf with nitrogen may eventually result in significant nitrate leaching to ground water when the system becomes nitrogen saturated. Appropriate management practices to conserve nitrogen within the turf sod will enable a reduction in nitrogen application and minimize the potential for nitrate leaching.

Publications:

Conference Presentations

Hull, R.J.; H. Liu and P.M. Groffman. 1992. Nitrate losses from six organic nitrogen sources applied to turf in the fall. Agron. Abstracts 84:170

Hull, R.J.; H. Liu, and P.M. Groffman. 1993. Nitrogen losses from six organic N sources applied to four turfgrasses in the fall. Agron. Abstracts 85: in press.

Other Publications

Hull, R.J. 1992. Minimizing nitrate leaching from turf. Turf Notes 2(6):1-4.

Hesketh, E.S., R.J. Hull and A.J. Gold. 1993. Estimating non-gaseous nitrogen losses from established turf. J. Turfgrass Management. In press.

Hull, R.J.; S.R. Alm and N. Jackson. 1993. Toward sustainable lawn turf. In A.R. Leslie (ed.). Integrated Pest Management for Turfgrass and Ornamentals. In press.

Application of Research Results:

Research on the nitrate leaching potential from turf has been supported by the R.I. Water Resources Research Center for several years. Results from this research have been presented at several national meetings of the American Society of Agronomy and at several commercial trade shows and conferences. Published recommendations on fertilizer management to minimize nitrate leaching from turf have appeared in the Cooperative Extension Service's, U. Mass and U.R.I. Turf Notes. This publication reaches professional turf growers and managers throughout southern New England and Long Island. Recommendations on turf fertilizer management have also been contributed to reports of the R.I. Resource Conservation and Development Area. This organization sends review teams to sites of environmentally sensitive projects and submits recommendations which will insure minimum negative impacts on environmental quality. One of us, R.J.H., has participated in two such reviews and submitted recommendations on turf establishment to reduce the potential for nitrate leaching.

Commercial turf producers and landscape managers have access to the results of this research and efforts to reach a wider audience are under way. National trade publications are being targeted for articles and a Cooperative Extension Service bulletin is being considered for next year. One trade journal article has already been submitted.

SYNOPSIS

PROJECT NUMBER: 03

START: June 1, 1991
END: Dec. 31, 1993

TITLE: Potential Pesticide Contamination of Groundwater and Surface Water in Rhode Island

INVESTIGATORS:
Wm. Michael Sullivan, University of Rhode Island, Kingston, R.I.
Calvin P.C. Poon, University of Rhode Island, Kingston, R.I.

FOCUS CATEGORIES:
ST, WQL, GW, AG

CONGRESSIONAL DISTRICT: Second

DESCRIPTORS:
Pesticides, Contaminant Transport, Groundwater Quality

PROBLEM AND RESEARCH OBJECTIVES:

Non-point sources of pollution have become a major concern of water quality problems in Rhode Island as well as in the Northeast region. The magnitude of non-point pollution and its effects on groundwater and surface water have not studied to the same extent as in point source pollution. Other than the conventional pollutants such as organics, suspended solids, and coliforms, very little information is available on non-point source toxic substances.

Pesticides are used extensively in agricultural lands to control annual grasses, broadleaf and sedge weeds, fungus, on crops and for wood or soil treatments. They are used on non-cropped industrial land and on lawns as well. Runoffs and leachate can carry pesticides to surface water and groundwater. The recent national survey of sampling in many states revealed pesticide contamination of groundwater. Because of the large numbers of drinking water wells in Rhode Island, an extensive sampling analysis program could be cost prohibitive. The objective of this project is to use a predictive model to screen the community drinking water wells throughout the

State. The model can be applied to scenarios or areas where particular combinations of pesticide applications, climate, water management, and soil characteristics so that the potential hazard to groundwater contamination can be ascertained. The use of this approach can result in a more effective sampling program where efforts of smpling can be directed to wells with the greatest potential hazards. Many community wells in Rhode Island have been removed from service due to the specified contaminants, including one with Aldicarb. Suspension of the pesticide use and natural flushing of the chemical from the aquifer gradually reduce its concentration in the groundwater. A predictive model can also be used to estimate when the drinking well can be put back into service when the pesticide concentration is reduced to an acceptable level for consumption.

METHODOLOGY:

The project selected PCGEMS as the principal computer model for predicting the potential hazard areas of groundwater with pesticide contamination. Long-term projection of pesticide migration in soil, and three-dimensional transport of pesticide once it reached the groundwater, were simulated for different pesticides and their application rates under different site-specific soil and climate conditions. Soil data were obtained from Rhode Island Soil Survey, NPURG, and built-in SESOIL database. Sources of chemical data included USEPA one-liner data base of some eight hundred pesticides; NPURG database; Handbook of Chemical Property Estimation Methods; and the Pesticide Manual. Monthly weather data according to the input formate required by the SESOIL program for various well locations were created from the daily weather data obtained from the PCGEMS weather database or specific weather stations near the well sites. Pesticides used and historical application rates for specific areas for the past years were reconstructed from inofrmation given by the University of Rhode Island Agricultural Extension Service or other private sources.

The wellhead protection program of the Rhode Island Department of Environmental Management provided the location and size of aquifers of the community drinking wells. All necessary input files were then contructed for simulation.

ACCOMPLISHMENT TO DATE:

When available, authentic weather records for specific well sites were used. For well sites at a distance from any weather station, a WHEN synthetic weather generator in the computer program HELP modl, version 2, was used to compute daily temperature, solar radiation, and precipitation values.

Pesticides in the simulation studies include Dicamba and 2, 4-D for turf, Carbofuran, Terbufos, and carbaryl for cropland, Atrazine for Sorghum, Aldicarb, Oxamyle, Carbofuran, methamidophos, and methomyl for potatoes. Other pesticides were also used in the study areas. However, it was found from a screening study using the SESOIL program that their leaching potential was extremely low (from 0.033 cm to 160 cm in 120 months leaching through the soil layer) and, therefore, these pesticides were excluded in this study.

In Kingston well fields a pesticide(s) application history was recreated because of crop rotation while in other areas with the same crop over the years, typical doses of a pesticide were used throughout the simulation period. The simulation was started with the SESOIL program, predicting the pesticide transport through the soil column until it reached the groundwater table. Thereafter the AT-123D program was used to simulate the pesticide movement towards the community well. Two cases of simulation were carried out. The first one assumed that the aquifer width was the same as the width of the wellhead protection area defined by the Rhode Island Department of Environmental Management. This was the worst case scenario with the pesticide distributed to a smaller and confined area. The second case assumed an infinite aquifer width or a best case scenario. In either case, the AT-123D program provided the temporal and spatial chemical distribution in the groundwater between the farm land and the well. Using the Y-Z plane chemical isopleph at the well site at any time and taking the weighted average of chemical concentration at that cross-section of the aquifer, the chemical concentration in the well water was obtained for a typical pumping rate of the well. Plots of any specific insecticide concentration of the well water versus time were then prepared. Figures 1 and 2 for example show respectively Aldicarb and 2,4-D concentrations in the Kingston well No.4 of the Chipuxet aquifer near the University of Rhdoe Island agricultural experimental station. The record of water sample analyses from the Rhode Island Department of Health, when available, was examined and compared with the simulated result. The Aldicarb and 2, 4-D concentrations for the Kingston well No.4 well in 1984 were respectively 10.5 to 19.5 ppb and 5.5 to 10 ppb from the simulation study. RIDOH's record in 1984 was 6 ppb of Aldicarb which was lowered than the simulated result. On the other hand, RIDOH's record shows less than 50 ppb of 2,4D although the exact concentration was not reported (perhaps due to instrument limitation). The simulated result of 5.5 to 10.0 ppb confirmed the occurence of low concentrations in the well.

All together six community well fields in Kingston, Wakefield, Westerly, Kent County (North Kingstown and Warwick wells), and Cumberland were studied. It is expected that all simulations of the insecticide migration from farm lands in the wellhead protection areas where these community drinking wells are located will be completed in October, 1993.

The significance of the result of this study can be illustrated in Figures 1 and 2. The latest application of Aldicarb near Kingston well No.4 was May 1981 after which its use was banned. Because of the slow movements of leaching and migration in the aquifer, the peak Aldicarb concentration did not show up in the well water until 7 1/2 years later. From then on, the

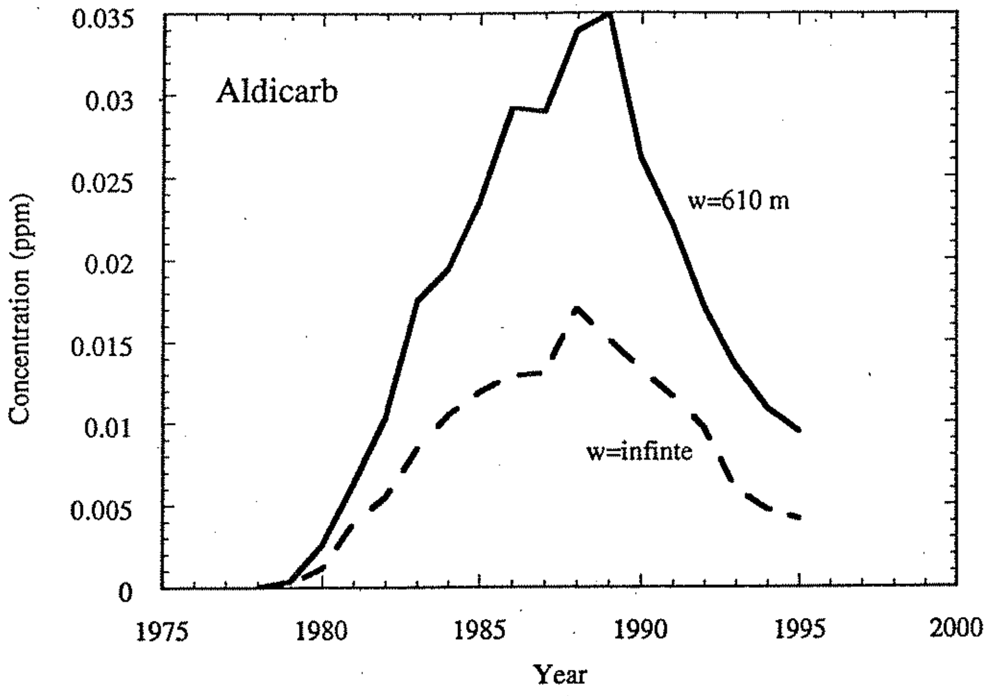

Figure 1. Simulated Aldicarb Concentration in URI Well No.4

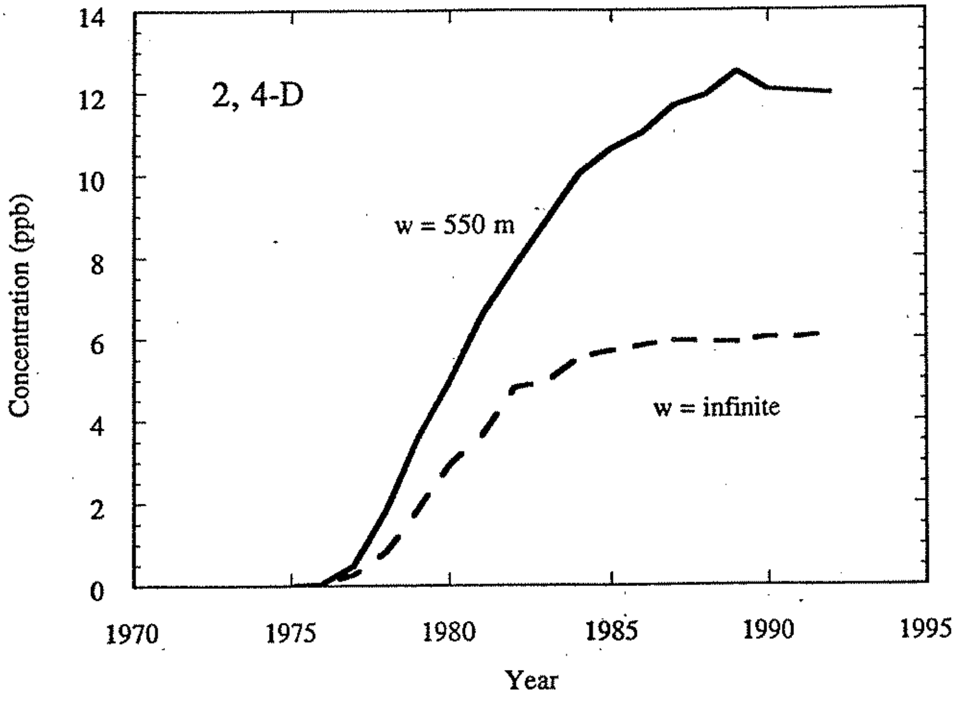

Figure 2. Simulated 2,4-D Concentration in URI Well No.4

concentration gradually deminished but as much as 4 to 9 ppb (representing the best and worse scenario) can still be expected in 1995. A complete flush-out of Aldicarb will not be expected until the year 2000 or later. Figure 2 shows that with the relatively steady application of 2, 4-D in the fields, the Kingston well No. 4 water will contain 6 to 12 ppb of the chemical. It is relatively easy to simulate a scenario of different rate of application at any year to see its effect on the chemical concentration in the well water. This is very useful for management practice in wellhead protection areas throughout the State.

SYNOPSIS

PROJECT NUMBER: 4

START: June 1, 1992
END: May 31, 1993

TITLE: Field Assessment of Geochemical Controls on Ground-Water Chemistry in the Pawcatuck River Basin of Southern Rhode Island

INVESTIGATOR: Anne I. Veeger, University of Rhode Island, Kingston, RI

FOCUS CATEGORIES: HYDGEO, HYDROL, GW, WQL

CONGESSIONAL DISTRICT: Second

DESCRIPTORS: Groundwater, geochemistry, chemical reactions, water quality, metals,

PROBLEM AND RESEARCH OBJECTIVES:

The chemical composition of ground water is a function of the origin and history of the aqueous solution. Solutes in recharge water may be derived from numerous sources, including salts in rainwater, dry fallout, organic reactions in the soil zone, and anthropogenic inputs. Following recharge, however, the chemical evolution of ground water is the result of water-rock interactions. Because the composition of an aqueous solution moves toward chemical equilibrium with the surrounding materials, it is possible to use changes in the chemical composition of ground water to delineate general flow patterns and identify the mixing of waters from different sources. The use of these hydrochemical data to supplement hydrologic information can lead to a more complete understanding of flow dynamics in an aquifer.

This approach is particularly useful in complex and heterogeneous aquifers such as those found in Rhode Island. The stratified glacial deposits that form the major ground-water reservoirs in the State are complex layered deposits with both lateral and vertical heterogeneity. Although water level measurements can be used to determine the direction of the hydraulic gradient, the presence of confining or semi-confining layers may deflect ground-water flow. Similarly, ground-water in the underlying crystalline bedrock is restricted to flow along fractures, which may not be parallel to the hydraulic gradient. In addition, glacial aquifers, which receive natural recharge along their length, may be affected by induced surface-water infiltration near high-volume wells or seasonal recharge-discharge variations. In these settings, physical measurements may be inadequate for a complete description of the system, but chemical data can provide the additional information necessary for evaluating the dynamics of the aquifer system.

This study provides information about the chemical reactions controlling the composition of ground water in some of the Pawcatuck River Basin ground-water reservoirs. These data may be useful for describing ground-water flow paths, identifying recharge areas and the degree of interaction between surficial and bedrock aquifers, and for predicting the impact of chemical and physical stresses on the system.

This research has been accomplished over a two year period. This synopsis covers the second phase of research in which the field assessment of geochemical controls on water chemistry was completed. To accomplish this, the following objectives were pursued:

1) characterization of the chemical composition in shallow surficial, deep surficial and bedrock aquifers of the Chipuxet, Queen-Usquepaugh, and Upper Wood River basins,

2) characterization of the chemical reactions controlling the water chemistry in each of the three aquifers studied,

3) geochemical evaluation of the degree of hydrologic interaction that may exist between the surficial and bedrock aquifers, and

4) development of contamination-potential criteria for these aquifers given the above results.

METHODOLOGY:

Site Selection and Sample Collection

Ground-water samples were collected from wells in the Chipuxet, Queen-Usquepaugh and Upper Wood River basin aquifers. Samples were collected from private wells and from observation wells installed by the U.S. Geological Survey where possible. Private wells were chosen on the basis of a survey sent to homeowners. Only those wells for which depth and aquifer material information were available were sampled. Field analyses included electrical conductance, pH, dissolved oxygen, and temperature. Analytical determination of calcium, magnesium, sodium, potassium, fluoride, chloride, nitrate, phosphate, sulfate, alkalinity, iron and silica were performed in the University of Rhode Island, Department of Geology, Hydrogeology Laboratory.

Mass balance modeling, to account for the mass of reactants and/or products that must dissolve and/or precipitate to account for the observed chemistry, was completed for the average water chemistry of bedrock, deep surficial and shallow surficial ground water in each of the aquifers. The composition of the parent minerals and the possible reaction products used in the mass balance modeling were determined in phase one of this study.

PRINCIPAL FINDINGS AND SIGNIFICANCE:

Geology

The Chipuxet aquifer is underlain by the Ten Rod Granite Gneiss, part of the Esmond plutonic suite. The Queen-Usquepaugh aquifer is underlain by Hope Valley

Alaskite Gneiss and the Upper Wood aquifer is underlain by the Hope Valley Alaskite Gneiss throughout much of its extent, however, the northern section of the aquifer overlies Scituate Granite Gneiss. The gross mineralogy of each of these rock types is similar, with sodic plagioclase, potassium feldspar, and quartz comprising more than 90% of the rock matrix. Accessory minerals include biotite, hornblende, magnetite, sphene and apatite in varying amounts, but generally less than 5% and in most cases less than 2%. The relative abundance of the accessory minerals varies between these rock types, but also may vary substantially within a rock type. The only significant difference in accessory minerals is the absence of apatite in the Hope Valley Alaskite Gneiss.

Water Chemistry

Distinctive chemical characteristics were found in each of the three bedrock aquifers systems investigated, and even greater differences were noted between the composition of ground in the overlying surficial material (stratified drift) and that of the bedrock ground water. Ground water in the bedrock is characterized by higher electrical conductivity, pH, and alkalinity than that of stratified drift ground water. In particular, silica, calcium, magnesium and potassium concentrations were found to increase both with depth within the surficial material and between the surficial material and the bedrock. Distinctive chemical signatures include the abundance of silica in Chipuxet bedrock ground water (avg. 20-25 mg/L) as compared to the other two aquifer studied (avg. 9-13 mg/L). and the absence of fluoride in ground-water from the Queen-Usquepaugh bedrock aquifer. Bedrock ground water from the Queen-Usquepaugh aquifer is also poor in sodium and enriched in calcium relative to the Upper Wood and Chipuxet aquifers.

The ground water chemistry compares favorably to the water chemistry produced in the water-rock interaction experiments in phase one of this study. The sodium to silica and calcium to silica ratios of Chipuxet bedrock ground water are the same as those observed in the Ten Rod Granite leachate, and those of the Upper Wood and the Queen-Usquepaugh are only slightly higher than those observed in the Hope Valley Alaskite Gneiss leachate.

Discussion

The chemistry of ground water in each of the aquifers is similar in many respects because of the similarity of the rock mineralogies. However, accessory can have a profound impact on the water chemistry and may provide the most useful indicator of reaction with a particular rock type. The absence of fluoride in Queen-Usquepaugh ground water is attributed to the absence of apatite in the Hope Valley Alaskite Gneiss. High fluoride concentrations observed in the Upper Wood (which also overlies Hope Valley Alaskite Gneiss) may be indicative of flow from the Scituate Granite Gneiss to the north. Anomalously high concentrations of dissolved constituents in stratified drift ground water and anomalously low concentrations in bedrock ground water have also been observed. This is tentatively attributed to a hydraulic connection between the two flow systems. Although additional field work is required to conclusively demonstrate that this connection exists, these findings suggest that the assumption of no-flow between the stratified drift and bedrock flow systems may be flawed in some areas.

SYNOPSIS

Project Number: 05 *Start*: June 1, 1992
End: May 31, 1993

Title: *TOXIC ORGANIC CHEMICALS IN RHODE ISLAND GROUNDWATER: CONTAMINANT FATE AND TRANSPORT*

Investigators: Amy P. Gamerdinger, Department of Natural Resources Science
University of Rhode Island

Focus Categories: TS

Congressional District: Second

Descriptors: Fate of Pollutants, Organic Compounds, Contamination, Toxic Wastes, Groundwater Pollution, Groundwater Quality

Problem and Research Objectives:

An estimated 24% of Rhode Island's population obtain their drinking water supply from groundwater, thus, preserving groundwater quality is important for human and environmental health. Organic chemicals are among the principal contaminants, from a variety of sources, which are found in Rhode Island groundwater.

An understanding of the fate and transport of organic chemicals in soils and groundwater sediments is necessary for addressing several groundwater quality issues such as: estimating the travel time of potential groundwater pollutants from the point of release to drinking water supply wells, the amount or concentration of the contaminant that will ultimately be present in the wells, and contaminant removal rates from soil and groundwater when cleanup and remediation strategies are employed.

Most of our current understanding of organic contaminant behavior in soil and groundwater is based on studies conducted for a single chemical in a completely aqueous system. In the environment, we often have complex mixtures of chemical contaminants in aqueous systems where organic solvents are also likely to be present. We know that the fate and transport of an organic chemical will be influenced by the presence of other contaminants and solvents. In order to properly assess organic pollutant fate and transport from waste sites or leaking fuel storage tanks, we need to consider contaminant behavior in the presence of other chemicals, such as organic solvents, which are known to influence fate and transport.

Our project considers the fate and transport of toxic organic chemicals in the presence of organic solvents which are known to modify pollutant behavior. We specifically address the two most important processes, retardation and attenuation, which influence contaminant fate and transport. Retardation describes contaminant-sediment interactions which slow the movement of the pollutant through the sediment. Attenuation describes the reduction in pollutant concentration due to transformation and degradation (destruction of the pollutant) by chemical and biological processes. General use of the term sediment includes surface and subsurface material.

The specific objectives of this two-year project are three-fold: a. To describe the fate and transport of organic pollutants in the presence of organic solvents; b. To modify existing mechanistic process descriptions and parameters which were derived from studies of a single chemical in an aqueous (100% water) system; c. To provide a means for incorporating modified process descriptions into currently existing environmental fate models.

Methodology:
Solvent-water partitioning, sediment-water partitioning, and miscible displacement techniques were adapted to characterize contaminant retardation and transport. Bacterial isolation and growth techniques were adapted to obtain and maintain bacterial populations. Bacteria which transform and mineralize PAHs (polycyclic aromatic hydrocarbons, a class of organic chemical contaminants) were used in mineralization experiments (closed flask system) to assess contaminant degradation.

Principle Findings and Significance (to date):

Solvent-Water partitioning
Partitioning of naphthalene in biphasic solvent-water systems was similar for the 4 solvents evaluated: hexane, decane, dodecane, hexadecane.

Bacterial Isolation: We isolated a bacterium from local soil in the vicinity of an underground oil storage tank. Standard enrichment culture techniques were used. The bacteria (pure culture) were able to use several of the polycyclic aromatic hydrocarbons, PAHs, (naphthalene, anthracene and pyrene) as substrates for growth; complete mineralization of the hydrocarbon substrate naphthalene to CO_2 was confirmed with radioisotope techniques. This bacteria was used as the inoculum in subsequent studies of naphthalene degradation and mineralization in solvent-water and sediment-water systems.

Hydrocarbon biodegradation surface and subsurface soil systems:
Complete degradation of naphthalene in the presence of 3 soils (2 surface and 1 aquifer material) was measured. The extent of degradation was positively correlated with the organic carbon content of the soil, suggesting that organic matter from the soil enhanced degradation. Degradation was reduced when water-soluble organic matter was removed from the two surface soils. These results suggest that enhanced degradation is positively correlated with the amount of organic carbon available via the aqueous phase. This could result from increased substrate availability due to the cosolvency effect of the water soluble fraction of the soil organic matter, or, due to growth of the bacteria on this water-soluble fraction of organic matter. Further experimentation and evaluation is required to understand the mechanism and under what conditions enhancement will be observed.

Hydrocarbon biodegradation biphasic solvent-water systems:
Complete degradation of naphthalene in the presence of 4 organic nonaqueous phase liquids (hexane, decane, dodecane, hexadecane) was evaluated. The extent of degradation was enhanced in the presence of the more hydrophobic organic solvents.

This could be due to a direct effect on the microorganism, or due to indirect effects such as increasing substrate availability to the bacteria. We suspect that degradation will be diminished in the presence of more hydrophilic solvents. Further experimentation is required to establish the relationship between solvent properties and their effect on biodegradation.

Concise summary of most important findings to date:
Bacteria which degrade PAHs were present in hydrocarbon contaminated soil. The bacterial population was viable in the presence of hydrophobic organic solvents (alkanes with chain length of 10 or greater). These solvents are also classified as L-NAPLs (nonaqueous phase liquids which are less dense than water). The overall extent of naphthalene degradation to CO_2 was enhanced in the presence of selected organic solvents, although the initial rate was slower. This suggests that contaminant degradation is a function of the mixture of contaminants that may be present on-site. Understanding the controlling mechanisms is important for predicting contaminant fate and for optimizing bioremediation strategies.

There are no completed publications to date from the first year of work.

Three manuscripts are planned; several experiments must be completed for each manuscript.

A proposal based on the findings of this work is in preparation and will be submitted to the DOE subsurface science program.

INFORMATION TRANSFER ACTIVITIES

Synopsis

Project # 22

Title: Information Transfer Project

Project Duration: September 1, 1992 - May 31, 1993

Principal Investigators: Leon T. Thiem and Calvin P.C. Poon

Graduate Student Vincent L. Jacques

Various methods of informing the public on important water resource issues covered under this project included the publication of four (4) Water Resource Center (WRC) newsletters, seven (7) seminars presented by principal investigators of projects previously or currently funded by the State Water Research Institute Program, three (3) Citizen Forums concerning controversial water related issues, the beginning of a State Water Resource Directory, which will provide information on individuals involved with water resources in Rhode Island, and the compilation of completion reports for the other FY-1992 funded State Water Research Institute Program projects.

Topics covered in the four newsletters included various excerpts form other water related newsletters and journals, up-dates on Rhode Island's most controversial water issues such as the Cross Bay Pipeline and Rhode Island's drinking water coliform problem, as well as briefings on the activities of the WRC describing past and upcoming seminars and Citizen Forums. These newsletters were distributed to all the other Water Resource Centers throughout the country (including some U S. Territories) as well as to professionals in Rhode Island involved in the water field.

Seven seminars were advertised and presented during this project by Principal Investigators of previously or currently funded projects by the WRC. The seminars were attended by both undergraduate and graduate students as well as professionals from the outside. Speakers and topics of these seminars included the following:

Dr. Richard Hull	Nitrate
Daniel Wise	Feasibility Study of the Use of Composted Municipal sewage Sludge as a Landfill Cover
Professor George Tsiatas	Potential Ground Water Yield of the Big River Area Including Recharge from the Big River Reservoir
Terry Walsh	Environmental Education: Water Protection, Management and Conservation
Professor Anne Veeger	Geochemical Controls on Ground Water Chemistry in the Pawcatuck River Basin in Southern Rhode Island
Lewci Shi & Yan Li	Potential Pesticide Contamination of Groundwater and Surface Water in Rhode Island

Three Citizen Forums discussing controversial water issues in Rhode Island were held during this project. These forums were well advertised and were attended by students, professionals and the general public.

The first Citizen Forum was held on December 1, 1992 at the University of Rhode Island and was titled "The East Bay Water Dilemma". Speakers and topics discussed included the following:

Mr. Michael Cooney; Manager of Accounting and Data Systems for the Bristol County Water Authority
- Up-to-date history of Bristol County Water Authority
- Condition of existing infrastructure
- Present and future needs of BCWA
- Cross-Bay Pipeline as proposed
- Connection to East Providence
- Recommendations

Mr. Daniel Varin; Associate Director. RI Division of Planing, Department of Administration
- Political aspects of the east Bay Water Dilemma
- Related past and speculated future legislation
- East Bay Task Force accomplishments and recommendations
- Ramifications of recommendations
- Current status of law suit E. Providence vs. BCWA, WRB, etc.

Mr. Russell Ross, Vice President, Camp, Dresser & McKee
- Scope of work hired to do
- Results, conclusions, and recommendations of study
- Economics involved with each alterative
- Review of audio-visuals (maps indicating alternatives proposed)

Mr. Richard Rafanovic; Chief Engineer/General Manager, Providence Water Supply Board
- Safe yield of Scituate Reservoir
- Legal/contractual obligations for Scituate Reservoir Water
- Compilation and Comprehensive Water Plans
- Recommendations

Ms. Ellen Greiner; Rhode Island Audobon Society
- Supply and demand options available to BCWA
- Water conservation tactics
- Infrastructure improvements
- Recommendations

The second Citizen Forum was held on March 10, 1993 at the Community College of Rhode Island, Flanagan Campus, in Lincoln, RI and was titled "Rhode Island's Coliform Plague". Speakers and topics discussed included the following:

Dr. Victor Cabelli; Professor, Microbiology Department, URI
- Definition, history and background of fecal coliform
- Brief description of risks to human health
- Brief discussion on Rhode Island's specific problems and concerns

June Swallow, P.E.; Chief of Drinking Water Quality Section, Rhode Island Department of Health
- Past, present and expected future regulations of fecal coliform in drinking water
- Associated risks to human health
- Brief discussion on Rhode Island's specific problems and concerns

Wiley Archer, P.E., Chief Engineer, Pawtucket Water Supply Board

- Brief history on Pawtucket's water supply infrastructure
- Overview of specific problems and causes for last summers coliform incident in the Pawtucket area
- Future safeguards to prevent another incident
- Associated economics concerning Pawtucket's coliform situation

Jack Keaney; Associate, Camp, Dresser & McKee
- Solutions provided for the city of Pawtucket
- Other general engineering solutions available for such incidents
- Preventive maintenance
- Existing engineering studies about fecal coliform

The third and final Citizen Forum was held on April 27, 1993 at the Community College of Rhode Island, in Warwick, RI and was titled "The New Drinking Water Regulations and Its Effect on Small Utilities". Speakers and topics discussed included the following:

Kevin Reilly; Drinking Water Expert, U.S. EPA Region I
- General background and implications of new regulations
- Monitoring and sampling procedures that are necessary
- Time schedule for implementation and compliance
- RI and MA role in implementing new regulations
- Availability of assistance to small utilities that can't afford compliance

June Swallow, P.E., Chief of Drinking Water Quality Section, Rhode Island Department of Health
- Application and implementation of new regulations as they pertain to RI
- Differences between EPA recommendations and RI plans of implementation
- Monitoring, sampling and time schedule for compliance
- Availability of assistance to small utilities that can't afford compliance

George Zoto; Mobilization Coordinator, Division of Water Supply. MADEP
- Application and implementation of new regulations as they pertain MA
- Differences between EPA recommendations and MA plans of implementation
- Monitoring, sampling and time schedule for compliance
- Availability of assistance to small utilities that can't afford compliance

Henry Meyer; Manager, Kingston Water District
- Expectations of how new regulations will effect the Kingston facility as well as other utilities in RI
- Associated costs and time schedules involved with becoming in compliance
- Other related concerns that small RI utilities have

The objective of each of these forums was to provide the public an opportunity to hear facts concerning these controversial water issues and how they actually effect the public. The forums also provided the public with the chance to ask questions to the panel of speakers concerning these important issues.

Also during this Information Transfer Project, a Water Resource Directory for the State of Rhode Island was begun. The directory will be a valuable source of information for all those individuals involved with water resources in Rhode Island. Upon completion, the database will contain information on all individuals involved with water in governmental agencies (RIDEM, RI Department of Health, U.S. EPA, USGS), in wastewater treatment, in water utilities of all sizes, and in research at all State Universities and schools.

In addition to the activities aforementioned, the drafted booklet entitled ELECTROFLOTATION was reviewed and approved by the RI Department of Environmental Management. The booklet targets State regulating agencies, Providence Chamber of Commerce, and the metal plating industry who could use the information concerning a low cost treatment technology developed by the Rhode Island Water Resources Center as the result of a technology development grant. The booklet was published and two hundred copies were distributed.

COOPERATIVE ARRANGEMENTS

The Water Resources Center at the University of Rhode Island has two advisory committees, namely the State Advisory Committee and the University Water Resources Coordinating Committee. The membership has been changed in the past year, reflecting the recent interest and availability of water resources experts in Rhode Island.

State Advisory Committee

Falcone, William	Water Resources Board
DeLima, Virginia	U.S. Geological Survey
Meyer, Henry	Kingston Fire District
Miller, Scott	Office of System Planning, Dept. of Administration
Rose, Vincent	Save the Bay
Salomon, Erich W.	Armbrust Chain Co.
Scott, Elizabeth	Office of Environmental Coordination
Stuart, Kristine	U.S. Dept. of Agriculture
Varin, Daniel W.	Dept. of Administration

The state advisory Committee is consisted of leading water resources officials of the state and federal agencies as well as representatives from prominent citizen groups and manufacturers.

The other committee is the University Coordinating Committee, consisting of faculty members of the University of Rhode Island from various colleges and the director of the Sea Grant program. Each member has a significant contribution to academic and research programs related to water the resources area.

University Coordinating Committee

Cain, J. Allen	Professor and Head of the State Geologist Office
DeLuise, Frank	Professor, Mechanical Engineering
Frohlich, Reinhard K.,	Professor, Geology
Gold, Arthur	Associate Professor
Miller, Robert H.	Dean, College of Resources Development
Nixon, Scott	Professor, Coordinator of Sea Grant Program
Calvin P.C. Poon	Professor, Environmental Engineering

The two committees met and discussed water resources issues and research priorities for the FY-1992 State Water Research Institute Program. As a result of the discussion and suggestions from the committee members, the research priorities were established as listed on page 3 of this report. Both committees also reviewed and ranked research proposals, made comments and suggestions of proposal alterations. They also served as points of contact to collect and to disseminate information to various groups of audience.

Project 02 worked closely with U.S. Department of Agriculture, Soil conservation Service and with the Cooperative Extension Service at the University of Massachusetts, as well as the commercial turf producers and landscaper managers in Rhode Island.

Project 03, by nature of its work, had close cooperation with the Agricultural Stabilization and Conservation Service, Soil Conservation Service, the GIS group and the Groundwater/ISDS Division of the R.I. Department of Environmental Management, as well as the agricultural extension service at the University of Rhode Island.

Project 04 worked closely with USGS subdistrict office in sample collections.

The project on information transfer worked with the Rhode Island Department of Environmental Management and citizen groups in Rhode Island.

PUBLICATIONS

1. <u>Referred Scientific Journal</u>

	Supporting Sction 104 Project No.
Hesketh, E.S., R.J. Hull and A.J. Gold, 1993. Estimating non-gaseous nitrogen lossess from established turf. Jour. Turfgrass Management In press.	02- (FY-92)
Hull, R.J., S.R. Alm and N. Jackson, 1993. Toward sustainable lawn turf. In A.R. Leslie(ed) Integrated Pest Management for Turfgrass and Ornamentals. In press	02 (FY-92)

3. <u>Dissertations</u>

Li, Shi-wei, 1993, Long Term Prediction of Insecticide Concentrations in Community Drinking Wells in Rhode Island. MS thesis, Dept. of Civil-Environmental Engineering College of Engineering, University of Rhode Island Kingston, R. I. In preparation	03- (FY-92)
Li, Jan, 1993. Use of PCGEMS in the Simulation of Insecticide Migration within Wellhead Protection Area of Kingston Wells. MS thesis Dept. of Civl-Environmental Engineering, College of Engineering, University of Rhode Island, Kingston, R. I. In preparation.	03 (FY-92)

4. <u>Water Resources Research Institute Reports</u>

Hull, R.J., P.M. Groffman, H. Lin, 1993. Controlling Nitrate Contamination of Groundwater Following Fall Fertilization of Turf. Technical Completion Report Water Resources Center, University of R.I. Kingston, R. I. 39 pgs.	02 (FY-92)
Veeger, A., 1993. Field assessment of Geochemical Control on Groundwater Chemistry in the Pawcatuck River Basin of South Rhode Island. Technical Completion Report, Water Resources Center, University of Rhode Island, Kingston, R.I.	04 (FY-92)

Poon, C.P.C. and W.M. Sullivan, 1993. Potential Pesticide Contamination of Groundwater in Rhode Island, Technical Completion Report for FY-1992. In preparation	03 (FY-92)

5. Conference Proceedings

Hull, R.J., H. Liu and P.M. Groffman, 1992. Nitrate Losses from six Organic Nitrogen Sources Applied to turf in the Fall. Water Resources Center University of Rhode Island Kingston, R.I. Agronomy Abstract 84:70	02 (FY-92)
Hull, R.J., H. Liu and P.M. Groffman, 1993. Nitrogen Lossses from Six Organic N Sources Applied to Four Turfgrasses in the Fall. Water Resources Center University of Rhode Island Kingston, R. I. Agronomy Abstract 85. In press	02 (FY-92)
Veeger, A.I. and K.L. Moulton, 1993. Low-Temperature Water-rock Interactions in Bedrock Aquifers of South Rhode Island: Results of Laboratory Simulations {abstr} in Geological Society in America, Abstracts with Program, Burlington, Vermont. Vol. 25. No.2. p.86	04 (FY-92)
Holden, J.B. and A.J. Veeger, 1993. The Effect of Human Activities on the Quality of Groundwater in the Chipuxet Aquifer, Rhode Island: {abstr.}, in Geological Society of America, Abstract with Program, Burington, Vermont, Vol. 25, No.2, P.24.	04 (FY-92)
Moulton, K.L. and Veeger, A.L., 1992. Low-temperature Chemical Reactions in Granite and Mafic Aquifiers: a laboratory study: {abstr.}, in Geological Society of America, Abstracts with Program, Cincinnati, Ohio, Vol. 24, No.7, P.A169.	04 (FY-91)

6. Other Publications

Poon, Calvin P.C., June 1993, Electroflotation, RI Dept. of Environmental Management and RI Water Resources Center, University of Rhode Island, Kingston, RI, 16 pgs.	22 (FY-92) S1 (FY-90)
Hull, R.J., 1992, Minimizing Nitrate Leaching from Turf. Turf Notes 2(G): 1-4	02 (FY-92)

TRAINING ACCOMPLISHMENTS

	Academic Level				
Field of Study	Undergraduate	Master's Degree	Ph.D. Degree	Post-Ph.D.	Total
Engineering					
Environmental		3			3
Geology		1			1
Plant Science	2	1			3
Natural Resources Science		1			1
	2	6			8

PROGRESS REPORT

POTENTIAL PESTICIDE CONTAMINATION OF GROUNDWATER & SURFACE WATER IN RHODE ISLAND

M. Sullivan, C.P.C. Poon, 1992

1892

WATER RESOURCES RESEARCH INSTITUTE
THE UNIVERSITY OF RHODE ISLAND

PROGRESS REPORT

POTENTIAL PESTICIDE CONTAMINATION OF GROUNDWATER AND SURFACE WATER IN RHODE ISLAND
FY-1991

Content:

PROJECT SUMMARY

Project: Potential Pesticide Contamination of Groundwater and Surface Water in Rhode Island

TABLE OF CONTENTS

APPENDICES

A. Files:

1. **Chemical Data.** An effort has been made to find literature values for all of the parameters in Table I for all of the pesticides in Table II. The chemicals for which sufficient data have been located to be able to run the SESOIL model are listed in the left two columns of Table II; those which cannot be modelled due to insufficient data are listed in the right column. [Note: An acronym glossary can be found in Appendix A.]

TABLE I - CHEMICAL PARAMETERS - LITERATURE VALUES

1) CHEMICAL NAME
2) SMILES
3) CASNO
4) PHYSICAL STATE (S,L OR G)
5) LOG KOW
6) BOILING POINT (C)
7) MELTING POINT (C)
8) WATER SOLUBILITY AT 25 C (PPM)
9) VAPOR PRESSURE AT 25 C (TORR, mmHG)
10) HENRY'S CONSTANT AT 25 C (M**3*ATM/MOL)
11) KOC
12) AIR DIFFUSION COEFFICIENT (CM**2/SEC)
13) COMPOUND VALENCE
14) NEUTRAL HYDROLYSIS CONSTANT (1/DAY)
15) BASE HYDROLYSIS CONSTANT (L/MOL/DAY)
16) ACID HYDROLYSIS CONSTANT (L/MOL/DAY)
17) LIQUID BIODEGRADATION RATE (1/DAY)
18) SOLID BIODEGRADATION RATE (1/DAY)

TABLE II - TARGET CHEMICALS

CAN BE MODELLED

2,4-D
Alachlor
Aldicarb
Atrazine
Benfluralin
Carbofuran
Chlorthalonil
Chlorpyrifos
Dicamba
Ethalfluralin
Fonofos
Isofenphos
Linuron
Mecoprop
Methamidophos
Methomyl
Metribuzin
Oxamyl
Pendimethalin
Permethrin
Terbufos
Trifluralin

CANNOT BE MODELLED

Acephate
Bendiocarb
Bensulide
DCPA
Endosulfan
EPTC
Fenvalerate
Maneb
Metalaxyl
Methyl parathion
Metiram
Metolachlor
Siduron

Sources for pesticide data include the EPA One Liner database and the NPURG database. Printed sources include the Handbook of Chemical Property Estimation Methods by

Dr. Alm.

Lymen, Reehl, and Rosenblatt and The Pesticide Manual by Worthing, et al, of the British Crop Protection Council.

2. **Soils.** The Soil Survey of Rhode Island has been used to determine the soil type at each well and on each farm of interest. The soil type description provides each soil layer depth, the permeability, the pH and the topographical slope. NPURG has been used to determine the approximate organic matter content of each of these soils.

3. **Wells.** Each municipal water supply well of interest has been located on a USGS topographical map. Longitude and latitude coördinates needed to pinpoint these wells were provided by GIS. USGS water table maps and bulletins were used to determine well, water table, and bedrock elevations.

   Wellhead Protection Areas (WHPAs) have been provided by DEM (Margaret Dein Bradley) by way of allowing the GRA to trace them onto the project's topo maps at the DEM office. Unfortunately, the designation of WHPAs by DEM is proceeding slowly and only four of the wellfields of interest have had them assigned so far. These are URI, Kingston Fire District, Annaquatucket (North Kingstown), and the Kent County Hunt River wells.

4. **Weather Data.** The monthly record of daily weather observations from the Kingston Weather Station has been provided by RI State Climatologist Dr. Carl Sawyer for every month from January, 1970, to the present. Average annual data for Providence (T.F. Green Airport) are included in the PCGEMS database.

5. **Weather Analysis.** Over 21 years of daily weather observations have been processed to yield climate data in the form needed by SESOIL. A compilation of the analytical results has been provided back to Dr. Sawyer by separate correspondence dated 19 May 92 and is also included as Appendix B to this report. The results include number of storms per month and their duration. This information will be used only for wellfields near to South Kingstown for which a pesticide application history has been reconstructed. For long-term simulation, average climatological data from the nearest weather station to the site will be used.

6. **Crops/Farms.** Farms which may be in the recharge areas for the wells of interest have been designated. Soils have been identified using the Soil Survey, as previously described. Measurement of areas of fields and identification of crops grown have been attempted by examination of aerial photos, consultation with the ASCS, and direct roadside surveillance. This file has the most serious need for

additional information. Specific crop data is the most difficult to come by, particularly where crops have changed or been rotated over the years. Farmers are not being contacted directly for this information.

7. **Pesticide Application.** Determination of pesticide applications relies heavily upon the knowledge and expertise of State Extension Agent Dr. W. Michael Sullivan, co-PI on this project. If it can be determined which crops were grown on a particular field and when, Dr. Sullivan knows which pesticides were most likely applied. Using brochures, such as the 1992 New England Guide to Weed Control in Turfgrass and the Agway White Potato Planning Guide, application rates (active ingredient per acre) can be determined. Any speculation regarding applications must be approved by Dr. Sullivan. If a range of application rates is possible, the high end is used for modelling, as the worst case.

B. Data Management

1. **Transformation of Climatological Data.** SESOIL requires climatological data in a particular format. The parameters needed are average monthly temperature, average annual fraction of sky covered by clouds for each month, average monthly relative humidity, average annual shortwave albedo of the surface for each month, monthly precipitation, monthly average storm duration, and number of storms during each month. While some of this data is available in usable form, some is not. It was necessary for the GRA to actually process 21 years of monthly reports, counting storms and calculating storm durations. See Appendix B.

2. **Recreation of Pesticide Application Histories.** The most extensively modelled field so far is URI field K5, located at the corner of Plains Road and 30 Acre Road, across the street from the Sherman Building. Through consultation with Dr. Sulivan, a probable history of the field from 1974 to the present has been constructed. It is presented as Appendix B to this report. The history includes crops grown, pesticides applied, application rates, and an application schedule. Such histories will be attempted for other sites, but the data on what crops were grown on which fields over a period of years is mostly inaccessable.

3. **Assembly of Chemical Data.** Sources for pesticide data include the EPA One Liner database and the NPURG database. Printed sources include the Handbook of Chemical Property Estimation Methods by Lymen, Reehl, and Rosenblatt and The Pesticide Manual by Worthing, et al, of the British Crop Protection Council. The two pieces of chemical information without which SESOIL will not work are the SMILES code and

the octanol/water partition coefficient, K_{ow}, usually given in the form of log K_{ow}. The SMILES code is a symbolic representation of the actual chemical structure. The value of K_{ow} represents the tendency of the chemical to partition itself between an organic phase (e.g., soil) and the aqueous phase. In paragraph A.1, Table II, above, those pesticides which are listed as "cannot be modelled" are so listed because either the SMILES code or a value for K_{ow} has not been located. These have even been requested from EPA by letter using the Freedom of Information Act, with only minor success. Other chemical characteristics which can affect the results, but without which SESOIL will run, are listed in paragraph A.1, Table I. Of these, the hydrolysis and biodegradation constants and the organic carbon adsorption coefficient (K_{oc}) have been the most difficult to find. To complicate matters, K_{oc} is also soil dependent, but the separation of values based on soil type is nearly non-existent.

C. Description of a Typical Simulation

Four types of files must be generated in order to run a SESOIL simulation: climate, soil, chemical, and application.These are described below:

1. **Climate.** There are two basic choices in this category: (1) use long-term annual averages which are available for Providence in the SESOIL database, or (2) use actual data, such as is available from the Kingston Weather Station. The actual data will be used only for wellfields near to South Kingstown for which a pesticide application history has been reconstructed. For long-term simulation, average climatological data from the nearest weather station to the site will be used.

2. **Soil.** The soil type is determined from the Soil Survey, then the data obtained from there is combined with the data from the SESOIL soil database.

3. **Chemical.** The chemical property estimation program PCCHEM, which is part of PCGEMS, is used to generate a chemical file. The input required to do this are listed among the properties in paragraph A.1, Table I. SMILES and log K_{ow} are absolutely required, but PCCHEM will estimate any of the other missing characteristics. A SESOIL chemical file is created from the PCCHEM file, plus the remaining properties in Table I, e.g., hydrolysis and biodegradation constants.

4. **Application.** Application files have two basic parts. The second and simplest part is the application schedule in which the application rate is specified, along with the month and year of application. The first part requires a great deal of soil data, plus some important decisions on

the part of the modeller. Information regarding the pH, permeability, liquid and solid phase biodegradation, organic carbon content, cation exchange capacity, Freundlich exponent and adsorption coefficient for each soil layer can be entered. Simplistic defaults are provided for all of these. It is left to the user to choose layer thicknesses. In doing so, the user must consider layer thicknesses given in the Soil Survey, as well as the intention of the particular model. However, no firm rules are given for determining these thicknesses, except that the top layer ought to be thin (say, 15 cm).

D. Simulations Run

The following simulations have been run, all of them based on URI field K5, whose soil type is Enfield silt loam. This concentration on just one field is justified as follows:

(a) Sufficient information was available to construct a relatively reliable 17 year pesticide application history for the field.

(b) This history has sufficient variety, with potatoes, turf, sorghum, and hay being grown, that the information, once gathered for this site, would probably be useful in modelling the majority of sites throughout the state.

(c) Given the variety of crops grown on the site, the following 12 pesticides were all likely used here: Bensulide, Pendimethlin, EPTC (Eptam), Aldicarb (Temik), Maneb, Vydate L (Oxamyl), Thiodan 50W (Endosulfan), Monitor 4-E (Methamidophos), Guthion SC (Azinphos-Methyl), Furadan (Carbofuran), Lannate (Methomyl), and Atrazine. These are listed in the order presented in Appendix C.

(d) This field lies beside the Kingston weather station, therefore the real data from the station, rather than seasonal averages, could be used in the models.

1. **Model K5 Atrazine Rev.0.** This model was run for the period 1980-1990 (80s decade), without hydrolysis or biodegradation factored in. Total depth modelled is 64 cm, which is approximately equal to the 25 inch depth given by the Soil Survey for the less permeable top layer of this soil. It is divided into 4 layers of the following thicknesses (cm): 12, 12, 20, and 20. The assumption which is the basis for modelling only the top 2 feet of soil is that this soil is less permeable than that below it, therefore any pesticides which pass through it will end up reaching the water table. In addition, the primary constituent of the soil which

affects the mechanisms which will prevent pesticides from passing through is organic carbon (OC). OC is located primarily at the surface and drops off with depth. The assumed ratios of OC in each layer to OC in the top layer are as follows for layers 1, 2, 3, and 4: 1.0, 0.5, 0.2, and 0, respectively. Dr. Sullivan concurs that these are reasonable assumptions.

2. **Model K5 Atrazine Rev.1.** This model is the same as Rev. 0, except that a hydrolysis constant of 0.00332 day^{-1} is factored in. Often hydrolysis is specified in terms of half-life, $t_{½}$, in this case, 209 days. The constant is calculated from the following equation: $c = (\ln 2) / t_{½}$. Even though hydrolysis is a process strongly dependent on pH, frequently the data needed to determine the constant at different pHs is lacking. In this case, the single constant was used for neutral, acid, and base hydrolysis.

3. **Model K5 Atrazine Rev. 2.** This model is also the same as Rev. 0, except this time liquid and solid phase biodegradation constants of 0.216 day^{-1} and 0.019 day^{-1}, respectively, are factored in. These are calculated from the half-lives in the same manner as the hydrolysis constants, above.

4. **Model K5 Atrazine Rev. 3.** This model combines the previous models by taking into account hydrolysis and biodegradation at the same time.

5. **Model K5 Atrazine Rev. 4.** This model is chemically the same as Rev. 3, but the total depth to groundwater is considered, rather than just the top layer. The groundwater depth is estimated to be about 23 feet, or about 7 m. The layer thicknesses have therefore been chosen as 15, 49, 318, and 318 cm, top to bottom. OC in the second layer is assumed to be 20% of OC at the surface. Biodegradation is assumed to be fully active in the top two layers and absent below. SESOIL deals with layers of different permeability by taking a weighted average of the values provided and assuming this average is the permeability for the entire column. In this case, the soil below the first 64 cm has a permeability about an order of magnitude higher, therefore the model will be skewed towards this higher permeability. This will result in the liquids travelling faster through the top layer than they would in reality, causing them to have less exposure time to the OC and to the processes which center around it.

6. **Model K5 Methamidophos Rev. 0.** This model was run for the period 1970-1980 (70s decade) with both hydrolysis and biodegradation active. Total depth modelled was 64 cm, using the same soil data as above.

7. **Model K5 Methamodophos Rev. 1.** This model is the same as Rev. 0, except there is no hydrolysis or biodegradation.

8. **Model K5 Methamidophos Rev. 2.** This model is the same as Rev. 0, except that the total depth modelled was 7 m, using the same soil data as in Model K5 Atrazine Rev. 4.

9. **Model K5 Aldicarb Rev. 0.** This model was run for the 70s decade with hydrolysis only, as no biodegradation data was available. Total depth modelled was 64 cm, using the same soil data as above.

10. **Model K5 Aldicarb Rev. 1.** This model is the same as Rev. 0, except that the total depth is again 7 m.

11. **Model K5 Methomyl Rev. 0.** This model was run for the 70s decade with both hydrolysis and biodegradation active. Total depth modelled was 64 cm, using the same soil data as above.

12. **Model K5 Methomyl Rev. 1.** This model is the same as Rev. 0, except that the total depth is again 7 m.

13. **Model K5 Carbofuran Rev. 0.** This model was run for the 70s decade with both hydrolysis and biodegradation active. Total depth modelled was 64 cm, using the same soil data as above.

14. **Model K5 Carbofuran Rev. 1.** This model is the same as Rev. 0, except that the total depth is again 7 m.

15. **Model K5 Pendimethalin Rev. 0.** This model was run for the 80s decade with biodegradation. Pendimethalin is not subject to significant hydrolysis. Total depth modelled was 64 cm, using the same soil data as above.

E. Results

1. In the briefest of terms, atrazine, methamidophos, aldicarb, methomyl, and carbofuran all passed through the top, less permeable 25 inches of soil relatively quickly, implying that they would all reach the water table in a matter of months to a couple of years. Only pendimethalin was nearly immobile.

   This is all that can be said with a high degree of confidence. The more detailed results discussed below are all subject to the vagaries of the model, the assumptions, and the lack of accurate input data. Although the absolute numbers must be used with great caution, it should be safe to make comparisons between datasets in order to determine relative effects.

2. The peak concentrations of pesticides in the soil moisture at the bottom of the 64 cm models is presented below, along with the total width of the concentration curve. The narrower this curve is, the more quickly the pesticide is moving through the soil and heading for the water table.

Pesticide	Peak Concentration ($\mu g/ml$)	Curve Width (mos.)
Aldicarb	6.49	6
Methamidophos	0.481	2
Methomyl	0.198	16
Carbofuran	0.141	4
Atrazine	0.0130	6

3. From the data above, it is clear that aldicarb is the most mobile of the pesticides modelled. Indeed, aldicarb was found in the URI wells in the mid-1980s [see Urish and Spizuoco, "Chipuxet Aquifer..." in References], which can be taken as a most qualitative verification of these model results. In order to determine if any danger is posed by the presence of these pesticides, the concentrations need to be compared with the drinking water standards; this has not been done in this project to date.

F. Future Work

1. Future work directly with SESOIL will involve continuing to try to find the needed elusive input data and actually running more models. The approach will probably continue to be the intensive modelling of certain representative fields. The results will then be extrapolated to obtain the bigger picture.

2. Other work in the future may involve employing the PCGEMS AT123D groundwater model in order to determine the concentrations of pesticides actually reaching the wells. It appears that this model may not be structured in such a way that this could be done directly, so innovative approaches may need to be devised.

G. **References**:

Jenkins, Jeffrey J., Bagdon, Joseph K., Lyons, Joseph, and Hugo, Morgan S. National Pesticide/Soils Database and User Decision Support System for Risk Assessment of Ground and Surface Water Contamination (NPURG), Version 9.500. University of Massachusetts Coöperative Extension and USDA Soil Conservation Service, 1991.

Lyman, Warren J., Reehl, William F., and Rosenblatt, David. Handbook of Chemical Property Estimation Methods. McGraw-Hill Book Company, New York, 1982.

Rector, Dean D. Soil Survey of Rhode Island. USDA Soil Conservation Service, Washington, DC, 1981.

Regelman, Emil. One Liner Data Base, Version 3.04. EPA Environmental Fate and Ground Water Branch, Washington, DC, 1992.

Urish, Daniel W., and Spizuoco, William J. "Chipuxet Aquifer: Characteristics, Usage, and Management Considerations", Dept. of Civil and Environmental Engineering, University of Rhode Island, revised October, 1991.

Worthing, Charles R., et al. The Pesticide Manual, 7th Edition. British Crop Protection Council, Lavenham Press, Great Britain, 1983.

NDudziak:nd

APPENDIX A

ABBREVIATIONS USED

ASCS = American Soil Conservation Service
AT123D = Analytical 1-, 2-, and 3-Dimensional Simulation of Waste Transport in the Aquifer System
CASNO = Chemical Abstract Service Number
Co-PI = Co-Principal Investigator
DEM = RI Dept. of Environmental Management
EPA = US Environmental Protection Agency
GIS = RI Geographical Information System
GRA = Graduate Research Assistant
K_{ow} = Octanol/water partition coefficient
K_{oc} = Organic carbon adsorption coefficient
NPURG = **N**ational **P**esticide/Soils Database and **U**ser Decision Support System for **R**isk Assessment of Ground and Surface Water Contamination
OC = Organic Carbon
PCCHEM = Personal Computer version of the Chemical Property Estimation Program
PCGEMS = Personal Computer version of the Graphical Exposure Modelling System (GEMS)
SESOIL = Seasonal Soil Compartment Model
SMILES = Simplified Molecular Interactive Line Entry System
$t_{½}$ = Half-life
URI = University of Rhode Island
USGS = US Geological Survey
WHPA = Wellhead Protection Area

APPENDIX B

Project: Potential Pesticide Contamination of Groundwater and Surface Water in Rhode Island

Subject: Modelling of Kingston Weather

Enclosures:
(1) Kingston Weather Station Data 1970 - 1980
(2) Kingston Weather Station Data 1980 - 1990
(3) Kingston Weather Station Data 1990 - 1992
(4) Kingston Weather Data Sheet, February, 1970

The results of the weather data analysis performed by the graduate research assistant follow as enclosures (1) through (3).

The key to the data codes on the enclosures is as follows:

TA = average temperature for the month (°C) (Kingston actual)
NN = average annual fraction of sky covered by clouds for the month (Providence standard average)
S = average monthly relative humidity (actual Kingston data through December, 1988; Providence standard averages from October, 1990, onward)
A = average annual shortwave albedo of the surface (Providence standard averages)
REP = average daily evapotranspiration for the month (not provided)
MPM = monthly precipitation (cm.) (Kingston actual)
MTR = monthly average storm duration (days) (Kingston actual)
MN = number of storms during the month (Kingston actual)
MT = (not applicable)

The following is the list of steps and rules which were devised in order to accomplish this analysis. It should be kept with the analysis data provided so that any future users may be aware of its assumptions, strengths, and weaknesses. It will permit them to reproduce its results and therefore be confident that they are usable and consistent. Enclosure (4) is an actual weather data sheet which has been marked up in order to show a typical analysis.

1. Note the observation time (4:30 or 5:00 PM). In most cases, the rain gage reading was recorded at this observation time on the day it is listed.

2. If a storm is in progress at the observation time, its precipitation will be split among two or more observations.

3. When a storm or its observation period overlaps two months, special care is needed. As can be seen in enclosure (4), .21" of precipitation was recorded at the 5 PM observation on March 1, although no storms occurred on that date. This precipitation was part of the last February storm. If a storm actually overlaps two months, it counts as two separate storms.

4. Traces (T) count as zero (0) precipitation. If a period of precipitation has only a trace, it either does <u>not</u> count as a storm or does <u>not</u> count towards hours of duration.

5. No special provisions are made for snow, etc. The meltwater is treated identically to rain.

6. For any 24 hour observation period, compare the hours of rain to the number of 1/100 inches of rain. If the number of 1/100's is less than the number of hours, use the number if 1/100's <u>as</u> the number of hours, even if this falls entirely in the middle of a large storm, e.g.:

<u>Observation Time:</u> 4:30 PM

Day	Start	Finish	Start	Finish	Precipitation
1	10 AM	2 PM	3:30 PM	-	.03"
2	-	-	-	-	.21"
3	-	7:30 PM			.56"
4					.02"

Above, the first storm seems to last 4 hours, but the precipitation is only .03", therefore count the duration as <u>3 hours</u>.

The second storm seems to start at 3:30 PM, but since the allocation of precipitation was used up by the first storm, count it as starting at 4:30 PM. [Note: If the precipitation were allocated differently (e.g. 2 hours and 1 hour), it would actually have <u>no</u> effect on the monthly average.] Day 2 lasts 24 hours, but with precipitation of only .21", count it as <u>21 hours</u>. The observation period ending Day 3 endures <u>24 hours</u> of storm. The remainder of the storm seems to last from 4:30 PM to 7:30 PM, which is 3 hours, but the observation on Day 4 is only .02", so count this as <u>2 hours</u>.

Therefore:	<u>Storm 1:</u>	<u>Storm 2:</u>
	3 hours duration	21
		+ 24
		+ 2
		47 hours duration

7. For some storms, the amount of precipitation is given, but the beginning, ending, or both times are missing. When insufficient time data is available to determine the duration, a precipitation rate of .05 in/hr is assumed. The observed precipitation divided by this rate yields the maximum number of hours of precipitation. This is compared to the maximum number of hours available within the known time constraints (observation times, if nothing else), and the smaller of the two numbers counts as the duration. A survey of the rainfall data shows .05 in/hr to be a reasonable rate assumption.

Enclosure (1)

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           Oct    Nov    Dec
  Kingston Weather Station Data 1970-1980 Rev. 3      10
        ****  YEAR 1   ****| Jan    Feb    Mar    Apr    May   June   July    Aug   Sept.
TA        12.28  6.94 -1.11|-4.56   0.17   1.22   6.00  14.56  18.56  20.89  20.67  18.89
NN         0.54  0.64  0.69| 0.71   0.59   0.70   0.71   0.71   0.74   0.66   0.66   0.67
S     70   0.70  0.67  0.73| 0.72   0.58   0.56   0.64   0.69   0.76   0.69   0.71   0.79
A          0.18  0.19  0.27| 0.29   0.33   0.29   0.19   0.18   0.18   0.18   0.18   0.18 71
REP        0.00  0.00  0.00| 0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
MPM       11.38 18.52  8.86| 5.82  16.36  11.35   7.92  12.95   2.21   9.60   8.33   2.82
MTR        0.50  0.50  0.62| 0.48   0.48   0.53   0.40   0.59   0.61   0.10   0.45   0.13
MN         6.00  9.00  6.00| 7.00   8.00   7.00   6.00   7.00   3.00  10.00   6.00   5.00
MT        30.40 30.40 30.40|30.40  30.40  30.40  30.40  30.40  30.40  30.40  30.40  30.40
        ****  YEAR 2   ****
TA        14.00  4.72  2.00|-0.39  -3.00   1.89   5.61  13.33  17.28  21.61  19.94  17.67
NN         0.58  0.70  0.63| 0.65   0.62   0.73   0.65   0.64   0.78   0.64   0.59   0.63
S     71   0.81  0.74  0.70| 0.68   0.63   0.68   0.62   0.69   0.78   0.77   0.72   0.77
A          0.18  0.19  0.27| 0.29   0.33   0.29   0.19   0.18   0.18   0.18   0.18   0.18
REP        0.00  0.00  0.00| 0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00 72
MPM       11.81 17.30  7.92| 7.47  16.54  16.38  12.47  17.55  25.32   4.67   6.93  15.47
MTR        0.33  0.50  0.50| 0.35   0.63   0.46   0.40   0.48   0.25   0.17   0.12   0.57
MN         9.00 13.00 10.00| 9.00   8.00  11.00  11.00   9.00  13.00   7.00   9.00   7.00
MT        30.40 30.40 30.40|30.40  30.40  30.40  30.40  30.40  30.40  30.40  30.40  30.40
        ****  YEAR 3   ****
TA         9.50  4.72  1.78|-0.17  -1.17   6.33   9.50  12.83  20.11  22.06  22.17  16.83
NN         0.57  0.71  0.83| 0.55   0.66   0.84   0.65   0.75   0.76   0.67   0.63   0.58
S     72   0.68  0.72  0.78| 0.63   0.63   0.70   0.66   0.77   0.77   0.78   0.76   0.81
A          0.18  0.19  0.27| 0.29   0.33   0.29   0.19   0.18   0.18   0.18   0.18   0.18 73
REP        0.00  0.00  0.00| 0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
MPM       13.06 21.39 16.69|10.19  10.03  10.54  19.74  12.42   9.32  12.60  10.44  11.13
MTR        0.54  0.51  0.95| 0.43   0.32   0.49   0.89   0.23   0.56   0.59   0.34   0.38
MN         7.00  8.00 11.00| 6.00   7.00   7.00   6.00  15.00  10.00   6.00   5.00   7.00
MT        30.40 30.40 30.40|30.40  30.40  30.40  30.40  30.40  30.40  30.40  30.40  30.40
        ****  YEAR 4   ****
TA        10.83  7.22  3.44|-0.61  -1.83   4.06   8.94  11.78  17.83   1.11  20.94  16.00
NN         0.65  0.74  0.66| 0.52   0.66   0.63   0.62   0.70   0.50   0.61   0.50   0.67
S     73   0.74  0.77  0.70| 0.63   0.70   0.58   0.60   0.68   0.64   0.68   0.69   0.77
A          0.18  0.19  0.27| 0.29   0.33   0.29   0.19   0.18   0.18   0.18   0.18   0.18 74
REP        0.00  0.00  0.00| 0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
MPM        8.56  7.29 20.42|12.04   6.10  12.27   7.59   8.00   9.17   3.73   5.33  17.93
MTR        0.38  0.61  0.71| 0.54   0.81   0.37   0.41   0.54   0.43   0.11   0.29   0.24
MN         7.00  5.00  9.00| 9.00   7.00   8.00  10.00  11.00   7.00   9.00   8.00   8.00
MT        30.40 30.40 30.40|30.40  30.40  30.40  30.40  30.40  30.40  30.40  30.40  30.40
        ****  YEAR 5   ****
TA         9.06  7.28  1.94| 1.28  -1.17   2.22   6.17  15.44  18.33  21.50  21.33  15.39
NN         0.50  0.66  0.65| 0.65   0.63   0.71   0.66   0.68   0.70   0.64   0.65   0.67
S     74   0.66  0.68  0.71| 0.69   0.66   0.62   0.57   0.69   0.73   0.73   0.70   0.77
A          0.18  0.19  0.27| 0.29   0.33   0.29   0.19   0.18   0.18   0.18   0.18   0.18 75
REP        0.00  0.00  0.00| 0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
MPM        6.10  5.61 12.95|19.23  10.34   8.08   9.27   8.48  12.98   9.09   8.03  16.00
MTR        0.30  0.44  0.75| 0.51   0.79   0.46   0.21   0.43   0.41   0.30   0.56   1.36
MN         4.00  6.00  6.00| 9.00   7.00  10.00   5.00   6.00   7.00   6.00   7.00   4.00
MT        30.40 30.40 30.40|30.40  30.40  30.40  30.40  30.40  30.40  30.40  30.40  30.40
        ****  YEAR 6   ****
TA        13.11  8.36  0.28|-3.78   2.06   4.11  10.22  13.03  19.44  20.72  20.28  16.00
NN         0.60  0.57  0.66| 0.62   0.57   0.65   0.65   0.65   0.67   0.60   0.59   0.59
S     75   0.73  0.72  0.70| 0.67   0.66   0.71   0.53   0.64   0.70   0.72   0.80   0.77
A          0.18  0.19  0.27| 0.29   0.33   0.29   0.19   0.18   0.18   0.18   0.18   0.18 76
REP        0.00  0.00  0.00| 0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
MPM       13.44 18.26 12.55|17.15   8.03   9.30   4.29   8.00   1.98   5.79  19.02   6.30
MTR        0.99  0.74  0.52| 0.73   0.44   0.61   0.57   0.42   0.31   0.22   0.55   0.41
MN         6.00  7.00 10.00| 8.00   9.00   7.00   5.00   8.00   4.00   9.00   6.00   6.00
MT        30.40 30.40 30.40|30.40  30.40  30.40  30.40  30.40  30.40  30.40  30.40  30.40
        ****  YEAR 7   ****
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        ****  YEAR 5   ****
TA         9.06   7.28   1.94|  1.28 -1.17   2.22   6.17  15.44  18.33  21.50  21.33  15.39
NN         0.50   0.66   0.65|  0.65  0.63   0.71   0.66   0.68   0.70   0.64   0.65   0.67
S     74   0.66   0.68   0.71|  0.69  0.66   0.62   0.57   0.69   0.73   0.73   0.70   0.77
A          0.18   0.19   0.27|  0.29  0.33   0.29   0.19   0.18   0.18   0.18   0.18   0.18-
REP        0.00   0.00   0.00|  0.00  0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
MPM        6.10   5.61  12.95| 19.23 10.34   8.08   9.27   8.48  12.98   9.09   8.03  16.00
MTR        0.30   0.44   0.75|  0.51  0.79   0.46   0.21   0.43   0.41   0.30   0.56   1.36
MN         4.00   6.00   6.00|  9.00  7.00  10.00   5.00   6.00   7.00   6.00   7.00   4.00
MT        30.40  30.40  30.40| 30.40 30.40  30.40  30.40  30.40  30.40  30.40  30.40  30.40
      1 ****  YEAR 6   ****
TA        13.11   8.36   0.28| -3.78  2.06   4.11  10.22  13.03  19.44  20.72  20.28  16.00
NN         0.60   0.57   0.66|  0.62  0.57   0.65   0.65   0.65   0.67   0.60   0.59   0.59
S     75   0.73   0.72   0.70|  0.67  0.66   0.71   0.53   0.64   0.70   0.72   0.80   0.77
A          0.18   0.19   0.27|  0.29  0.33   0.29   0.19   0.18   0.18   0.18   0.18   0.187
REP        0.00   0.00   0.00|  0.00  0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
MPM       13.44  18.26  12.55| 17.15  8.03   9.30   4.29   8.00   1.98   5.79  19.02   6.30
MTR        0.99   0.74   0.52|  0.73  0.44   0.61   0.57   0.42   0.31   0.22   0.55   0.41
MN         6.00   7.00  10.00|  8.00  9.00   7.00   5.00   8.00   4.00   9.00   6.00   6.00
MT        30.40  30.40  30.40| 30.40 30.40  30.40  30.40  30.40  30.40  30.40  30.40  30.40
        ****  YEAR 7   ****
TA     2   9.83   3.00  -2.61| -6.44 -2.36   5.06   9.06  14.61  17.61  21.61  21.28  17.33
NN         0.63   0.46   0.59|  0.50  0.56   0.56   0.45   0.55   0.69   0.56   0.68   0.68
S          0.74   0.64   0.65|  0.64  0.65   0.63   0.55   0.57   0.72   0.67   0.77   0.77
A     76   0.18   0.19   0.27|  0.29  0.33   0.29   0.19   0.18   0.18   0.18   0.18   0.187
REP        0.00   0.00   0.00|  0.00  0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
MPM       15.49   1.93   9.55|  8.97  7.39  12.88  11.18   7.75  13.74   3.71  12.14  13.36
MTR        0.42   0.17   0.43|  0.51  0.24   0.46   0.75   0.39   0.37   0.37   0.20   0.57
MN        13.00   3.00   9.00|  7.00  9.00   7.00   5.00   6.00  10.00   7.00  12.00   7.00
MT        30.40  30.40  30.40| 30.40 30.40  30.40  30.40  30.40  30.40  30.40  30.40  30.40
        ****  YEAR 8   ****
TA     3  11.06   7.67  -0.11| -4.06 -6.33   0.44   7.28  13.06  18.22  20.17  21.50  15.17
NN         0.62   0.72   0.59|  0.60  0.46   0.59   0.60   0.63   0.48   0.56   0.72   0.48
S     77   0.74   0.73   0.69|  0.72  0.64   0.64   0.56   0.69   0.64   0.67   0.79   0.76
A          0.18   0.19   0.27|  0.29  0.33   0.29   0.19   0.18   0.18   0.18   0.18   0.18
REP        0.00   0.00   0.00|  0.00  0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.007
MPM       20.37   9.17  19.79| 24.08  4.52   8.23   5.51  24.38   3.66   7.98  12.24   6.65
MTR        0.43   0.33   0.54|  0.82  1.10   0.70   0.28   0.69   0.25   0.71   0.86   0.27
MN        12.00  10.00   9.00|  8.00  1.00   6.00   4.00   8.00   7.00   4.00   8.00   6.00
MT        30.40  30.40  30.40| 30.40 30.40  30.40  30.40  30.40  30.40  30.40  30.40  30.40
        ****  YEAR 9   ****
TA        10.61   5.72   1.06| -0.50 -5.72   4.83   8.14  15.78  17.61  22.11  21.00  17.39
NN     4   0.46   0.63   0.57|  0.68  0.54   0.69   0.73   0.72   0.54   0.64   0.72   0.57
S          0.75   0.77   0.69|  0.77  0.59   0.68   0.66   0.72   0.71   0.73   0.79   0.72
A     78   0.18   0.19   0.27|  0.29  0.33   0.29   0.19   0.18   0.18   0.18   0.18   0.18
REP        0.00   0.00   0.00|  0.00  0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.007
MPM        9.68  10.21  14.25| 31.52 11.91   7.39  13.69  18.01   4.95   5.66  21.74  13.31
MTR        0.39   0.32   0.65|  1.02  0.61   0.43   0.64   0.53   0.36   0.19   0.21   0.29
MN         6.00   6.00   6.00|  9.00  7.00   8.00  10.00  11.00   5.00   7.00  17.00   9.00
MT        30.40  30.40  30.40| 30.40 30.40  30.40  30.40  30.40  30.40  30.40  30.40  30.40
        ****  YEAR 10   ****
TA     5  11.44   8.44   2.61| -1.17 -2.83   2.67   8.89  14.61  17.44  21.89  22.33  18.22
NN         0.62   0.64   0.55|  0.61  0.52   0.66   0.70   0.58   0.56   0.52   0.66   0.50
S     79   0.75   0.70   0.56|  0.53  0.51   0.58   0.63   0.62   0.68   0.67   0.71   0.65
A          0.18   0.19   0.27|  0.29  0.33   0.29   0.19   0.18   0.18   0.18   0.18   0.18
REP        0.00   0.00   0.00|  0.00  0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00 8
MPM       11.76  13.59   3.91|  4.29  3.61  25.55  14.25   4.17   7.04   4.78   4.50   2.34
MTR        0.33   0.78   0.45|  0.24  0.24   0.53   0.31   0.16   0.07   0.05   0.20   0.13
MN        11.00   6.00   4.00|  5.00  6.00  10.00  11.00  10.00  14.00  11.00   8.00   4.00
MT        30.40  30.40  30.40| 30.40 30.40  30.40  30.40  30.40  30.40  30.40  30.40  30.40
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Enclosure (2)

Kingston Weather Station Data 1980-1990 Rev. 2 10

		Oct	Nov	Dec	Jan	Feb	Mar	Apr.	May	June	July	Aug	Sept	
		****	YEAR 1	****										
TA	6	10.11	4.67	-1.67	-6.78	1.83	2.89	9.67	14.11	19.11	22.50	20.17	16.39	
NN		0.57	0.58	0.57	0.61	0.69	0.66	0.63	0.66	0.61	0.61	0.58	0.66	
S	80	0.68	0.61	0.59	0.54	0.64	0.58	0.57	0.67	0.66	0.70	0.72	0.72	
A		0.18	0.19	0.27	0.29	0.33	0.29	0.19	0.18	0.18	0.18	0.18	0.18	
REP		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	81
MPM		10.72	10.44	5.31	2.29	12.42	2.34	13.28	4.45	12.90	6.45	2.31	7.01	
MTR		0.31	0.44	0.28	0.27	0.42	0.24	0.36	0.24	0.22	0.21	0.12	0.14	
MN		7.00	8.00	8.00	7.00	13.00	9.00	11.00	7.00	11.00	10.00	5.00	7.00	
MT		30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	
		****	YEAR 2	****										
TA	7	9.72	5.89	-0.39	-5.44	0.11	2.83	7.17	14.17	16.94	21.83	19.61	17.06	
NN	81	0.60	0.64	0.73	0.61	0.70	0.57	0.55	0.70	0.75	0.59	0.63	0.67	
S		0.70	0.66	0.69	0.61	0.60	0.63	0.51	0.67	0.73	0.61	0.67	0.74	
A		0.18	0.19	0.27	0.29	0.33	0.29	0.19	0.18	0.18	0.18	0.18	0.18	
REP		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	82
MPM		10.64	10.13	18.59	15.06	7.70	8.28	12.60	5.21	36.45	3.91	8.51	10.46	
MTR		0.50	0.45	0.51	0.30	0.29	0.31	0.35	0.16	0.37	0.22	0.13	0.09	
MN		8.00	9.00	11.00	12.00	9.00	14.00	6.00	12.00	11.00	4.00	9.00	9.00	
MT		30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	
		****	YEAR 3	****										
TA	8	11.11	7.89	3.44	-1.00	-0.22	4.83	8.22	12.39	19.67	22.28	21.33	18.61	
NN		0.54	0.64	0.75	0.59	0.62	0.73	0.76	0.78	0.62	0.57	0.58	0.48	
S	82	0.71	0.69	0.70	0.63	0.63	0.68	0.63	0.68	0.61	0.56	0.61	0.56	
A		0.18	0.19	0.27	0.29	0.33	0.29	0.19	0.18	0.18	0.18	0.18	0.18	
REP		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	83
MPM		7.09	11.10	6.27	12.22	11.79	20.19	32.92	12.34	8.46	4.42	9.37	3.99	
MTR		0.33	0.20	0.35	0.38	0.58	0.42	0.58	0.27	0.14	0.11	0.13	0.24	
MN		6.00	9.00	9.00	6.00	7.00	13.00	8.00	14.00	8.00	6.00	12.00	2.00	
MT		30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	
		****	YEAR 4	****										
TA	9	11.28	6.89	0.22	-3.17	3.11	0.33	7.89	13.22	19.89	21.44	22.22	15.61	
NN	83	0.57	0.59	0.64	0.69	0.71	0.64	0.69	0.69	0.66	0.68	0.55	0.66	
S		0.72	0.64	0.60	0.66	0.72	0.59	0.64	0.68	0.71	0.74	0.65	0.67	
A		0.18	0.19	0.27	0.29	0.33	0.29	0.19	0.18	0.18	0.18	0.18	0.18	
REP		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	84
MPM		12.42	33.02	17.20	7.47	17.20	13.97	10.97	21.39	16.56	17.86	2.77	5.13	
MTR		0.62	0.45	0.48	0.40	0.40	0.54	1.00	0.36	0.41	0.17	0.07	0.23	
MN		5.00	9.00	11.00	6.00	11.00	8.00	4.00	14.00	7.00	12.00	5.00	8.00	
MT		30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	
		****	YEAR 5	****										
TA		13.11	7.06	3.72	-4.61	-0.28	4.67	9.50	14.28	16.56	21.28	20.67	17.28	
NN	10	0.66	0.58	0.67	0.68	0.65	0.59	0.64	0.74	0.66	0.61	0.64	0.60	
S	84	0.67	0.63	0.67	0.57	0.58	0.53	0.57	0.65	0.70	0.72	0.76	0.77	
A		0.18	0.19	0.27	0.29	0.33	0.29	0.19	0.18	0.18	0.18	0.18	0.18	
REP		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	85
MPM		9.58	5.13	10.01	2.59	4.19	9.96	3.07	14.88	11.96	7.39	32.28	6.99	
MTR		0.33	0.16	0.26	0.26	0.64	0.33	0.15	0.33	0.21	0.18	0.34	0.10	
MN		6.00	6.00	9.00	8.00	5.00	7.00	8.00	10.00	15.00	7.00	7.00	11.00	
MT		30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	
		****	YEAR 6	****										
TA		11.78	7.22	-0.83	-0.50	-2.06	3.67	8.67	13.83	17.83	20.61	19.44	16.11	
NN	85	0.54	0.77	0.62	0.57	0.70	0.55	0.71	0.62	0.62	0.75	0.67	0.78	
S		0.69	0.76	0.65	0.62	0.65	0.65	0.70	0.68	0.69	0.78	0.77	0.78	
A		0.18	0.19	0.27	0.29	0.33	0.29	0.19	0.18	0.18	0.18	0.18	0.18	
REP		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	86
MPM		6.27	23.29	2.54	14.91	8.66	8.56	5.51	4.95	10.92	16.79	10.62	2.34	
MTR		0.13	0.82	0.21	0.32	0.65	0.50	0.36	0.16	0.24	0.25	0.18	0.12	
MN		9.00	9.00	7.00	7.00	7.00	7.00	12.00	11.00	14.00	10.00	11.00	9.00	
MT		30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	
		****	YEAR 7	****										

```
         ****   YEAR 5    ****|
 TA         13.11   7.06   3.72|-4.61 -0.28   4.67   9.50 14.28 16.56 21.28 20.67 17.28
 NN          0.66   0.58   0.67| 0.68  0.65   0.59   0.64  0.74  0.66  0.61  0.64  0.60
 S     84    0.67   0.63   0.67| 0.57  0.58   0.53   0.57  0.65  0.70  0.72  0.76  0.77
 A           0.18   0.19   0.27| 0.29  0.33   0.29   0.19  0.18  0.18  0.18  0.18  0.18
 REP         0.00   0.00   0.00| 0.00  0.00   0.00   0.00  0.00  0.00  0.00  0.00  0.00 8
 MPM         9.58   5.13  10.01| 2.59  4.19   9.96   3.07 14.88 11.96  7.39 32.28  6.99
 MTR         0.33   0.16   0.26| 0.26  0.64   0.33   0.15  0.33  0.21  0.18  0.34  0.10
 MN          6.00   6.00   9.00| 8.00  5.00   7.00   8.00 10.00 15.00  7.00  7.00 11.00
 MT         30.40  30.40  30.40|30.40 30.40  30.40  30.40 30.40 30.40 30.40 30.40 30.40
         ****   YEAR 6    ****
 TA         11.78   7.22  -0.83|-0.50 -2.06   3.67   8.67 13.83 17.83 20.61 19.44 16.11
 NN    85    0.54   0.77   0.62| 0.57  0.70   0.55   0.71  0.62  0.62  0.75  0.67  0.78
 S           0.69   0.76   0.65| 0.62  0.65   0.65   0.70  0.68  0.69  0.78  0.77  0.78
 A           0.18   0.19   0.27| 0.29  0.33   0.29   0.19  0.18  0.18  0.18  0.18  0.18
 REP         0.00   0.00   0.00| 0.00  0.00   0.00   0.00  0.00  0.00  0.00  0.00  0.00 86
 MPM         6.27  23.29   2.54|14.91  8.66   8.56   5.51  4.95 10.92 16.79 10.62  2.34
 MTR         0.13   0.82   0.21| 0.32  0.65   0.50   0.36  0.16  0.24  0.25  0.18  0.12
 MN          9.00   9.00   7.00| 7.00  7.00   7.00  12.00 11.00 14.00 10.00 11.00  9.00
 MT         30.40  30.40  30.40|30.40 30.40  30.40  30.40 30.40 30.40 30.40 30.40 30.40
         ****   YEAR 7    ****
 TA         11.39   5.00   1.61|-2.06 -2.11   3.72   9.00 14.06 19.17 21.89 19.94 16.72
 NN          0.58   0.73   0.67| 0.65  0.39   0.62   0.80  0.72  0.70  0.74  0.55  0.68
 S           0.73   0.74   0.67| 0.68  0.55   0.69   0.77  0.66  0.72  0.76  0.72  0.79
 A     86    0.18   0.19   0.27| 0.29  0.33   0.29   0.19  0.18  0.18  0.18  0.18  0.18
 REP         0.00   0.00   0.00| 0.00  0.00   0.00   0.00  0.00  0.00  0.00  0.00  0.00 87
 MPM         6.88  20.60  24.84|15.72  2.31  12.93  20.98  4.60  3.71  2.67  8.00 15.52
 MTR         0.38   0.40   0.60| 0.41  0.54   0.37   0.94  0.40  0.18  0.21  0.80  0.20
 MN          7.00   9.00   7.00| 9.00  2.00   7.00   7.00  6.00 10.00  7.00  5.00  8.00
 MT         30.40  30.40  30.40|30.40 30.40  30.40  30.40 30.40 30.40 30.40 30.40 30.40
         ****   YEAR 8    ****
 TA         10.11   5.94   1.11|-3.44 -0.11   3.61   7.83 13.67 18.06 22.44 22.72 16.06
 NN          0.45   0.63   0.61| 0.59  0.60   0.51   0.77  0.70  0.63  0.70  0.54  0.53
 S     87    0.74   0.71   0.69| 0.67  0.66   0.63   0.68  0.77  0.64  0.81  0.75  0.74
 A           0.18   0.19   0.27| 0.29  0.33   0.29   0.19  0.18  0.18  0.18  0.18  0.18
 REP         0.00   0.00   0.00| 0.00  0.00   0.00   0.00  0.00  0.00  0.00  0.00  0.00 88
 MPM         6.02   9.63   8.92| 8.66 17.40  11.94   7.65  7.65  8.00 18.26  2.97  7.59
 MTR         0.30   0.76   0.47| 0.39  0.58   0.28   0.28  0.33  0.20  0.23  0.24  0.17
 MN          6.00   6.00   7.00| 8.00  6.00  10.00   6.00 14.00  8.00 17.00  3.00  7.00
 MT         30.40  30.40  30.40|30.40 30.40  30.40  30.40 30.40 30.40 30.40 30.40 30.40
         ****   YEAR 9    ****|
 TA          8.67   6.39   0.33| 0.50 -1.72   2.67   7.06 13.67 19.44 21.00 21.17 17.89
 NN          0.60   0.55   0.59| 0.00  0.00   0.00   0.00  0.00  0.00  0.00  0.00  0.00
 S           0.73   0.70   0.60| 0.00  0.00   0.00   0.00  0.00  0.00  0.00  0.00  0.00
 A     88    0.18   0.19   0.27| 0.29  0.33   0.29   0.19  0.18  0.18  0.18  0.18  0.18 89
 REP         0.00   0.00   0.00| 0.00  0.00   0.00   0.00  0.00  0.00  0.00  0.00  0.00
 MPM         7.14  25.07   4.65| 4.67  8.28  12.34  16.36 15.32 12.85 16.61 14.50 15.85
 MTR         0.41   0.53   0.22| 0.28  0.49   0.60   0.29  0.26  0.31  0.29  0.21  0.26
 MN          7.00   8.00  10.00| 7.00  9.00   6.00  12.00 13.00 12.00 10.00 12.00 10.00
 MT         30.40  30.40  30.40|30.40 30.40  30.40  30.40 30.40 30.40 30.40 30.40 30.40
         ****   YEAR 10   ****
 TA         11.11   5.67  -6.72| 2.28  1.39   4.39   8.67 12.50 18.78 21.94 22.22 16.94
 NN          0.00   0.00   0.00| 0.00  0.00   0.00   0.00  0.00  0.00  0.00  0.00  0.00
 S     89    0.00   0.00   0.00| 0.00  0.00   0.00   0.00  0.00  0.00  0.00  0.00  0.00
 A           0.18   0.19   0.27| 0.29  0.33   0.29   0.19  0.18  0.18  0.18  0.18  0.18 90
 REP         0.00   0.00   0.00| 0.00  0.00   0.00   0.00  0.00  0.00  0.00  0.00  0.00
 MPM        17.88  19.08   2.29|15.49  8.36   5.03  15.09 16.21  2.64 16.38  5.82  8.23
 MTR         0.48   0.30   0.26| 0.51  0.25   0.39   0.36  0.40  0.13  0.51  0.22  0.23
 MN          8.00  12.00   7.00|10.00  8.00   7.00  10.00 14.00  7.00  8.00  9.00  8.00
 MT         30.40  30.40  30.40|30.40 30.40  30.40  30.40 30.40 30.40 30.40 30.40 30.40
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Enclosure (3)

1 Kingston Weather Station Data 1990-1992 Rev. 2

2

		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	
		****	YEAR 1	****										
TA		12.33	6.72	0.27	-1.55	-1.11	2.72	8.16	13.27	18.44	21.61	20.94	17.33	
NN		0.50	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.50	0.50	0.50	
S	90	0.75	0.70	0.75	0.70	0.70	0.70	0.70	0.70	0.75	0.80	0.80	0.80	
A		0.18	0.19	0.27	0.29	0.33	0.29	0.19	0.18	0.18	0.18	0.18	0.18	
REP		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9,
MPM		9.00	10.97	11.17	10.17	9.50	10.66	10.59	9.05	7.36	7.49	9.90	8.62	
MTR		0.47	0.21	0.72	0.30	0.60	0.53	0.36	0.32	0.06	0.13	0.28	0.39	
MN		8.00	6.00	8.00	9.00	5.00	9.00	7.00	8.00	8.00	9.00	11.00	9.00	
MT		30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	
		****	YEAR 2	****										
TA		12.30	6.28	2.11	-1.11	-0.30	1.50	6.78	~~13.27~~	~~18.44~~	~~21.61~~	~~20.94~~	~~17.33~~	
NN		0.50	0.60	0.60	0.60	0.60	0.60	0.60	~~0.60~~	~~0.60~~	~~0.50~~	~~0.50~~	~~0.50~~	
S	91	0.75	0.70	0.75	0.70	0.70	0.70	0.70	~~0.70~~	~~0.75~~	~~0.80~~	~~0.80~~	~~0.80~~	
A		0.18	0.19	0.27	0.29	0.33	0.29	0.19	~~0.18~~	~~0.18~~	~~0.18~~	~~0.18~~	~~0.18~~	
REP		0.00	0.00	0.00	0.00	0.00	0.00	0.00	~~0.00~~	~~0.00~~	~~0.00~~	~~0.00~~	~~0.00~~	92
MPM		9.00	10.97	11.17	10.17	9.50	10.66	10.59	~~9.05~~	~~7.36~~	~~7.49~~	~~9.90~~	~~8.62~~	
MTR		0.39	0.79	0.40	0.44	0.28	0.59	0.31	~~1.00~~	~~1.00~~	~~1.00~~	~~1.00~~	~~1.00~~	
MN		8.00	5.00	11.00	6.00	8.00	6.00	9.00	~~0.00~~	~~0.00~~	~~0.00~~	~~0.00~~	~~0.00~~	
MT		30.40	30.40	30.40	30.40	30.40	30.40	30.40	~~30.40~~	~~30.40~~	~~30.40~~	~~30.40~~	~~30.40~~	

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Enclosure (4)

Station KINGSTON County WASHINGTON State RHODE ISLAND Month FEBRUARY, 19 70

Time of Complete Observation (local time) 5p Standard time in use E

Date	AIR TEMPERATURE °F								WATER TEMP. °F		PRECIPITATION							WIND		EVAPORATION (inches & hundredths)			ADDITIONAL DATA—REMARKS
	24 Hrs. Ending at Obsn.		At Observation			Supplemental Readings at ___			24 Hours Ending at Obsn.						24 Hr. Amounts		At obsn. Snow, Sleet, Hail, Ice on gnd. (Inches)	Anemometer Dial Reading (Miles)	24 Hr. Movement	Gage Reading or Amount Added +	Reading When Tank Filled or Amount Removed −	Amount of Evaporation	
	Max.	Min.	Dry-bulb	Wet-bulb	Dew Point	Dry-bulb	Wet-bulb	Dew Point	Max.	Min.	Time of beginning	Time of ending	Time of beginning	Time of ending	Rain, Melted snow, etc. (In. & hundredths)	Snow, Sleet, Hail (ins. & tenths)							
																		606					Storm Duration
1	46	23	Storm #1 :															743	137				1 40.5
2	48	31	5:00 pm - 1:30 pm = 3½ > 3 1/100's								1:30p	—	#1		.03			915	172				2 3
3	54	43	∴ 3 + 24 + 13.5 = 40.5 hrs								—	—			1.88			180	255				3 22.25
4	53	7									—	6:30a			1.73	.9	.9	286	106				4 21
5	26	3	Storm #2:								10:30p	—					.7	290	004				5 13.5
6	37	22	6AM - 10.30pm = 7½ > 3 1/100's								—	6:00a	#2		.03	.5	T	304	014				Total 100.25 hrs
7	40	14	∴ 3hrs														T	334	030				
8	43	17															T	344	010				100.25 hrs / 5 storms = 20.05 hrs/storm
9	37	19																386	042				
10	46	31	Storm #3 :								8:15a	—	#3		.64			462	076				= 0.84 day/storm
11	47	34	22 ¼ hrs								—	6:30a			.80			582	120				
12	35	25									9:30p	—	Not					782	201				
13	34	19	Only a trace ∴ Not a storm								—	9:30a	a storm		T	.2		812	029				
14	25	4									11:30p	—						932	120				
15	32	19	Storm #4 :								—	8:30p	#4		.30	3.8	2.6	055	113				CHANGE TO RAIN 12NOON
16	39	25	21 hrs												.11		1.6	192	137				
17	36	16															.6	245	053				
18	41	27															.2	349	104				
19	48	31															T	584	235				
20	42	14															0	673	089				
21	33	15																793	120				
22	47	14																895	105				
23	43	25																184	279				
24	46	13																313	129				
25	53	21																410	097				
26	44	6	Storm #5:															620	210				
27	33	5	5pm(2/28) - 6:30pm(2/27) = 22½								6:30p	—						697	077				
28	35	28	> 7 1/100's								—	11:30p	#5		.07	T	T	784	087				
29			The precip. recorded on 3/1												.21		From 3/1 observation at 5PM.						
30			is part of this storm														No rain on 3/1 itself.						
31			∴ 7 + 6½ = 13½ hrs																				
Sum	1143	551													5.59	5.4			3151				
Avg	40.8	19.7												Greatest	1.88	3.8	2.6			Adjusted Total			

X̄ = 30.2

5 / .84

5 storms, .84 day

Observer URI AGRL EXP STA. Station KINGSTON Month FEBRUARY

37-4266-1

APPENDIX C

Constructed Pesticide Application Schedule for URI Field #K5

Year	Month	Activity or Pesticide Applied	Rate(#ai/A) [$\mu g/cm^2$]
0 1974	Fall	Start turf.	[illegible]
1 1975	April	Bensulide (1x) time	10.0 [112.085]
2 1976	April	Pendimethlin (1x)	2.0 [22.417]
	Fall	Harvest turf.	
3 1977	May	Plant potatoes.	
		EPTC (Eptam) (1x)	6.0 [67.251]
		○ Aldicarb (Temik) (1x)	2.25 [25.219]
	July	Maneb (Maneb) (3x)	2/time [67.251]
		Vydate L (Oxamyl) (2x)	1/time [22.417]
		Thiodan 50W (Endosulfan) (2x)	1/time [22.417]
		Monitor 4-E (Methamidophos) (1x)	1.0 [11.2085]
	August	Maneb (4x)	2/time [89.668]
		Guthion SC (Azinphos-Methyl) (1x)	0.75 [8.406]
		Furadan (Carbofuran) (1x)	1.0 [11.2085]
	Fall	Harvest potatoes.	
4 1978	May	Plant potatoes.	
		EPTC (Eptam) (1x)	6.0 [67.251]
		○ Aldicarb (Temik) (1x)	2.25 [25.219]
	July	Maneb (Maneb) (3x)	2/time [67.251]
		Vydate L (Oxamyl) (2x)	1.0 [22.417]
		Thiodan 50W (Endosulfan) (2x)	1.0 [22.417]
		Guthion SC (Azinphos-Methyl) (1x)	0.75 [8.406]
		Lannate (Methomyl) (1x)	0.9 [10.088]

Year	Month	Activity or Pesticide Applied	Rate(#ai/A) [μg/cm^2]
	August	Maneb (4x)	2/time [89.668]
		Furadan (Carbofuran) (1x)	1.0 [11.2085]
		Vydate L (Oxamyl) (2x)	1.0 [22.417]
		Thiodan 50W (Endosulfan) (2x)	1.0 [22.417]
		Guthion SC (Azinphos-Methyl) (1x)	1.0 [11.2085]
	Fall	Harvest potatoes.	
		Start turf.	
5 1979	April	Bensulide (1x)	10.0 [112.085]
6 1980	April	Pendimethlin (1x)	2.0 [22.417]
	Fall	Harvest turf.	
7 1981	May	Plant potatoes.	
		EPTC (Eptam) (1x)	6.0 [67.251]
		0 Aldicarb (Temik) (1x)	2.25 [25.219]
	July	Maneb (Maneb) (3x)	2/time [67.251]
		Furadan (Carbofuran) (1x)	1.0 [11.2085]
		Vydate L (Oxamyl) (2x)	1.0 [22.417]
		Monitor 4-E (Methamidophos) (1x)	1.0 [11.2085]
	August	Maneb (4x)	2/time [89.668]
		Thiodan 50W (Endosulfan) (2x)	1.0 [22.417]
		Guthion SC (Azinphos-Methyl) (1x)	0.75 [8.406]
8 1982	Spring	Plant sorghum.	
	June	✓Atrazine (1x)	1.0 [11.2085]
9 1983	Spring	Plant sorghum.	
	June	✓Atrazine (1x)	1.0 [11.2085]
10 1984	to present	Plant in hay. Apply no pesticides.	

A. Soil There are two types of soils that we use in our models. One is enfield silt loam (file name ssoil001). We use this one to present upper layer soil (64cm). The other one is combined soil which has three different soil layers.One thing We would like to mention here is intrinsic permeability (k1). If combined permeability is used(k1 is weighted average value of different layers), the relatively intrinsic permeability in application should equal to zero. We recommend to use k1=0, then we can put different k value to simulate different soil layer.

B. Climate In order to simulate actual pesticide applications for the URI field, we build the weather file (sclim004) that collects the Kingston weather station data from 1975-1984 in the format compatible with the sesoil input format.

C. Farms in our research are URI#1 and URI#3. Measurement of areas of fields and identification of crops grown have been carried out by examination of aerial photos, direct roadside surveillance, and previously work of other students.

D. Chemical For this study, we simulate seven pesticides which can be modelled with sufficient chemical data. They are: aldicarb, atrazine, carboforan, methamidophos,pendimethalin, methomyl, and oxamyl.

E. Application After several simulations using this program, we find that the limit of simulations with real climate imformation is ten-year. A long term simulation can be done, however, if the last year climate is repeated up to a total 99 years.

File name	Chemical name	Period	field	time to reach GWT(month)
ssout020	atrazine	1975-1984	URI#1	6
ssout038	aldicarb	1975-1984	URI#1	13
ssout041	atrazine	1975-1984	URI#1	27
ssout042	carbofuran	1975-1984	URI#1	16
ssout043	methamidophos	1975-1984	URI#1	5
ssout044	pendimethalin	1975-1984	URI#1	
ssout045	methamidophos	1975-1984	URI#1(k1>0)	3
ssout046	methomyl	1975-1984	URI#1	27
ssout047	oxamyl	1975-1984	URI#1	6
ssout049	aldicarb	1975-1994	URI#1	13
ssout050	aldicarb	1975-1994	URI#3	13

We simulated pesticide infiltration that the sesoil program can be modeled. Those pesticides usually are used in growing turf, potatoes and sorghum. We still need to collect more imformation on what pesticides once used in pasture, and the logkow value and smile number for the following chemicals.

chemical name	logkow	smile number
BENSULIDE		
EPTC		
MANEB		
THIODAN 50W		
GUTHION SC		
CHLOROTHALONIL		
BAYALAXL		
RUBIGAN		
DIAZINON 4E		
TEREAM		
OFFANOL 5G OR 1.5G		

A. AT123D run (Aldicarb, simulation period 20 yrs, 1975-1994.)

a) Create AT123D input dataset from SESOIL file ssout038.
b) In order to simulate 20yrs aldicarb transportation to the well, we have carefully chosen the number of beginning time and ending time in terms of DT when the solution is desired. Since only 19 time steps can be printed, NBGTIs are 25(AT016) and 31(in the remaining files), respectively. NEDTIs are 241(AT016) and 247(in the remaining files), respectively.
c) The aquifer width input must be infinite when the pollution source is not in the center of the coordinate which is setup for simulation running. Otherwise aquifer width should be set as the width of the pollution source field with the center of the coordinate located at the center of the field.
d) The two contaminant fields simulated are URI#1 and URI#3.
e) The well protection head area is the boundary that can be applied only to determine which field should be simulated. It can not be applied as an input data of aquifer width for running AT123D.
f) The hydraulic conductivity K_h, is assumed to be 0.44 mhr^{-1}. A hydraulic gradient should be assumed along the longitudinal direction which results in a theoretical velocity (V=Q/A). The AT123D program requires input of hydraulic conductivity K_h and a theoretical hydraulic gradient without considering the porosity. The program will calculate the retarded darcy velocity by dividing the theoretical velocity by porosity.

Table 1. Aldicarb transportation simulations in groundwater

File name	Aquifer width (m)	Field width (m)	Time for results	Target field
At010	infinite	118	mid of each year	URI#3
AT011	118	118	mid of each year	URI#3
AT016	infinite	230	end of each year	URI#1
AT018	infinite	230	mid of each year	URI#1
AT020	230	230	mid of each year	URI#1

B. Results

The results are obtained through following steps:

a) After inputting each AT file, we obtained Y-Z plane graphs at X=distance from field center to the well with desired time steps;
b) To obtain the weight average concentrations of these Y-Z

graphs, multiply the isoline concentration with the corresponding area one by one and added up the results, and the sum is divided by the whole area to yield the graph.

Table 2.

File name	Aquifer type	Weight average concentration	Field	Percentage of release mass into GW (%) 6 yrs period
AT010	infinite	the lowest	URI#3	7.74
At011	finite	the highest	URI#3	98
AT016	infinite	----	URI#1	------
AT018	infinite	the lowest	URI#1	20.5
At020	finite	the highest	URI#1	68.6

Table 3. The max. conc. & min. conc. of aldicarb in well #4 at desired time

URI#1 + URI#3	Year	MAX.conc.(ppm)	MIN.conc.(ppm)
	1982	2.15E-2	4.26E-3
	1983	2.38E-2	4.53E-3
	1984	1.32E-2	2.84E-3
	1985	7.86E-3	9.00E-4
	1986	5.22E-3	6.05E-4

The results from running AT files indicate that we can only get the range of contaminant concentration(weight average conc.) at certain time and point, as shown in Table 2.

Note: the velocity of GW flow in all calculations of AT123D is based on $V = v/n$, where v is calculated by dividing the pumping rate Q with the cross section of aquifer A, and corrected with porosity (divided by porosity). However, the AT123D program actually requires an input of $v = Q/A$ without porosity correction. Once the input is made, the program corrects the velocity term automatically with the inputted porosity.
When velocity changes the program also automatically corrects dispersion coeff

FISCAL YEAR 1993 PROGRAM REPORT

CALVIN P.C. POON, DIRECTOR

1892

WATER RESOURCES RESEARCH INSTITUTE
THE UNIVERSITY OF RHODE ISLAND

FISCAL YEAR 1993 PROGRAM REPORT

Rhode Island Water Resources Research Institute
University of Rhode Island
Rhode Island

FISCAL YEAR 1993 PROGRAM REPORT
Grant No. 14-08-0001-2044

for

U.S. Department of the Interior
Geological Survey

by

Water Resources Center
University of Rhode Island
Kingston, RI 02881

Calvin P.C. Poon, Director

July 1994

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ABSTRACT

The objectives of the FY-93 Rhode Island Water Resources Research Institute Program are (1) to identify critical policy and management issues of water resources in the State and in the New England region, (2) to conduct research in order to generate information useful to address the issues and to solve the problems, (3) to transfer the information to potential users throughout the State and New England region, (4) to educate the public about water quality protection, and (5) to train both graduate and undergraduate students in water resources research. Current and anticipated state and regional water problems are water management in relation to water right/water allocation, water conservation practices and effects, wetland management, regulations of new water quality point of use; water quality in relation to radon and organic compounds in groundwater, stormwater quality and effects of detention/retention basins, and nutrient removal in wetlands; surface-groundwater interactions in relation to the role of wetlands, and information dissemination on water quality management such as stormwater overflow control and aquifer management in Rhode Island.

The FY-1993 program addressed many of these issues and problems. Residents in southern Rhode Island in recent dry summers (1987, 91, 93) located downstream from turf farms, nurseries, and vegetable farms claimed that irrigation withdrawals were responsible for diminishing stream flows and the drying up of sink holes and other small water bodies. Several state agencies are eager to develop a statewide water policy. Extensive data collection on surface and groundwater resources, seasonal pattern of water supply, water demand, economic value of water in alternative uses, have been and are being conducted as well as extensive discussions with agencies and water users have been carried out. A model

for the water supply and demand will be developed from which opportunities for reallocating water resources according to economic and other criteria will be identified. The information will be useful for the development of water rights and water allocation policy in the State. Water quality affected by non-point source of stream sediment resuspension in adverse hydrologic conditions was studied by analyzing sediment metal and volatile organic contents as well as by simulating sediment resuspension in a modified USEPA-PES chamber with a horizontal oscillating grid. Various oscillating speeds were used to simulate the shear stresses to be expected in various flow conditions. Seasonal variations of the impacts of the resuspended sediment will be analyzed. Also depositing an optimal layer of sand of various grades on the sediment core will be investigated as a possible mitigation technique to minimize the pollution effects of resuspended sediments. A large number of private drinking water wells contain radon at a concentration significantly higher than the USEPA proposed 300 pCi/l limit. Analyzing the geology and radon, uranium, Ca, Mg, Na, K, Fe, Mn, Si, F, Cl, NO_3 PO_4, and SO_4 of the water, no correlation was found to exist between dissolved uranium and radon concentration. The higher radon concentrations correspond to the bedrock containing the most uranium, and groundwater from bedrock wells yields higher concentrations of radon than that from surficial material wells. In order to better understand the fate and transport of toxic organics in groundwater, the presence of bacterial degradation and the effect of solvent(s) on the bacterial degradation were investigated. A bacterium was isolated from a local contaminated site which was able to use PAHs for growth. The bacterium used naphthalene as a substrate for growth. The organic carbon content of soil as well as some hydrophobic organic solvents enhanced the degradation.

Information transfer activities include publication of a newsletter and conduct forums on water quality protection. Throughout the year, the Rhode Island Water Resources Center worked closely with all state and federal agencies dealing with water resources in Rhode Island, as well as New England Water Resources Center Directors, and citizen groups on program planning, research coordination, citizen participation in seminars and public forums. Several graduate students have been successfully trained in water resources research and completed their master thesis research under the guidance of the principal investigators of the projects sponsored by this Center.

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RESEARCH PROJECT SYNOPSES

WATER PROBLEMS AND ISSUES OF RHODE ISLAND

The state of Rhode Island and other New England states are rich in water. However, urbanization and land development have led to water shortage and water quality problems in some areas. Agricultural water withdrawals from major rivers in drought periods in recent years have caused conflicts among users of surface water and groundwater resources in Rhode Island. There is a need for an appropriate allocation scheme which allows water use to various groups with equity. Through a better understanding of the economic and hydrologic impacts of surface water and groundwater withdrawals on competing users of water resources, and equitable allocation scheme may be designed and implemented.

Many chemicals from industrial discharges, municipal sewage treatment plants effluent, and stormwater runoff have strong affinity for particles in the aquatic environment. Heavy metals have the tendency to be adsorbed on particles, which settle during periods of low stream flow velocities and resuspended during periods of high flow. The resuspended metals and other chemicals such as nutrients, are transported with water flow as a non-point source of pollutants. Under changing physico-chemical conditions between the sediments and the water column, sediment bound chemicals can dissolve in the water, violating water quality criteria and entering the food chain. The study of sediment bound metals or other chemicals are important to pollution regulating agencies in two issues, (1) related to Waste Load Allocations, it is important to be able to differentiate between input from regulated point sources and input from bottom sediments, and (2) related to the pollution control effort, it is important to develop some mitigation technique to reduce the impact of contaminated bottom sediment.

Groundwater with Radon has been associated with increased risk of stomach cancer and an increased risk of lung cancer related to the inhalation of radon outgassing from sinks, showers and other indoor water uses. Many measurements of radon concentration in Rhode Island groundwater exceed 1,000 pCi/l, well in excess of the USEA proposed 300 pCi/l MCL. Groundwater is the only viable source of drinking water in Washington County, Rhode Island. Given the potential hazard associated with radon, a systemic assessment of radon in the groundwater reservoirs of the State is needed to provide detailed information to state agencies, water suppliers and the general public.

In addition to radon, organic chemicals are among the principal contaminants found in Rhode Island groundwater. The fate and transport of an organic chemical in soil and groundwater are influenced by the presence of other contaminants and solvents. It is, therefore, important to modify the existing environmental fate models by incorporating new process descriptions and parameters including retardation and attenuation. Such study will be useful for the assessment of organic pollutant fate from waste sites or leaking fuel storage tanks.

PROGRAM GOALS AND PRIORITIES

The research needs on water resources in Rhode Island and in the New England region as identified by the State Advisory Committee and the University Water Resources Coordinating Committee have been:

Water Management

1. Water rights and water allocation
2. Management of wetlands as pollution mitigators
3. Water conservation practices and effects
4. Evaluating of significance of low stream flow .
5. Evaluation of groundwater flow relative to contamination sources
6. Effect of new water quality point of use regulations (costs, usage)

Water Quality

1. Impact of stormwater on water quality
2. Effect of detention/retention basins
3. Fate of organic compounds in groundwater
4. Occurrence and significance of radon in water supplies
5. Role of wetlands in nutrient removal

Surface-groundwater Interactions

1. Role of wetlands in ground and surface water quality
2. Role of wetlands (natural and constructed) in groundwater recharge/discharge
3. Characterization of surface water-groundwater interactions

Technology Transfer

Maintain water resources library and data center, provide public information on water resources, conduct public meetings and seminars.

Guided by these research needs, the Rhode Island Water Resources Center developed its program goals to meet some of these research needs as well as to transfer the information of water resources research/management/education to the public. Research solicitation was sent out to the public targeting primarily the institutions of higher education in Rhode Island. Based on the responses and the quality of the proposals submitted, four research projects and one information transfer project that meet the research needs developed for the FY-1993 were selected. In addition to relevance of research needs and technical competency, a reasonable budget was also a criterium in selecting the projects for FY-1993 program support.

The first project, Project 02, entitled *Designing a System of Water Rights and a* Water *Allocation Policy for Rhode Island* focused its study on the Wood/Pawcatuck River system in southern Rhode Island which serves agricultural, municipal, and industrial water users. Historical data and existing models of the surface water and groundwater resources in the region were collected. The frequency distribution of the water supply are being estimated using daily weather data to describe the seasonal pattern of water supply in the system. Surveys are being done on competing demands of water withdrawn from the Wood/Pawcatuck River system. The direct economic value of water in alternative uses will be estimated for the activities in the region. After a model development for the water supply and demand has been developed, opportunities for reallocating water resources according to in competing case. The information will be used to develop an equitable system of water rights and a water allocation policy for the region. The project work is expected to be completed after 1994 summer.

The second project, Project 03, used an improved USEPA PES to create shear stress on the sediment-water interface, causing the sediment resuspension in a water column. It was tested at various oscillation speeds, trace metal, both dissolved and particulate, of core samples were analyzed, in addition to TSS/VSS, moisture content, volitile organic content analyses. Three of four surveys for this study have been completed. The last survey is scheduled on July 21, 1994. After the completion of the chemical analyses and PES testing, the seasonal variation of the impacts of the resuspended sediment will be analyzed. In addition, different grades of clean sand (course, medium, and sediment resuspension under sever hydrologic flow conditions.

The third project, Project 04, entitled *Radon in the Groundwater Reservoir of Southern Rhode Island: a Field Assessment*, collected water samples from 100 private wells in the Upper Wood, Queen-Usquepaugh, and the Chipuxet River Basin aquifers. Field analyses included temperature, pH, Eh, electrical conductance, and dissolved oxygen. Laboratory analysis included radon, uranium, alkalinity, Ca, Mg, Na, K, Fe, Mn, Si, F, Cl, NO_3, PO_4, and SO_4, conducted in the USGS National Water Quality Laboratories in Denver, and Lakewood, Colorado as well as in the Department of Geology's Hydrogeology Laboratory of the University of Rhode Island. All well samples yielded radon levels above the proposed EPA limit of 300 pCi/l and many were more than an order of magnitude greater. The finding indicates no correlation exists between dissolved uranium and radon concentration. The higher radon concentrations correspond to the bedrock containing the most uranium, and groundwater from bedrock wells yields higher concentrations of radon than that from surficial material wells.

The fourth project, Project 05, entitled *Toxic Organic Chemicals in Rhode Island Groundwater: Contaminated Fate and Transport*, completed its second year of the study. A bacterium able to use several of the polycyclic aromatic hydrocarbons (PAHs) including naphthalene, anthracene and pyrene as substrates for growth was isolated for subsequent naphthalene degradation study. The organic carbon content of soil was found to enhance naphthalene degradation. Degradation was also enhanced in the presence of the more hydrophobic organic solvents (decane, dodecane, and hexadecane) and decreased in the presence of octane and hexane. A complete mineralization of the naphthalene to CO_2 was confimed with radioisotope techniques.

The level of funding and sources for various projects including the information transfer activities are listed in Table l.

Table l. Sources and Levels of Funding FY-1993

Project	**Level**	**Source of Funding Ending May 31, 1994**
02, Designing a System of Water Rights and a Water Allocation Policy of R.I.	$14,692 30,208	U.S. Geological Survey University of Rhode Island
03, Chemical Impact of Bottom Sediment Resuspension in Rivers--Assessment and Mitigation	$14,692 36,241	USGS URI
04, Radon in the Groundwater Reservoirs of Southern Rhode Island: A Field Assessment	$14,985 39,408	USGS URI
05, Toxic Organic Chemicals in Rhode Island Groundwater: Contaminant Fate and Transport	$15,057 30,565	USGS URI
22, Information Transfer Activities	$15,928 32,533	USGS URI
01, Center Administration	$25,365	USGS URI
FY-1993 Total Funding	$100,527 221,833	USGS URI

SYNOPSIS

Project Number: 02

Title: Designing a System of Water Rights and a Water Allocation Policy for Rhode Island.

Investigators: Dennis Wichelns, University of Rhode Island
Thomas F. Weaver, University of Rhode Island

Focus Categories: ECON, AG, WU, IG

Congressional District: Second

Descriptors: Water rights, economics, irrigation, policy analysis

Problem and Research Objectives

Agricultural water withdrawals from major river systems in southern Rhode Island were the focus of heated debate during the unusually dry summers of 1987, 1991, and 1993. Residents located downstream from turf farms, nurseries, and vegetable farms claimed that irrigation withdrawals were responsible for diminished stream flows and the drying up of sink holes and other small water bodies. The state's Department of Environmental Management held several meetings to address the concerns of local residents in 1987 and staff members have worked with farmers to address water management issues during the recent dry summers. However, the agency has not yet developed a statewide policy regarding water rights, or the allocation of water resources during periods of shortage. The inevitable scarcity of water during future drought years will cause similar conflicts among users of surface water and groundwater resources in Rhode Island, unless an appropriate allocation scheme is designed and implemented.

Several agencies and user groups are eager to develop a statewide water policy. The Office of Statewide Planning, the Department of Environmental Management, the Division of Agriculture within DEM, and others have expressed interest in research that will result in the formation of an appropriate policy.

State agencies will benefit through a better understanding of the economic and hydrologic impacts of surface water and groundwater withdrawals on competing users of water resources. Farmers will benefit through more precise description of the economic and hydrologic impacts of agricultural water use in Rhode Island. An appropriate water rights system will allocate water efficiently and equitably during periods of shortage, to ensure that competing users are able to maintain economically important activities with minimal disruption.

The goal of this research is to determine the appropriate policy for allocating water during periods of shortage in southern Rhode Island. At present, there is limited information available regarding the impact of water withdrawals on stream flows and groundwater in the region. There is also a lack of information describing the incremental value of water to farmers, industries, and residents in southern Rhode Island. However, information describing the various components of water supply and demand, and the impact of water withdrawals on the amount of water available for alternative uses, is required in order to develop an efficient allocation policy. This information will be developed in this study and an economic analysis will be performed to examine policy alternatives.

Methodology

The Wood/Pawcatuck River system is an important watershed in southern Rhode Island, serving agricultural, municipal, and industrial water users with a relatively reliable supply of high-quality surface water and groundwater. During recent drought years, however, both the volume and quality of water in the system were diminished and complaints among water users were filed with the state's Department of Environmental Management. This river system is chosen for analysis because several current studies are developing useful data and because the water resource issues in the watershed are very representative of the critical issues facing Rhode Island at this time.

The water supply and demand situation for the Wood/Pawcatuck River system will be examined using historical data (to the extent available) and existing models of the surface water and groundwater resources in the region (eg. Gold, et al., 1988). The frequency distribution of the water supply will be estimated using daily weather data to describe the seasonal pattern of water supply in the system.

Competing demands on the Wood/Pawcatuck River system will be estimated using available data regarding withdrawals from the system. It may also be necessary to conduct a survey of water users in the watershed to determine actual water withdrawals during a selected period of time. The direct economic value of water in alternative uses will be estimated for the activities that describe the major diversions in the region. Daily water demands will be estimated to maintain consistency with the water supply information.

Water demand and supply relations will be combined in a water balance simulation model of the Wood/Pawcatuck River system. Existing irrigation scheduling programs will be used when appropriate to simulate daily water demands. The complete model will permit prediction of periods when water demands will most likely exceed water supply. Opportunities for reallocating water resources according to economic and other criteria will be identified by comparing the relative values of water in competing uses. This information will be used to develop the components of an appropriate system of water rights and a water allocation policy for the region.

Faculty and graduate students in the Department of Resource Economics at the University of Rhode Island will conduct the research for this study. Specialists in the University's Departments of Natural Resource Science, Civil Engineering, and Geology will be contacted for assistance with technical information and physical system modeling. Scientists in the U.S. Geological Survey will be called on for similar assistance and to provide data describing stream flows and groundwater depths in the Wood/Pawcatuck River system. The expected linkages among surface water and groundwater resources in the region will be described as completely as possible, given the available data and the hydrologic models developed to date.

Principal Findings and Significance

To date, we have reviewed much of the literature describing water demand and supply issues and we have collected a large amount of existing data that describe water demand and supply in Rhode Island. Robin Johanson has worked throughout the past year to assemble these data and to establish important contacts among water resource professionals in the state. In particular, she has been working closely with representatives of the state Department of Environmental Management and the Soil Conservation Service to identify the important issues and to formulate an appropriate methodology.

We have had many discussions, among our group, regarding the development of a simulation model to describe water demand and supply conditions in a representative watershed in southern Rhode Island. We will press ahead with that work this summer, by collecting original data from farmers and other water users in the region. Those data will be used to construct the simulation model that can be used to examine alternative water policy scenarios. The data collection and modeling work will be conducted as part of Ms. Johanson's research program.

SYNOPSIS

Start: June 1, 1993
End: May 1, 1995

Project Number: 03

Title: Chemical Impact of Bottom Sediments Resuspension in Rivers - Assessment and Mitigation

Investigators: Eid Alkhatib & Raymond Wright

Focus: Sediments

Congregational District: Second

Descriptors: Sediments, River Beds, Resuspension, Chemical Potential, Metals, Waste load

Problem and Research Objectives:

It has been well documented that many toxic chemicals from industrial discharges, sewage treatment plant effluent, and stormwater runoff have high affinity for particles. These chemicals, specifically metals, have the tendency to be adsorbed on particles, which settle during periods of low stream velocities and resuspend during periods of higher stream velocities. During the periods of resuspension, the adsorbed metals will be reintroduced into the water column and transported with water flow as a non-point source of pollutants. Under changing physio-chemical conditions between the sediments and the water column, sediments bound chemicals can dissolve in the water, violate set water quality criteria and enter the food chain. The magnitude of bottom sediment suspesion is a function of stream velocity. Higher stream velocities associated with changing hydrologic conditions such as heavy storms, can suddenly become significant factors which induce higher bottom shear forces and subsequently create different condition in the water column.

The Pawtuxet River is considered to be one of the most polluted rivers in Rhode Island. Historically, the river was subject to point source loadings of heavy metals and other toxic contaminants from many industries located in Rhode Island. Over the years large amounts of metals and other contaminants were accumulated in bottom sediments and trapped in impoundments and other low velocity areas. Now, these areas act as source points for the introduction of various chemical constituents into the water column, specially during the periods of high flows. These contaminated sediment fines will find their way to Narragansett Bay. This has been substantiated by various studies conducted to evaluate the water quality in Pawtuxet River (Mccarthy 1986) and (Richardson 1991). Most of these studies emphasized water quality modeling and analyses. The problem of establishing a direct procedure to determine the chemical impact of the bottom sediments has not been addressed.

The objectives of this study may be summarized in the following manner:

1- Determine the bottom sediments chemical characteristics (metals) at four potential locations in Pawtuxet river, and determine the seasonal variation in it's composition.

2- Determine the feasibility of applying a cost effective procedure using PES to simulate the chemical impact (metals) from bottom sediments into the water column of Pawtuxet River under various stream velocities, and develop relationships to associate that with various hydrologic storm conditions.

3- Develop a mitigation technique for the reduction of chemical impact from bottom sediments resuspension and test it's feasibility on sediment cores using the PES unit.

Methodology:

Four river sampling stations were selected for this study. The selection of these stations was based on location, accessibility, vegetation, bank slopes and river depth.

Cores and sediment samples collection

The PES cores are retrieved by inserting an acrylic core in the bottom sediment. Sediment cores are collect at 3 locations at each of the four selected river stations. The dimensions of the acrylic core are 30 cm high, 12.75 cm outside diameter, and an inside diameter of 11.75 cm. These dimensions were selected to fit the core precisely in the PES unit. A 1.25 cm thick beveled plate with 15 cm diameter and a circular grove will be slid underneath the core before extracting the sediment sample with overlying river water. On the river bank , the cores are to be transferred to another beveled plate which had a tube of clay placed in a groove. Subsequently, each core is pressed into the clay to prevent any leakage and transferred in an ice box to CVE laboratory.

URI PES

The PES consists of a cylindrical chamber inside which a perforated horizontal grid oscillates vertically in the water column and creates shear stress on the sediment-water interface which causes the sediment to be entrained into the water column. URI PES was constructed using the specification from the EPA PES, however, the stabilization plate for the core has been improved to be more flexible by using a plate with 360 degrees of freedom and adjustable screws. The PES has an aluminum drive disc and linkage bar driven by a 1/8 horsepower variable speed motor. An aluminum driving rod connecting the linkage bar to the grid is kept in alignment through the use of bronze bushings. The bar is set 1.27 cm off the center of the disk to create a vertical displacement of 2.54 cm in the water column. The oscillating grid is made of plexiglass and has 42.8% porosity formed by evenly spaced holes 1.2 cm in diameter and 1.5 cm between holes. The calibration of URI PES was conducted by the analysis of cores in parallel with an EPA PES (Wright et al, 1989). The EPA PES was originally calibrated using annular flume in Santa Barbra, California at the University of California under sponsorship from EPA. The calibration consisted of testing the cores with identically hand-packed sediment, simultaneously in the EPA and URI PES apparatus.

PES testing

Each of the collected core samples will be tested with equivalent bottom shear stress of 0.5, 1, 2, 3 and 4 dyne/cm^2 which are equivalent to 0.02, 0.04, 0.08, 0.10, and 0.12 oscillation/second

of the grid according to annular flume calibration. During each level of stress, samples will be drawn for turbidity measurement. The percentage of light refracted (turbidity) will be measured using a Milton Roy Spectrophotometer. The turbidity subsamples will be drawn from the port on the core every 1,3 and 5 minutes after the initiation of a new stress and in 5 minute intervals thereafter, until suspended solids were at steady state. The judgement of the steady state condition occurred when the light attenuation changed less than 2% over 5 minutes. At the steady state conditions, 50 ml samples will be collected for the analysis of trace metals and 100 ml samples will be collected for total suspended solids and volatile suspended solids samples.

Mini-Vane shear testing

An average Bingham shear stress (dyne/cm^2) is determined from 5 position on the sediment surface, using Brookfield Digital Viscometer model HATDV-II with a maximum torque of 14,374 dyne-centimeters.

During this study, a stainless steel miniature vane with height of 4 mm and a diameter of 8 mm was manufactured and used on the sediment samples.

Mitigation of Chemical Impact:

Conceptually, if we covered the bottom sediment of a contaminated area with an optimum layer of sand, such that the highly contaminated portion of the fines embedded into the sediment will be suppressed under this cover, we expect that, the sediments resuspension into the water column will be reduced. This layer of sand cover will be optimized to minimize resuspension under the worst possible hydrologic flow condition. The proposed mitigation technique will be tested in the following manner:

- Three grades of clean sand will be selected. Primarily, we are planning to use coarse, medium, and medium-fine sands for evaluation. Depending on the outcomes of this study, other sand grades may be used.

- Using the PES unit, the degree of reduction in sediment suspension and it's associated chemical impact will be evaluated. Different thickness of sand layer covers will be applied and tested on a number of sediment cores.

<u>Accomplishments to Date:</u>

1- Literature survey of various research studies related to this project have been collected and results of that will be incorporated in the final report.

2- Three of four surveys have been conducted on the Pawtuxet River with a total of forty sediment cores collected. Enclosed is a checklist showing the progress to date on the analysis of the samples.

  A. PES Testing: A selected core from each station (PWS01, PWS02, PWS03, PWS04) has been agitated by the PES. For the last two surveys, this will be doubled to two cores per station. Samples were collected and analysis completed as presented in the enclosed table.

  B. A number of samples were taken from each core for analysis.

    1) Trace metal samples - 12 (6 dissolved + 6 particulate) per core. Total of 48 per survey for SI and SII. Total

	Number of Cores collected	Number of cores run through PES	TSS/VSS	Shear Vane Testing	Moisture Content	VOC of Sediments	Acid Digestion of Cores	Trace Metal Analysis of PES Samples on 5100 PC	Trace Metal Analysis of PES samples on 3030 FAA	Trace Metal Analysis of Sediment Samples	OTHER
SURVEY I											
PWS 01	3	1	✓	✓	✓	✓	✓	✓	✓	✓	
PWS 02	3	1	✓	✓	✓	✓	✓	✓	✓	✓	
PWS 03	3	1	✓	✓	✓	✓	✓	✓	✓	✓	
PWS 04	3	1	✓	✓	✓	✓	✓	✓	✓	✓	
SURVEY II											
PWS 01	3	1	✓	✓	✓	✓	✓	✓	✓	✓	
PWS 02	3	1	✓	✓	✓	✓	✓	✓	✓	✓	
PWS 03	3	1	✓	✓	✓	✓	✓	✓	✓	✓	
PWS 04	3	1	✓	✓	✓	✓	✓	✓	✓	✓	
SURVEY III											
PWS 01	4	2	✓	✓	✓	✓	✓		✓		
PWS 02	4	2	✓	✓	✓	✓	✓		✓		
PWS 03	4	2	✓	✓	✓	✓	✓		✓		
PWS 04	4	2	✓	✓	✓	✓	✓		✓		
SURVEY IV											
PWS 01											
PWS 02											
PWS 03											
PWS 04											

PES Analysis Checklist as of 1 July 1994 of 96 for survey III.

2) TSS/VSS - 6 per core. Total of 24 per survey for SI and SII. Total of 48 for survey III.

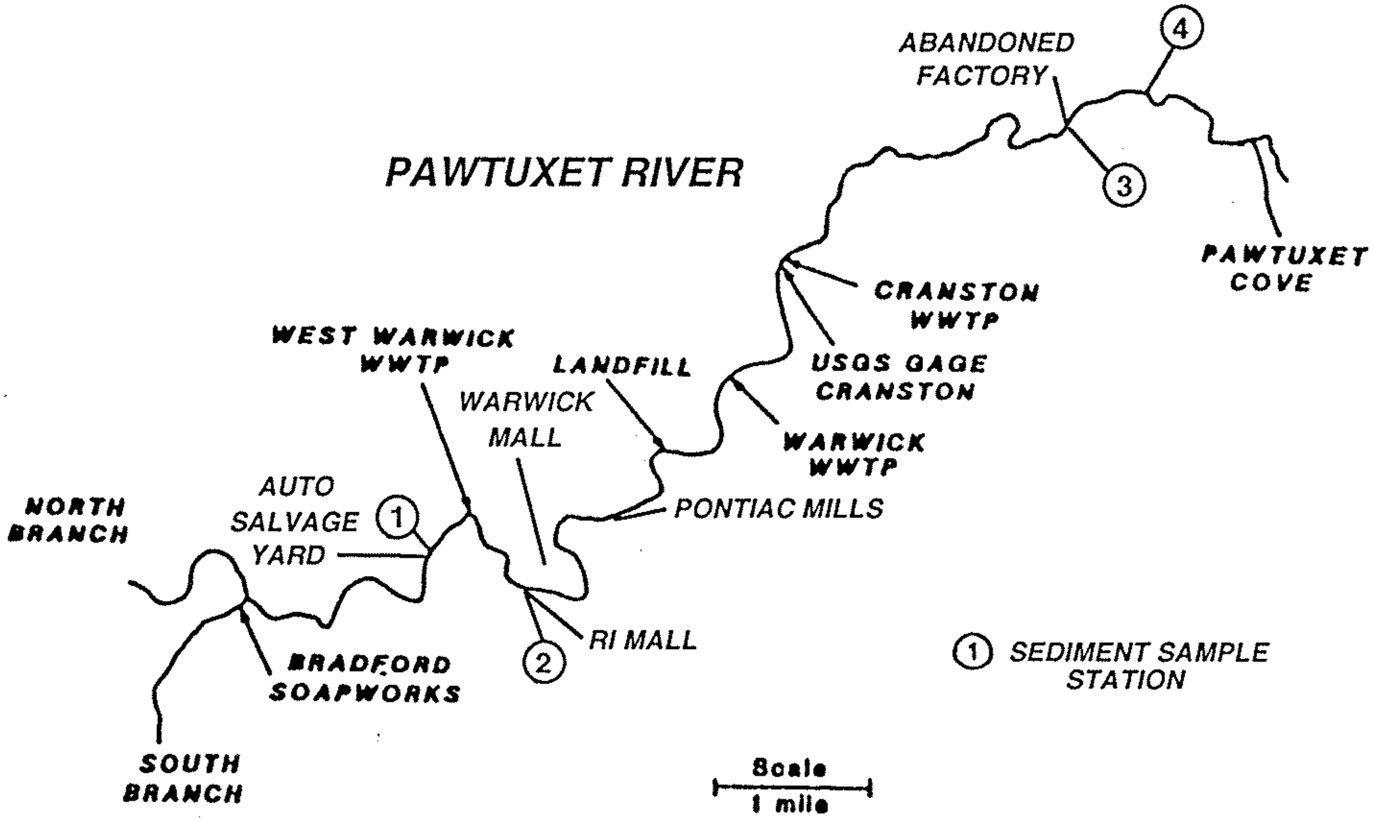
3) Moisture content - One per station for survey I. Two per station for surveys II & III.

4) VOC - One per core.

5) Sediment samples for digestion - Two per station for survey I and survey II. One per core for survey III.

2- The expected completion date for the analysis of the first three surveys is August 15, 1994. Collection of survey IV is scheduled on July 21, 1994.

3- The development of a mitigation technique for the reduction of chemical impact from bottom sediments will start after finishing the analysis of survey number IV.


PAWTUXET RIVER
ABANDONED FACTORY
4
3
PAWTUXET COVE
CRANSTON WWTP
USGS GAGE CRANSTON
WARWICK WWTP
WEST WARWICK WWTP
LANDFILL
WARWICK MALL
PONTIAC MILLS
NORTH BRANCH
AUTO SALVAGE YARD
1
2
RI MALL
BRADFORD SOAPWORKS
SOUTH BRANCH
1 SEDIMENT SAMPLE STATION
Scale
1 mile

SYNOPSIS

PROJECT NUMBER: 04

START: June 1, 1993
END: March, 1995

TITLE: Radon in the ground-water reservoirs of southern Rhode Island: a field assessment

INVESTIGATORS: Anne I. Veeger, O. Don Hermes and Nicole C. Ruderman
Dept. of Geology, University of Rhode Island, Kingston, RI

FOCUS CATEGORIES: GW, HYDGEO, HYDROL, RAD, WQL

CONGRESSIONAL DISTRICT: Second

DESCRIPTORS: Groundwater hydrology, groundwater quality, hydrogeology, radioactive isotopes, water chemistry

PROBLEM AND RESEARCH OBJECTIVES:

The Unites States Environmental Protection Agency (USEPA) has determined that elevated levels of radon gas in indoor air is the second leading cause of lung cancer, cigarette smoking being the number one cause. Approximately 1 to 7 percent of radon-related deaths are the result of radon that is released from well water during normal household activities. Because of the potential health threat of radon, the USEPA originally proposed a maximum contaminant level (MCL) of 300 pCi/L for radon in drinking water (Federal Register, July 18, 1991). This MCL was not accepted by Congress and is currently under revision.

Radon-222 (^{222}Rn) is a radioactive isotope with a half-life of 3.8 days. It is produced during the decay of uranium-238 to lead-206. Because of its short half-life and the relatively slow flow of ground water, ^{222}Rn is not transported great distances in aquifers. Therefore, when high levels of ^{222}Rn are found in ground water, its source, uranium, must be present in the surrounding rock or sediment. Previous studies of the crystalline rocks underlying the state have found significant amounts of uranium (Nevins, 1991). Furthermore, unconsolidated material derived from the uranium-bearing bedrock has been deposited in the bedrock valleys of Rhode Island during the retreat of the last ice sheet. Therefore, the potential for high levels of radon exists in wells in surficial material as well as in the underlying bedrock.

Ground water is the drinking water source for approximately 24% of Rhode Island as a whole, and 100% of southern Rhode Island. Previous research in Rhode Island has discovered elevated levels of radon in ground water from bedrock wells. However, no work has been done to evaluate the occurrence of radon in the surficial material aquifer which are the highest yielding aquifers in the State. This study focuses on the distribution of ^{222}Rn in surficial aquifers and its relation to radon and uranium distribution in the underlying bedrock. The study area includes 3 of the major ground-water reservoirs in the Pawcatuck River Basin, Rhode Island: the Upper Wood, the Queen-Usquepaugh, and the Chipuxet.

The field assessment was completed in one year and included the following objectives:

- measurement of ^{222}Rn levels and chemical composition of ground water in wells screened in glacial material as well as bedrock; and
- determination of the variability of ^{222}Rn within the three-dimensional framework of the aquifer;

The interpretive phase of this study is ongoing and includes the following objectives:

- evaluation of the factors controlling ^{222}Rn levels, for example: uranium content in the underlying bedrock, depth to bedrock, and chemical evolution of the ground water; and
- development of a conceptual model for the distribution of ^{222}Rn in the aquifers of the Pawcatuck River Basin, Rhode Island.

METHODOLOGY:

Site Selection and Sample Collection

Ground-water samples were collected from private wells in the Upper Wood, Queen-Usquepaugh, and the Chipuxet River basin aquifers. Surveys were sent to homeowners throughout these three river basins asking for well depth and a description of the aquifer material. 100 wells were chosen on the basis of this survey and the underlying bedrock. Ground-water samples were collected only after each well was 3-well volumes had been evacuated and pH, temperature, end electrical conductivity had stabilized. Standard water sampling and preservation techniques were used. Field analyses included temperature, pH, Eh, electrical conductance, and dissolved oxygen. Ground-water samples collected for the following laboratory analysis: radon, uranium, alkalinity, calcium, magnesium, sodium, potassium, iron, manganese, silica, fluoride, chloride, nitrate, phosphate, and sulfate.

The radon samples were analyzed within three days of collection at the United States Geological Survey (USGS) National Water Quality Laboratory in Denver, Colorado. The uranium analyses were completed at the USGS National Water Quality Laboratory in Lakewood, Colorado. All other analyses were performed in the University of Rhode Island, Department of Geology, Hydrogeology Laboratory.

PRINCIPAL FINDINGS AND SIGNIFICANCE:

Geology

These three aquifers are unconsolidated aquifers of glacial origin deposited in bedrock valleys during the retreat of the late Wisconsin ice sheet. The deposits consist of fine to coarse sand and gravel, with some silt, derived from granitic igneous and metamorphic rocks to the north. The aquifers vary in thickness ranging from less than 50 feet of saturated thickness to greater than 150 feet of saturated thickness in the deepest portions of the bedrock valley. The sediment was deposited in a glacio-fluvial and glacio-lacustrine environment resulting in strongly heterogeneous aquifer materials.

The Upper Wood River aquifer is underlain by the Sterling Plutonic Suite Granite Gneiss and the Scituate Igneous Suite Granite. The Queen-Usquepaugh aquifer is underlain by the Esmond Plutonic Suite Granite Gneiss and the Scituate Igneous Suite Granite. The Chipuxet is underlain solely by the Esmond Plutonic Suite

Granite Gneiss. The uranium-bearing minerals found in the bedrock are zircon, allanite, sphene, and monazite. The average uranium content of the Esmond Gneiss is 1.9 ppm, Sterling Gneiss is 3.3 ppm, and Scituate Granite is 4.1 ppm (Nevins, 1991).

Water Chemistry

Wells (both surficial and bedrock) from the Esmond Suite had the lowest radon content (range 500 to 30,400 pCi/L, mean 3,900 pCi/L), the Sterling Suite was not significantly different (range 700 to 27,300 pCi/L, mean 4,050 pCi/L), however, the Scituate Suite had significantly higher levels (range 1,600 to 83,450 pCi/L, mean 13,900 pCi/L). In both the Esmond and Scituate Suite surficial materials wells, radon concentrations increased with increasing depth and proximity to the bedrock surface. However, in the surficial material above the Sterling Plutonic Suite (found only in the Upper Wood aquifer) there was no increase with depth.

In the Esmond Suite, shallow surficial wells averaged 1,100 pCi/L, wells close to bedrock 1,800 pCi/L, and bedrock wells 8,600 pCi/L. In the Scituate Igneous Suite, shallow wells averaged 2,600 pCi/L, wells close to bedrock 9,500 pCi/L, and bedrock wells 28,900 pCi/L. In the Sterling Suite both the shallow surficial and deep surficial wells close to bedrock had about the same radon levels, 1,600 pCi/L and 1,300 pCi/L, respectively, and bedrock wells averaged 11,600 pCi/L. No statistical relationship was found between radon levels and uranium concentrations in the ground-water samples. However, the higher radon levels correlated with the higher uranium content in the underlying bedrock.

There exist distinct chemical differences between the surficial materials ground water and the bedrock ground water within the three aquifers. Groundwater in the underlying bedrock is characterized by higher pH and alkalinity. Furthermore, fluoride, calcium (except in the Chipuxet), and silica concentrations increased with depth into the surficial material and from the surficial material to bedrock. Chloride, however, decreased with depth in the three aquifers. Distinctive chemical characteristics of the aquifers include higher sodium values in the Upper Wood as compared to the Queen-Usquepaugh and Chipuxet aquifers. Also, a lower pH and fluoride, and higher sulfate, and magnesium is found in the Chipuxet. The Chipuxet bedrock aquifer is also characterized by a lower fluoride concentration (average .5 mg/L) than the other two aquifers. The Queen-Usquepaugh is distinguished from the other two aquifers by its lower chloride, nitrate, and potassium concentrations but higher calcium and alkalinity in its bedrock aquifer.

Discussion

All wells sampled yielded radon levels above the proposed EPA limit of 300 pCi/L and many were more than an order of magnitude greater. Although the EPA will probably adopt a standard that is less rigorous than 300 pCi/L, this study reveals that much of the ground water in southern Rhode Island has elevated radon levels that may be cause for concern. Radon concentrations in the surficial materials varied with respect to proximity to bedrock surface in both the Queen-Usquepaugh and the Chipuxet aquifers. However, there was no variation with respect to proximity to the bedrock surface in the Upper Wood aquifer. Therefore, in the Queen Usquepaugh and Chipuxet aquifers (but not the Upper Wood) either the deeper surficial material has a greater capacity for radon production (due to higher uranium content or a more favorable siting of uranium in the aquifer materials) or there is discharge of radon-bearing ground water from the underlying bedrock aquifer into the surficial material.

Geochemical modeling of the chemical data will be used to evaluate the likely that mixing is occurring between these two aquifers.

The finding that no correlation exists between dissolved uranium and radon concentrations is consistent with that of other studies. The solubility of uranium is a function of redox conditions in the aquifer and is therefore not expected to parallel radon concentrations because radon is a noble. As expected,the higher radon concentrations correspond to the bedrock containing the most uranium, and ground water from bedrock wells yields higher concentrations of radon than that from surficial material wells. This may be a function of uranium availability in the surficial materials or it may be a function of the release rate of radon to the water as uranium decays in the aquifer materials. Interpretation of the geochemical evolution of these waters may provide insight into which of these factors is controlling the distribution of radon in the surficial materials.

SYNOPSIS

Project Number: 05

Start: June 1, 1993
End: May 31, 1994

Title: *TOXIC ORGANIC CHEMICALS IN RHODE ISLAND GROUNDWATER: CONTAMINANT FATE AND TRANSPORT*

Investigators: Amy P. Gamerdinger, Richard W. Traxler,
University of Rhode Island

Focus Categories: TS, ST

Congressional District: Second

Descriptors: Bacteria, Biodegradation, Contaminant Transport, Hazardous Waste, Pollutants, Organic Compounds, Toxic Substances

Problem and Research Objectives:

An estimated 24% of Rhode Island's population obtain their drinking water supply from groundwater, thus, preserving groundwater quality is important for human and environmental health. Organic chemicals are among the principal contaminants, from a variety of sources, which are found in Rhode Island groundwater.

An understanding of the fate and transport of organic chemicals in soils and groundwater sediments is necessary for addressing several groundwater quality issues such as: estimating the travel time of potential groundwater pollutants from the point of release to drinking water supply wells, the amount or concentration of the contaminant that will ultimately be present in the wells, and contaminant removal rates from soil and groundwater when cleanup and remediation strategies are employed.

Most of our current understanding of organic contaminant behavior in soil and groundwater is based on studies conducted for a single chemical in a completely aqueous system. In the environment, we often have complex mixtures of chemical contaminants in aqueous systems where organic solvents are also likely to be present. We know that the fate and transport of an organic chemical will be influenced by the presence of other contaminants and solvents. In order to properly assess organic pollutant fate and transport from waste sites or leaking fuel storage tanks, we need to consider contaminant behavior in the presence of other chemicals, such as organic solvents, which are known to influence fate and transport.

Our project considers the fate and transport of toxic organic chemicals in the presence of organic solvents which are known to modify pollutant behavior. We specifically address the two most important processes, retardation and attenuation, which influence contaminant fate and transport. Retardation describes contaminant-sediment interactions which slow the movement of the pollutant through the sediment. Attenuation describes the reduction in pollutant concentration due to transformation and degradation (destruction of the pollutant) by chemical and biological processes. General use of the term sediment includes surface and subsurface material.

The specific objectives of this two-year project are three-fold: a. To describe the fate and transport of organic pollutants in the presence of organic solvents; b. To modify existing mechanistic process descriptions and parameters which were derived from studies of a single chemical in an aqueous (100% water) system; c. To provide a means for incorporating modified process descriptions into currently existing environmental fate models.

***Methodology*:**
Solvent-water partitioning, sediment-water partitioning, and miscible displacement techniques were adapted to characterize contaminant retardation and transport. Bacterial isolation and growth techniques were adapted to obtain and maintain bacterial populations. Bacteria which transform and mineralize PAHs (polycyclic aromatic hydrocarbons, a class of organic chemical contaminants) were used in mineralization experiments (closed flask system) to assess contaminant degradation. Nonaqueous phase liquid solvent treatments included hexadecane, dodecane, decane, octane, and hexane.

Mineralization experiments. The solvent treatment, naphthalene in acetone, ^{14}C-labeled naphthalene in acetone, and the inoculum were added to each 250 ml flask under sterile conditions. The total acetone in each flask did not exceed 0.2%, a concentration which was shown to have no effect on bacterial growth (Bauer and Capone, 1985). A third series of experiments (3 A-E) were conducted with the same solvent treatments that are specified for experiments 2 A-E in Table 1. In this series, the bacterial inoculum was equilibrated for 2 days with 25 g of aquifer material prior to adding the solvent or naphthalene. Additional control experiments, without ^{14}C naphthalene and without the bacterial inoculum, were also conducted.

An inlet to each flask was connected to an air pump; the outlet was connected to 3 CO_2 traps in series, which contained a 4:1 methanol:ethanolamine solution (Zhou and Traxler, 1992). The flasks were closed except during aeration and sampling; they were placed on a shaking water bath at a temperature of 27 +/- 1 °C throughout the experiment.

The CO_2 traps were changed at discrete time intervals following a ten minute aeration period; a 0.3 ml sample was taken and $^{14}CO_2$ was measured by liquid scintillation counting. Prior to termination of the experiments, one ml of 1 $\underline{M}$ HCL was added to the flasks to force bicarbonate from solution to CO_2, which was collected in the traps. The remaining liquid in each flask was filtered (0.2 μm) and radioactivity associated with the filtrate and with the cells that remained on the filter paper was determined by liquid scintillation counting.

Naphthalene sorption and partitioning. Naphthalene sorption onto aquifer material was measured using the miscible displacement technique in a laboratory soil column (Nielsen and Biggar, 1962; Biggar and Nielsen, 1962, 1963; Zhong et al, 1986; Lee et al, 1988; Gamerdinger et al, 1990). The soil-water partition coefficient (K_p) was calculated from the retardation factor ($R = 1 + \rho K_p / \theta$) which was determined through mathematical moment analysis (Valocchi, 1985).

Naphthalene partitioning between each of the solvents was measured in biphasic solvent-water systems. A known concentration and activity of ^{14}C naphthalene was added to 1 ml of each solvent followed by 7 mls of D.I. water. The vials were tightly sealed with teflon lined caps, equilibrated for 10 days, and centrifuged prior to sampling and analysis of each phase. The partition coefficient was determined by computing the concentration ratio of naphthalene in the solvent relative to the aqueous phase.

Principle Findings and Significance (to date):

Bacterial Isolation: We isolated a bacterium from local soil in the vicinity of an underground oil storage tank. Standard enrichment culture techniques were used. The bacteria (pure culture) were able to use several of the polycyclic aromatic hydrocarbons, PAHs, (naphthalene, anthracene and pyrene) as substrates for growth; complete mineralization of the hydrocarbon substrate naphthalene to CO_2 was confirmed with radioisotope techniques. This bacteria was used as the inoculum in subsequent studies of naphthalene degradation and mineralization in solvent-water and sediment-water systems.

Hydrocarbon biodegradation surface and subsurface soil systems:
Complete degradation of naphthalene in the presence of 3 soils (2 surface and 1 aquifer material) was measured. The extent of degradation was positively correlated with the organic carbon content of the soil, suggesting that organic matter from the soil enhanced degradation. Degradation was reduced when water-soluble organic matter was removed from the two surface soils. These results suggest that enhanced degradation is positively correlated with the amount of organic carbon available via the aqueous phase. This could result from increased substrate availability due to the cosolvency effect of the water soluble fraction of the soil organic matter, or, due to growth of the bacteria on this water-soluble fraction of organic matter. Further experimentation and evaluation is required to understand the mechanism and under what conditions enhancement will be observed.

Hydrocarbon biodegradation biphasic solvent-water systems:
Biodegradation of naphthalene in the presence of 5 organic nonaqueous phase liquids (hexane, octane, decane, dodecane, hexadecane) was evaluated (Figure 1). The extent of degradation was enhanced in the presence of the more hydrophobic organic solvents and decreased in the presence of octane and hexane.

This could be due to a direct effect on the microorganism, or due to indirect effects such as increasing substrate availability to the bacteria. We suspect that degradation will be diminished in the presence of more hydrophilic solvents. Further experimentation is required to establish the relationship between solvent properties and their effect on biodegradation.

Naphthalene partitioning
Partitioning of naphthalene in biphasic solvent-water systems was similar for the solvents evaluated.

Table 1. Solvent-Water Partition Coefficients of Naphthalene

Solvent	K [†]
Hexane	394 (12)
Octane	402 (13)
Decane	437 (4)
Dodecane	412 (22)
Hexadecane	415 (12)

[†] The standard deviation (n=3) is reported in parentheses.

These results indicate that substrate availability was similar in each of the 5 solvent-water and soil-solvent-water systems that were evaluated.

Concise summary of most important findings to date:
Bacteria which degrade PAHs were present in hydrocarbon contaminated soil. The bacterial population was viable in the presence of hydrophobic organic solvents (alkanes with chain length of 10 or greater). These solvents are also classified as L-NAPLs (nonaqueous phase liquids which are less dense than water). The overall extent of naphthalene degradation to CO_2 was enhanced in the presence of the more hydrophobic ($\log P > 5.9$) organic solvents, although the initial rate was slower. This suggests that contaminant degradation is a function of the mixture of contaminants that may be present on-site. Understanding the controlling mechanisms is important for predicting contaminant fate and for optimizing bioremediation strategies.

References:

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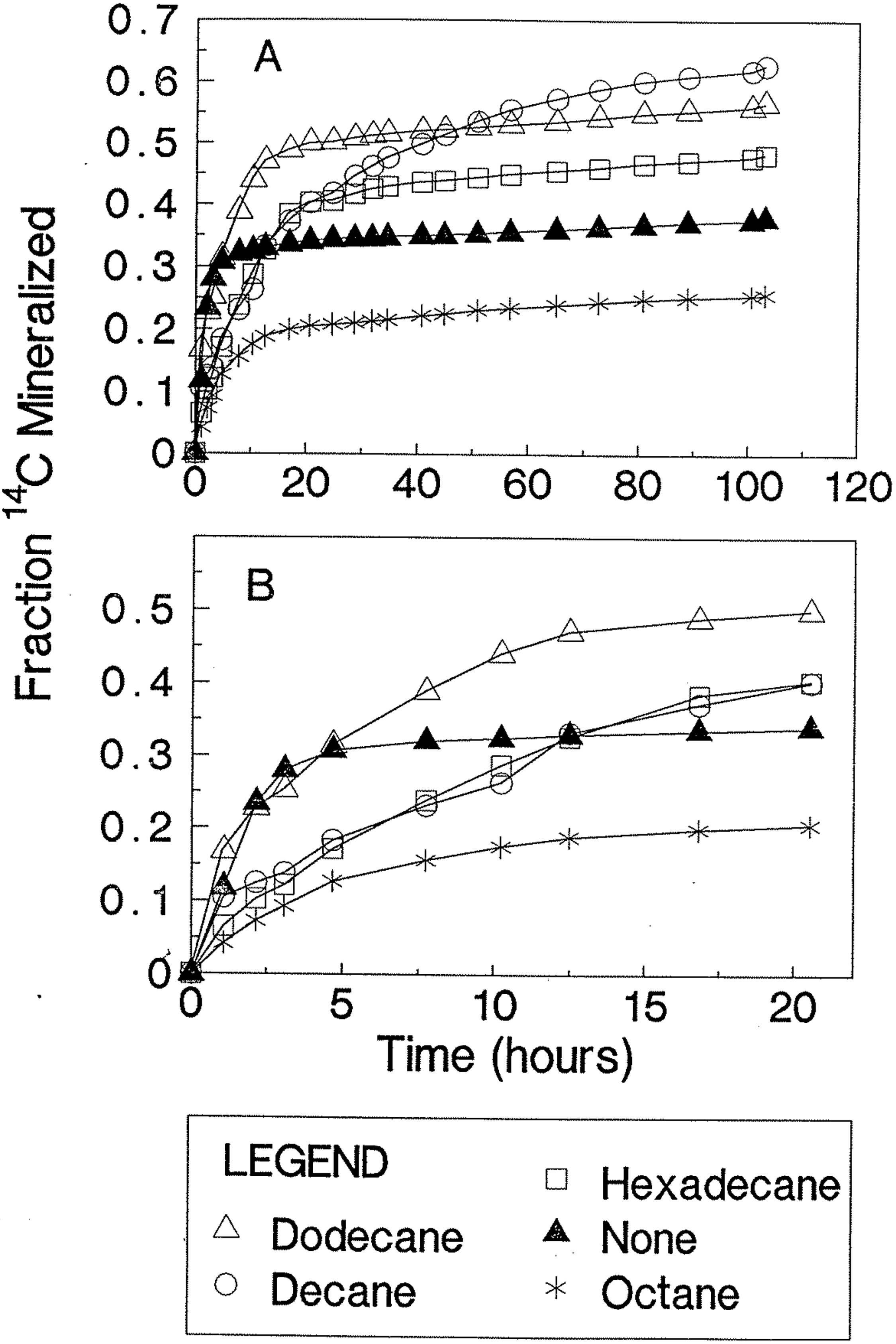
Zhong, W.Z.; Lemley, A.T.; Wagenet, R.J. In *Evaluation of Pesticides in Groundwater*; Garner, W.Y., Honeycutt, R.C., Nigg, H.; Eds.; American Chemical Society Symposium Series No. 315: Washington, DC, 1986; pp 61-67.

Zhou, X.; Traxler, R.W. *Appl. Microbiol. Biotechnol.* **1992**, *38*, 254-258.


A
B
Fraction ^{14}C Mineralized
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100
120
0
5
10
15
20
Time (hours)
LEGEND
△ Dodecane
○ Decane
□ Hexadecane
▲ None
∗ Octane

Publications

Articles in refereed scientific journals:

Gamerdinger, A.P., R.S. Achin, R.W. Traxler. 1995. Effect of hydrophobic organic solvents on naphthalene biodegradation in solvent-water systems. J. Environ. Qual. (in review).

Gamerdinger, A.P., R.S. Achin, R.W. Traxler. 1995. Effect of soil organic matter on the transport and biodegradation of naphthalene in soil. Soil Sci. Soc. Amer. J. (in preparation).

There are no completed publications to date from the first year of work. Three manuscripts are planned; several experiments must be completed for each manuscript.

Information Transfer Synopsis

Project: #22-FY1993

Title: Information Transfer Project

Project Duration: September 1, 1993 - May 31, 1994

Graduate Assistant: John O. Wingate

The information transfer activities can be divided into three major parts: (a) the newsletter, (b) coordinated efforts in water resources education, and (c) Updating and expanding the Water Resources Directory.

The newsletter was published four times during the nine months of information transfer activity. The newsletters were distributed in Rhode Island to the State and Coordinating Committees, the research community, water agencies, non-government organizations, and nationally to the other Water Resources Research Institutes. Items covered in the newsletter include research briefs from Water Resources Center funded investigators, relevant state and federal legislation, planning activities of this center, and discussion of water related environmental issues.

Three seminars were presented; two by professionals working in water resources related fields, and one by a current investigator for the Water Resources Center. The seminars were well attended by the university community and several professionals from the outside. The seminars were arranged in an educational format which provided plenty of time for interaction between the attendees and speaker. The presenters and topics are included below.

Dr. Eid Alkhatib	"Wastewater Management For Non-sewered Communities"
Adjunct Professor Tom Wright	"Controlling and Treating Contaminated Groundwater Beneath the central Landfill"
Microbiologist Alicia Lehrer	"Comparisons of the Effectiveness of Ultraviolet and Chlorine Disinfection"

Two Citizen Forums were held for the discussion of controversial water resources related issues in Rhode Island. The objective of the first forum was to explore the alternatives to the proposed $467 million combined sewer overflow abatement plan. The existing combined sewer overflow system (CSO) was a major contributing factor to closures of the upper Narragansett Bay to shellfishing and swimming following large rain events. The controversy at hand was how the project was to be funded and whether the upgrade should be paid by sewer users, or by the entire state. The first Citizen Forum was held on November 17, 1993 at the Department of Health's auditorium in Providence. Speakers and the topics discussed include the following:

Tom Brueckner, Chief of Operations and Engineering, Narragansett Bay Commission
Discussion: General background and implications of the CSO Abatement Project, explanation of the major design options, significance of the chosen design ("Mix 3") .

Philip Holmes, Former President, Rhode Island Shellfishermans Association
Discussion: The decline of the Shellfishing industry due to stormwater pollution. The contributions to state income from "clean bay industries."

Jay Manning, Principal Sanitary Engineer, Department of Environmental Management, Division of Water Resources.
Discussion: The Department of Environmental Management's CSO Policy.

William Penn, Executive Director, Rhode Island Clean Water Finance Agency
Discussion: Financing of the CSO Abatement Project through the State Revolving Fund.

Paul Pinault, Executive Director, Narragansett Bay Commission
Discussion: The Narragansett Bay Commissions policy towards upgrading the CSO system. Financing options for the abatement project.

The second Citizen Forum was held on February 24, 1994 at the University of Rhode Island. The question asked of the panel members was ; "Is there a need for Aquifer Management in Rhode Island." There is currently no laws controlling the quantity of groundwater that can be withdrawn from any particular well in Rhode Island. There are several sole-source aquifers in southern Rhode Island which are particularly vulnerable to excessive withdrawal from unregulated development and various utility and farming interests. Environmental engineer , Bill Spizuoco, wrote a handbook for developing legislation on aquifer management which was brought to the table for discussion. Speakers and topics discussed included the following:

Carleton Maine, Former Assistant Director of Rhode Island Department of Environmental Management.
Discussion: Environmental effects of excessive withdrawal from the Chipuxet Aquifer. Historic overview of DEM's policies regarding aquifer management.

William J. Spizuoco, Environmental Engineer and author of; "Pro-Active Management, Protection, and Apportionment of Conjunctive Water Uses in the Chipuxet Aquifer and River."
Discussion: A plan to effectively manage water withdrawal from the Chipuxet Aquifer.

W. Michael Sullivan, Professor of Plant Science, University of Rhode Island.
Discussion: Economic challenges to agricultural based operations due to aquifer management.

Dan Varin, Associate Director for Planning, Rhode Island Department of Administration.
Discussion: State policy on aquifer management. Previous attempts towards legislation on aquifer management.

The goal of each forum was to provide the public an opportunity to listen and ask questions regarding controversial water resources issue facing the community. The Citizen Forums were well advertised yet were only moderately attended. Feedback from those who did attend was very positive and offered reassurance that Citizen Forums provide an excellent educational tool for the Rhode Island community.

Other activities which encompass the FY-1993 Information Transfer Project include the completion of the Rhode Island Water Resources Directory. The directory was initiated in FY-92 with a partial listing of RI Department of Health water suppliers, RIDEM, and several water resources related service industries. The currently available version has 15 categories of water resources related professionals including "Engineers & Consultants," "Volunteer Water Quality Monitoring Programs," and "URI Faculty."

Another project which was completed was the setup of a computer station and procedures for accessing the National Groundwater Information Center Database (NGIS). A modem was installed and linkage to the data base was completed. Users who care to access the most comprehensive groundwater database in the world can do so for a fee of $2.00 per minute.

New software installed in the Water Resources Center's computer includes Microsoft Office (Word, Powerpoint, and Excell), Norton Antivirus, and Wordperfect 6.0. Several templates for Citizen Forum and Seminar flyers, as well as the capability for graphics in the Newsletter were arranged.

COOPERATIVE ARRANGEMENTS

The Water Resources Center at the University of Rhode Island has two advisory committees, namely the State Advisory Committee and the University Water Resources Coordinating Committee. The member ship has been changed in the past year, reflecting the recent interest and availability of water resources experts in Rhode Island.

State Advisory Committee

Combs, Walter	Dept. of Health
Falcone, Willaim	Water Resources Board
DeLima Virginia	U.S. Geological Survey
Mark, Eugene	
Meyer, Henry	Kingston Fire District
Miller, Scott	Office of System Planning, Dept. of Adm.
Rose, Vincent	Save the Bay
Salomon, Erich W.	Armbrust Chain Co.
Scott, Elizabeth	Office of Environmental Coordination
Stuart, Everett	U.R. Dept. of Agriculture
Szymanski, Edward	Dept. of Environmental Management
Varin, Daniel W.	Dept. of Administration
Weygand Robert A.	Lieutenant Governor

The state advisory Committee is consisted of leading water resources officials of the state and federal agencies as well as representatives from prominent citizen groups and manufacturers.

The other committee is the University Coordinating Committee, consisting of faculty members of the University of Rhode Island from various colleges and the director of the Sea Grant program. Each member has a significant contribution to academic and research programs related to water in the area.

University Coordinating Committee

Cain, J. Allen	Professor & Head of the State Geologist Office
DeLuise, Frank	Professor, Mechanical Engineering
Frohlich, Reinhard K.	Professor Geology
Gold, Arthur	Associate Professor
Miller, Robert H.	Dean, College of Resources Development
Nixon, Scott	Professor, Coordinator of Sea Grant Program
Calvin P.C. Poon	Professor, Environmental Engineering

The two committees met and discussed water resources issues and research priorities for the FY-1993 State Water Research Institute Program. As a result of the discussion and suggestions from the committee members, the research priorities were established as listed on page 3 of this report. Both committees also reviewed and ranked research proposals, made comments and suggestions of proposal alterations. They also served as points of contact to collect and to disseminate information to various groups of audience.

Project 02 worked closely with U.S. Department of Agriculture, Soil Conservation Service, U.S. Geological Survey subdistrict Office in Providence, Rhode Island, Department of Environmental Management, to collect and discussion of data in order to identify the important issues and to formulate an appropriate methodology.

Project 03, by nature of its work, had close cooperation with the U.S. Environmental Protection Agency on the Pawtuxet River Basin Study.

Project 04, worked closely with USGS subdistrict office in sample collections and with USGS National Water Quality Laboratories in Denver and Lakewood, Colorado for sample analysis.

The project on information transfer worked with the Rhode Island Department of Health, R.I. Department of Environmental Management, Narragansett Bay Commission, and citizen groups in Rhode Island.

PUBLICATIONS

1. Referred Scientific Journal

	Supporting Section 104 Project No.
Gamerdinger, A.P., R.S. Aching, R.W. Traxler, 1994, *Effect of Hydrophobic Organic Solvents on Naphthalene Biodegradation in Solvent-Water Systems.* Jour. Environ. Qual., Submitted (in review).	05-(FY-93)
Gamerdinger, A.P., R.S. Achin, R.W;. Traxler, 1995, *Effect of Soil Organic Matter on the Transport & Biodegradation of Naphthalene in Soil.* Soil Sci. Soc. Amer. Jour. (in prep.)	05-(FY-93)

3. Dissertations

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Veeger, A., 1994 *Radon in the Groundwater Reservoirs of Southern Rhode Island: A Field Assessment.* Technical Completion Report, Water Resources center, Univ. of Rhode Island.	04-(FY-93)
Gamerdinger, A.P., R.W. Traxler, 1994. *Toxic Organic Chemicals in Rhode Island Groundwater: Contaminant Fate & Transport,* Technical Completion Report, Water Resources Center, Univ. of Rhode Island	05-(FY-94)

Alkhatib, Eid, R. Wright, 1994. *Chemical Impact of Bottom Sediments Resuspension in Rivers-Assessment & Mitigation,* Technical Completion Report, Water Resources Center, Univ. of Rhode Island. 03-(FY-94)

5. Conference Proceedings

Ruderman, N.C., Veeger, A.I., 1994, *The Occurrence of Radon (222 Rn) in Groundwater Reservoirs of Southern Rhode Island:* [abstr.] in Geological Society of America, Abstracts with Program, Binghamton, New York, Vol. 26, No. 3. p.69. 04-(FY-94)

Veeger, A.I., 1994, *Hydrogeochemistry of Glacial & Bedrock Aquifers in the Pawcatuck River Basin of Southern Rhode Island:* [abstr.], in Geological Society of America, Abstract with Program, Binghamton, New York, Vol. 26, No. 3, p. 78. 04-(FY-94)

TRAINING ACCOMPLISHMENTS

Academic Level

Field of Study	Under-graduate	Master's Degree	Ph.D. Degree	Post-Ph.D.	TOTAL
Engineering					
Environmental		2			2
Geology		1			1
Natural Resources Sci.		2			2
		5			5

Completion Report

Radon in the Ground-Water Reservoir of Southern Rhode Island

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and O. Don Hemes

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WATER RESOURCES RESEARCH INSTITUTE
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Completion Report

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U.S. Department of the Interior
Geological Survey

and
Water Resources Center
University of Rhode Island

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Abstract

A field study was conducted to evaluate the distribution of Radon (^{222}Rn) in the glacial aquifers of the Pawcatuck River Basin, Rhode Island. A total of 95 ground-water samples were collected from private wells in stratified-sediment and bedrock aquifers of the Upper Wood, Queen-Usquepaugh, and Chipuxet River basin aquifers. Furthermore, gamma-ray emissions from the regolith material throughout the study area were measured. The ground-water samples were analyzed for basic chemical constituents as well as uranium and ^{222}Rn to help evaluate the factors controlling ^{222}Rn distribution. The Upper Wood River aquifer is underlain by the Sterling Plutonic Suite Granite Gneiss and the Scituate Igneous Suite Granite. The Queen-Usquepaugh aquifer is underlain by the Esmond Plutonic Suite Granite Gneiss and the Scituate Igneous Suite Granite, and the Chipuxet is underlain solely by the Esmond Plutonic Suite Granite Gneiss. The uranium-bearing minerals found in the bedrock are zircon, allanite, sphene, and monazite. The average uranium content of the Esmond Gneiss is 1.9 ppm, Sterling Gneiss is 3.3 ppm, and Scituate Granite is 4.1 ppm. There was no significant difference between the measured eU and eTh concentrations of the regolith of the three aquifers. The bedrock aquifers were found to be chemically distinct from the overlying stratified-sediment, with distinguishing characteristics being higher pH, alkalinity, conductivity (except in the Chipuxet), fluoride, calcium (except in the Chipuxet), sodium, and silica concentrations in the bedrock aquifers because of the longer residence time and therefore greater chemical evolution in these waters. All wells sampled in this study yielded radon levels above the proposed EPA limit of 300 pCi/L, with many being an order of magnitude or more greater. Wells in areas underlain by the Esmond Suite had the lowest radon content (range 500 to 30,400 pCi/L, median 1,399 pCi/L), areas underlain by the Sterling Suite were not significantly different (range 700 to 27,300 pCi/L, median 1,595 pCi/L), however, the areas underlain by the Scituate Suite had significantly higher levels (range 1,600 to 83,450 pCi/L, median 5,895 pCi/L). In wells underlain by both the Esmond and Scituate Suites, radon concentrations increased with increasing depth and proximity to the bedrock surface in surficial material wells, and were highest in the bedrock wells. However, in the surficial material above the Sterling Plutonic Suite (found only in the Upper Wood aquifer) there was a slight decrease in radon concentration with depth, but the bedrock wells were once again significantly greater. Well yield and the siting of uranium seem to be the controlling factors in the distribution of radon between surficial and bedrock wells. No statistical relationship was found between radon levels and uranium concentrations in the ground-water samples because the source of radon in ground water is uranium in the solid phase. However, the higher radon levels correlate with the higher uranium content in the underlying bedrock, and therefore underlying bedrock uranium content is also an important factor in radon distribution. In the Queen-Usquepaugh and the Chipuxet aquifers (but not in the Upper Wood where the Sterling Plutonic Suite is located) either the deep surficial material has a greater capacity for radon production (due to higher uranium content or a more favorable siting of uranium in the aquifer materials) or there is discharge of radon-bearing ground water from the underlying bedrock aquifers into the surficial material above. Although the EPA will most likely adopt a standard less rigorous than 300 pCi/L, this study reveals that much of the ground water in southern Rhode Island has elevated radon levels that may be cause for concern.

Introduction

Radon-222 (^{222}Rn) is a radioactive isotope with a half-life of 3.8 days. It is produced during the decay of uranium-238 to lead-206 (Figure 1). Radon-222 is ejected from the solid, transferred to the adjacent pore space, and escapes as a gas or is held in place by the water, which prevents the radon from recoiling into adjacent mineral grains (Wanty et al, 1993). Because of its short half-life and the relatively slow flow of ground water in most settings, ^{222}Rn is unlikely to be transported great distances in aquifers. Therefore, when high levels of ^{222}Rn are found in ground water, its source (uranium) is likely to be present in the surrounding rock or sediment. Previous studies comparing radon in ground water to bedrock type and uranium content found higher ground-water radon concentrations in the bedrock containing the most uranium (Cothern et al, 1987; Folger et al, 1994; Hall et al, 1987; Hollocher et al, 1993; and Nevins, 1991). Since radon is undergoing a form of nuclear disintigration when it decays, it is reported as disintegrations per unit time. A becquerel (Bq) is one disintegration per second. Radioactivity in ground-water is usually reported as picocuries per liter (pCi/L); 1 pCi/L = 37 Bq/m^3 (Wanty et al, 1993).

The United States Environmental Protection Agency (USEPA) has determined that elevated levels of radon gas in indoor air is the second leading cause of lung cancer, cigarette smoking being the number one cause. Several studies conducted on the contribution of radon from domestic water supplies with high radon concentrations to indoor radon levels have shown that higher indoor-air radon concentrations correlate with indoor well water use (Figure 2) (Folger et al, 1994; Hess et al, 1985; Lawrence et al, 1992; Wanty et al, 1992). Approximately 1 to 7 percent of radon-related deaths are the result of radon that is released from well water during normal household activities (Cothern et al, 1986). At the 1983 National Workshop on Radioactivity in Drinking Water, a population-weighted average radon concentration in public water supplies serving less than 1,000 people was estimated at 780 pCi/L (Cothern et al, 1987). Because of the potential health threat of radon, the USEPA originally proposed a maximum contaminant level (MCL) of 300 pCi/L for radon in drinking water (Federal Register, July 18, 1991). This MCL was not accepted by Congress and is currently under revision.

The small public water suppliers and private wells are in greater danger of radon contamination because they are located in the less productive crystalline rock aquifers. The USEPA predicted higher radon concentrations in much of New England as compared to the rest of the United States, with Maine and New Hampshire having the highest (Cothern et al, 1987). In Rhode Island, the sediment contains the uranium-bearing minerals zircon, allanite, sphene, and monazite originating from the granitic bedrock in Rhode Island. In 1986, the Rhode Island Department of Environmental Management (RIDEM) initiated a statewide, private well water quality survey (RIDEM, 1990). Radon was detected in each of the 310 private wells tested. If the USEPA were to adopt an MCL of 300 pCi/L for radon, over 90% of these wells would exceed the standard. Studies were also conducted on indoor-air radon concentrations throughout Rhode Island. Using composition of underlying bedrock, glacial deposit distribution, and indoor radon data collected by Rhode Islanders Saving Energy (RISE) program, Nevins (1991) made a geologic radon potential map of Rhode Island. This radon potential map of the state showed that Rhode Island has moderate to high radon potential according to EPA's criteria.

In addition to the uranium content of the underlying bedrock, radon concentration in well water is also a function of the composition and physical properties of the rock and sediment composing the aquifer. Previous investigations of ground-water radon potential in other states have found that several factors including uranium mineralization, fracture aperature in the underlying bedrock, and degree of metamorphism also impact radon concentrations of ground water (P. Folger, written communication, 1994; Hollocher et al,1993; Krishnaswami et al,1988; LeGrand,1987; and Wathen,1987).

Ground water is the potable water source for approximately 24% of Rhode Island as a whole, and 100% of southern Rhode Island. Previous studies of these crystalline rocks underlying the state have found significant amounts of uranium (Nevins, 1991). Therefore, the potential for high levels of radon exists in wells in surficial material as well as in the underlying bedrock.

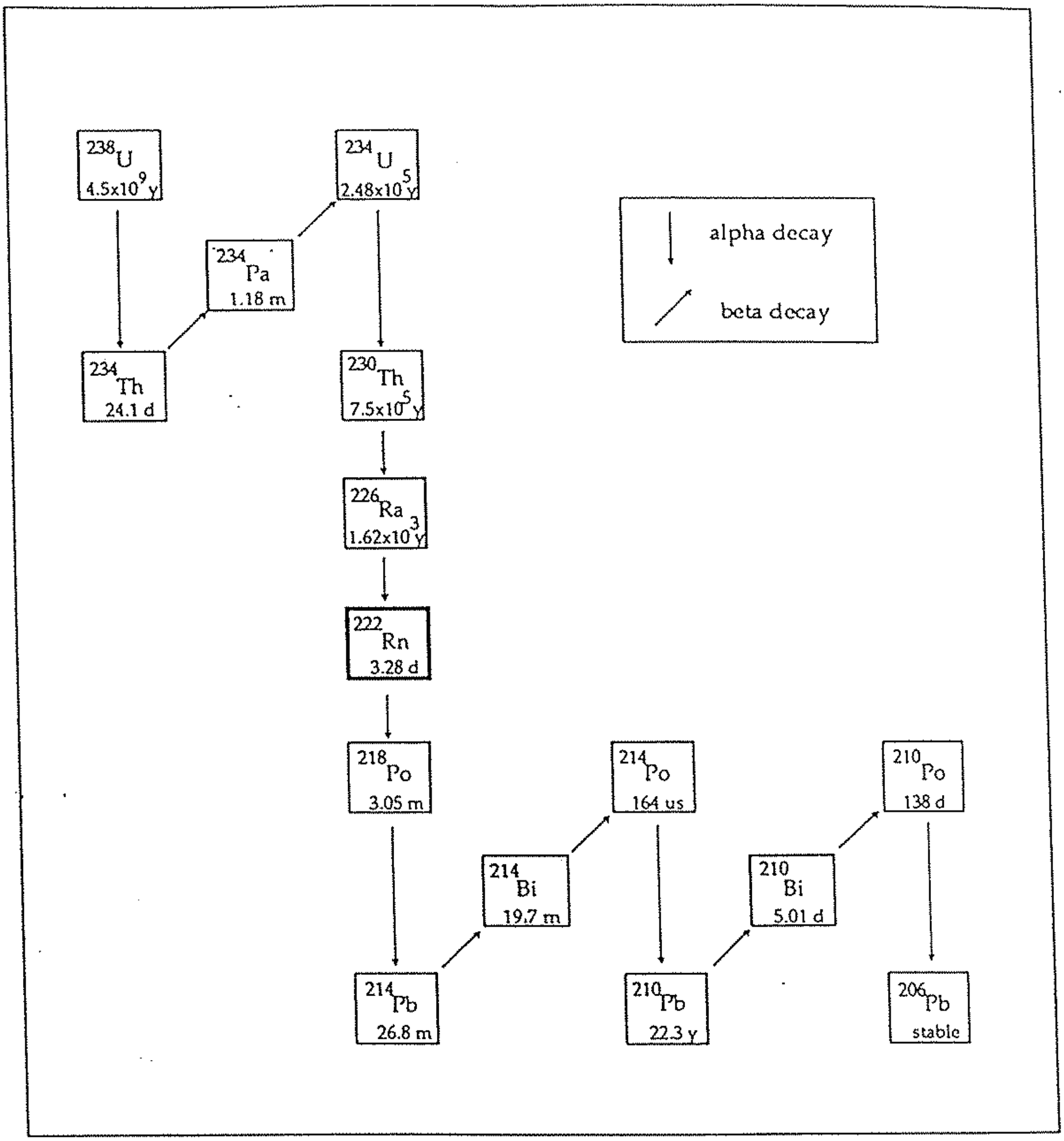

Figure 1. The uranium-238 decay series. The mode of decay and half-life of each isotope in series is shown. ^{238}U: half-life 4.51 E + 09 years, ^{222}Rn: half-life 1.05 E - 02 years.

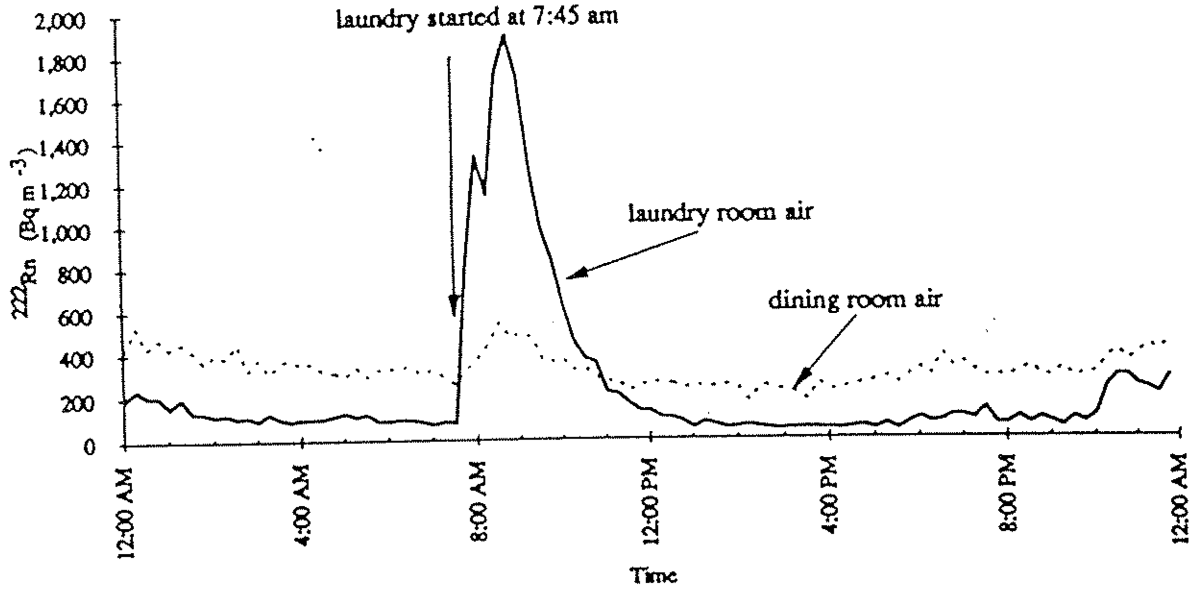

Figure 2. Radon concentration in air inside a home showing the effects of one washing machine usage. (from Folger et al, 1994)

The field assessment was completed in one year and included the following objectives:

- measurement of ^{222}Rn levels and chemical composition of ground-water in wells screened in glacial material as well as bedrock; and
- determination of the variability of ^{222}Rn within the three-dimensional framework of the aquifer;

The interpretive phase of the study, completed in the second year, includes the following objectives:

- evaluation of the factors controlling ^{222}Rn levels, for example: uranium content in the underlying bedrock, depth to bedrock, and chemical evolution of the groundwater; and
- development of a conceptual model for the distribution of ^{222}Rn in the aquifers of the Pawcatuck River Basin, Rhode Island.

Study Area/Geology

The Pawcatuck River Basin is located in southern Rhode Island (Figure 3). The three aquifers included in this study, the Upper Wood River, Queen-Usquepaugh, and Chipuxet, are unconsolidated aquifers of glacial origin deposited in southward-trending bedrock valleys during retreat of the late Wisconsinan ice sheet (Hughes, 1985). The sides of the valley are bedrock highs covered with a thin deposit of till. Large braided meltwater streams from the glaciers at the head of the valley flowed south, depositing sediment along the valley floor in a delta sequence. This glacio-fluvial / glacio-lacustrine environment created a strongly heterogeneous aquifer materials distribution. The glacial deposits in the valleys consist of fine to coarse sand and gravel, with some silt, derived from granitic igneous and metamorphic rocks to the north. A geologic cross-section of the Chipuxet aquifer is provided in Figure 4. Deposition in the Upper Wood and Queen-Usquepaugh produced a similar accumulation of sediment. The sand and gravel deposits are parts of the stream, delta slope, and delta plain sequences, whereas the silt, and fine sand deposits were part of a lacustrine environment. The presence of gravel at the base of the stratified drift deposits is a buried esker, or ice tunnel deposit (Holden, 1994; Jeff Campbell, written communication). The aquifers vary in thickness, ranging from less than 50 feet of saturated thickness to greater than 150 feet of saturated thickness in the deepest portions of the bedrock valley. Ground water flow in these unconfined aquifers is in a southerly direction through the porous granular material. Well yields from the stratified drift deposits range from 100 to 1,150 gallons per minute (Johnston and Dickerman, 1985). These aquifers are complex, and in some areas vertical mixing between the bedrock and surficial material aquifers may occur

Rhode Island is located within the Avalon lithotectonic zone, a zone containing approximately 10 structurally and stratigraphically distinct bedrock terranes (Plate 1- modified after Hermes et al, 1994). The Hope Valley Shear Zone runs down through the western portion of the study area and divides the terranes into two distinct groups, the Esmond-Dedham terrane to the east and the Hope Valley terrane to the west and south. The member of the Hope Valley terrane of interest is the Sterling Plutonic group alaskite gneiss, dating to the late Proterozoic, approximately 600 million years before present (MYP) (Murray, 1988). The alaskite gneiss is a quartz-rich granitic gneiss containing sodic plagioclase and microcline, with accessory hornblende, magnetite, biotite, muscovite, sphene, and zircon. The Esmond igneous suite augen granite gneiss is a late precambrian (approximately 570 MYP), calcalkaline rock containing quartz, plagioclase, biotite, potassium feldspar, and accessory epidote, chlorite, muscovite, sphene, monazite, apatite, and zircon (Hermes and Zartman, 1985). The final bedrock type located within the study area is the Scituate Igneous Suite granite, located in the northern portion of the study area. This granite is Devonian in age (approximately 370 MYP) and is composed of quartz, plagioclase, potassium feldspar, and accessory biotite, allanite, sphene, fluorite, calcic hornblende, calcite, and zircon (Hermes and Zartman, 1985). Water flow through these crystalline rocks is along fractures. Wells completed in these crystalline bedrock aquifers have lower yields than stratified-drift aquifers, up to 40 gallons per minute (Johnston and Dickerman, 1985).

The Upper Wood River is underlain by the Sterling Plutonic Suite Granite Gneiss and the Scituate Igneous Suite Granite. The Queen-Usquepaugh aquifer is underlain by the Esmond Plutonic Suite Granite Gneiss and the Scituate Igneous Suite Granite. The Chipuxet aquifer is underlain solely by the Esmond Plutonic Suite Granite Gneiss (Plate 1). The uranium-bearing minerals found in the bedrock are zircon, allanite, sphene, and monazite. The average uranium content of the Esmond Gneiss is 1.9 ppm, Sterling Gneiss is 3.3 ppm, and Scituate Granite is 4.1 ppm (Nevins, 1991).

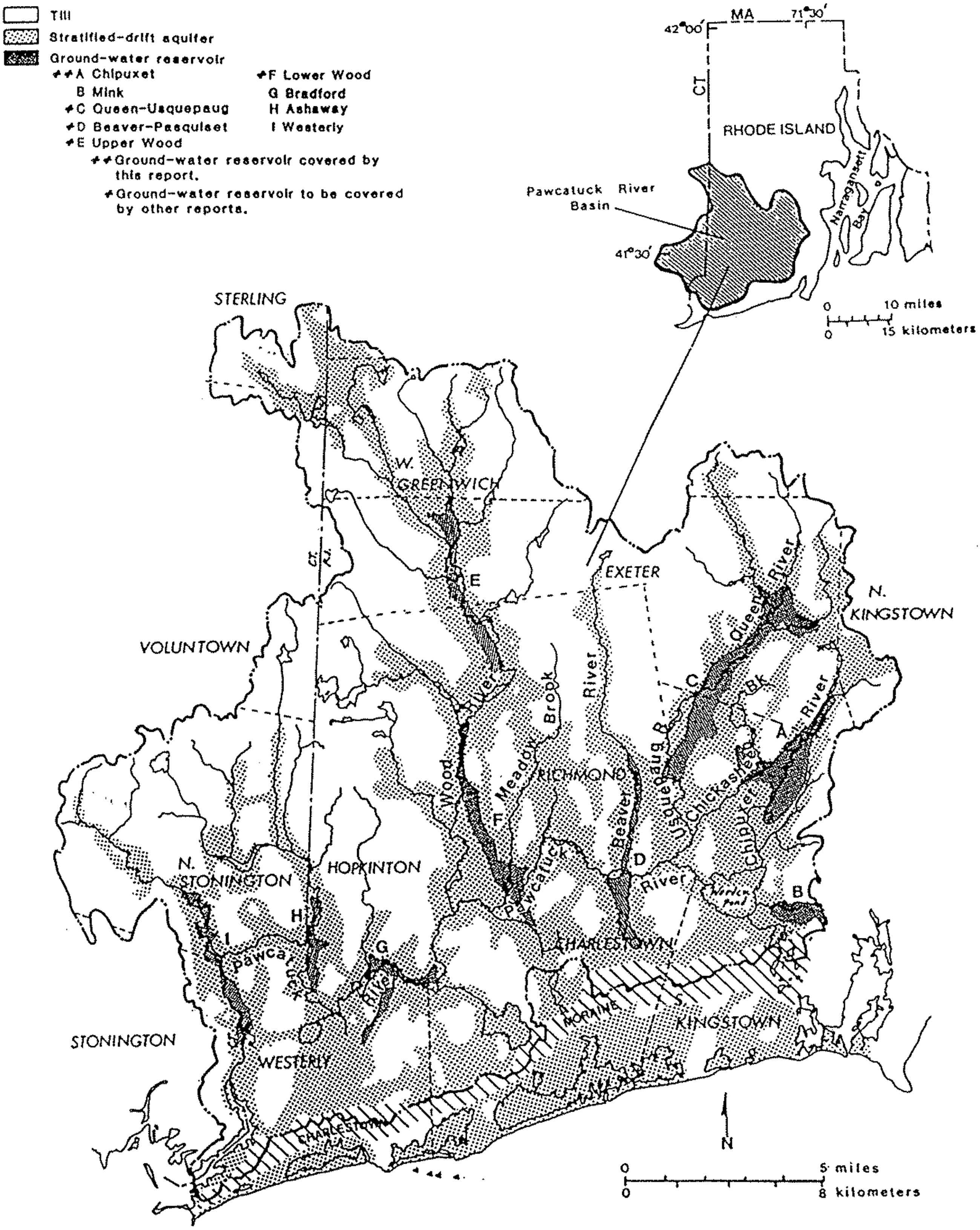

Figure 3. Location of Queen-Usquepaugh, Chipuxet, and Upper Wood River aquifers and the other major aquifers in the Pawcatuck River basin and generalized surficial geology (Johnston and Dickerman, 1985).

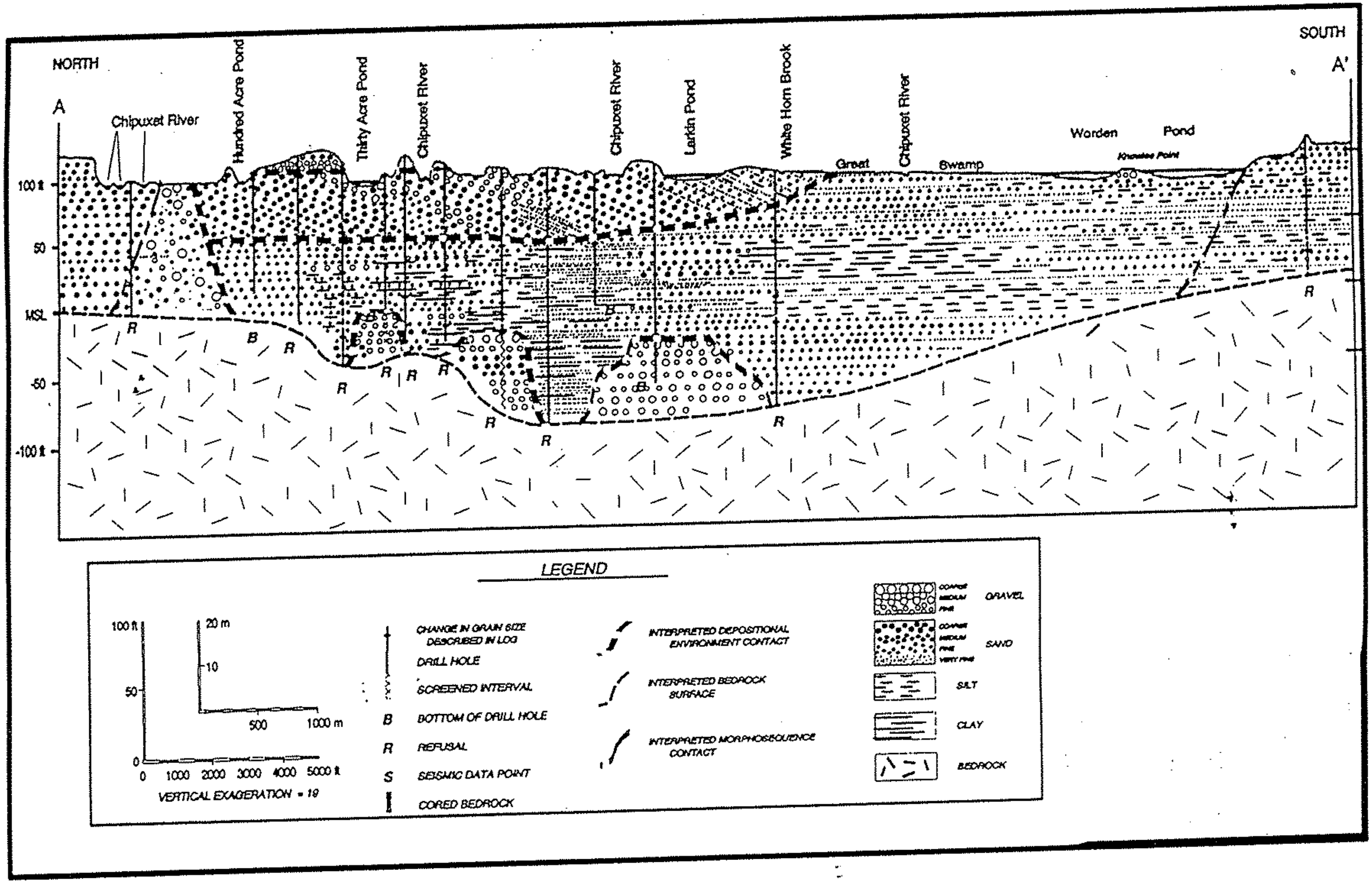

Figure 4. Geologic cross-section A-A' of the Chipuxet River valley, Rhode Island. (Jeff Campbell, written communication).

Approach and Methodology

Ground-water samples were collected from the stratified-sediment and bedrock aquifers within the three river basins. Wells completed in shallow surficial material and those close to the bedrock surface were sampled to try and obtain information concerning the distribution of radon within the surficial material. The samples from the stratified-drift deposits close to bedrock will either represent the more chemically evolved stratified-drift aquifer ground water, or a mixture between the underlying bedrock ground water and that of the surficial material just above it. Ground-water samples within the underlying bedrock were taken to evaluate the radon potential of these uranium-bearing bedrock units.

A gamma-ray spectrometer was used to measure the amount of radioactivity in the regolith material that can be attributed to uranium, thorium, and potassium, three naturally occurring radioactive elements that produce gamma rays. This gamma-ray emission data may provide insight into the radon potential of the surficial material throughout the study area.

In order to understand the nature of the screened interval aquifer material of both the surficial and bedrock wells, all available well logs were obtained from the Rhode Island United States Geological Survey (USGS)-Water Resources Department. Information recorded was stratified drift aquifer material (sand or gravel, for example), depth to bedrock, and well yield. Also, any information the homeowner provided concerning their well was recorded.

Field Methods

Ground-water samples were collected from wells in the Upper Wood River, Queen-Usquepaugh, and Chipuxet basin aquifers. Surveys were sent to homeowners throughout these three river basins asking for well and aquifer information (Appendix A). Wells were chosen on the basis of this survey and the underlying bedrock. Each well was screened for possible contamination using electrical conductance. Wells with less than 200 μS/cm specific conductance were preferred because they had the least amount of input from anthropogenic sources. Using the homeowner's well pump, ground-water samples were collected after 3-well volumes had been evacuated from each well, and pH, temperature, and electrical conductivity had stabilized. The standard sampling procedures is included in Appendix B. Field analyses included temperature, pH, electrical conductance, and dissolved oxygen.

In the Upper Wood aquifer, 29 out of 37 wells were sampled within or above the Sterling Suite, the remaining 8 wells were sampled within or above the Scituate Suite (Plate 1). Most of the wells (16 out of 21) in the Queen were sampled within and above the Scituate Suite, the remaining 5 wells were sampled from within and above the Esmond Suite. A total of 37 wells were sampled in the Chipuxet aquifer. Ground-water samples were collected for the following laboratory analyses: radon, uranium, alkalinity, calcium, magnesium, sodium, potassium, iron, manganese, silica, fluoride, chloride, nitrate, phosphate, and sulfate. All samples (except radon) were filtered through 0.45 μm filters and stored at 4 ^{o}C in high-density polypropylene bottles. Samples collected for cation analysis were acidified with concentrated hydrochloric acid and those collected for uranium analysis were acidified with concentrated nitric acid, both to a pH of 2.

Because of the volatility of radon gas, a sampling procedure developed by the USGS was followed when collecting the ^{222}Rn samples (Rich Wanty, written communication, 1993). First, the flow rate was reduced so no agitation existed in the discharging well water. A 10 ml sample of ground water was collected from inside the hose with a pipette prior to the water coming into contact with the atmosphere. The sample was then dispensed into a vial containing 10 ml of mineral oil-based liquid scintillation cocktail. The sample was immediately capped and shaken so as to partition the ^{222}Rn into the scintillator phase due to its high solubility in this fluid.

A Gad-6 gamma-ray spectrometer was used to measure the gamma-ray emissions from the regolith material throughout the study area. A total of 47 readings were taken from stratified-drift, till, and outcrops in the three river valleys. These data were used to calculate %K (potassium), eU (uranium), and eTh (thorium) content of the materials.

Laboratory Methods

The radon samples were analyzed within three days of collection at the USGS National Water Quality Laboratory in Denver, Colorado. The uranium analyses were completed at the USGS National Water Quality Laboratory in Lakewood, Colorado. The manganese analyses were performed in the University of Rhode Island, Department of Civil Engineering, Environmental Engineering Laboratory. All other analyses were performed in the University of Rhode Island, Department of Geology, Hydrogeology Laboratory. A summary of analytical techniques is included in Table 1.

Table 1. Summary of analytical techniques.

Chemical Parameter	Analytical Technique
Specific Conductance	YSI model 32 conductivity bridge.
pH	Combination electrode, Accumet model pH/°C/mV meter.
Fe	1,10 phenanthroline colorimetric method (Std Method 3500).
Alkalinity	Standard method 2320 (Clesceri et al, 1989), potentiometric titration, alkalinity using Accumet model 925 pH/°C/mV meter.
F, Cl, Br, NO_3, SO_4	Ion chromatography, Dionex Series 4500i with AS4A anion separator column.
Na, K, Mg, Ca	Ion chromatography, Dionex Series 4500I with CS3 cation separator column.
SiO_2	Standard method 4500-Si D, molybdosilicate colorimetric method (Clesceri et al, 1989) using Milton Roy model 1201 spectrophotometer.
Mn	Atomic absorption air-acetylene flame method.
Uranium	Fluorometric analytical method, laser phosphorimetry with standard addition of sodium hexametaphosphate.
Radon	Liquid scintillation method modified after Prichard and Gesell (1977).

Results

Gamma-ray Data

The data for the gamma-ray emissions are included in Table 2. Only slight differences were found between the measured eU and eTh concentrations of the regolith of the three aquifers. In the Queen-Usquepaugh stratified drift, the median eU was 2.16 ppm, and eTh was 9.15 ppm. The Upper Wood stratified drift had median eU and eTh values of 1.87 ppm and 9.15 ppm, respectively. The median eU and eTh values of the Chipuxet stratified drift deposits were 2.35 ppm and 9.53 ppm, respectively.

Table 2. Airborne gamma-ray data of regolith material in the Pawcatuck River Basin.

Aquifer	sample #	eU ppm	eTh ppm	median eU
Queen-Usquepaugh	Q5	2.57	11.7	
	Q8	3.03	14.34	2.16
	Q9	1.48	7.79	(n = 7)
	Q10	2.16	7.21	
	Q11	1.43	5.97	
	Q13	1.63	9.15	
	Q14	2.68	9.88	
Upper Wood River	W1	2.37	10.25	
	W2	2.55	8.88	1.87
	W3	1.77	10.64	(n = 9)
	W4	1.55	9.67	
	W5	1.87	8.03	
	W6	1.73	9.15	
	W11	1.77	9.06	
	W16	2.43	11.94	
	W17	1.9	8.31	
Chipuxet	C1	2.35	9.37	
	C4	2.28	8.73	2.35
	C5	2.04	9.7	(n = 9)
	C6	1.72	6.34	
	C7	1.74	11.31	
	C10	2.37	9.25	
	C11	2.76	11.22	
	C12	2.73	11.19	
	C13	3.00	9.34	

Radon Distribution

Wells (both surficial and bedrock) in areas underlain by the Esmond Suite had the lowest radon content (range 500 to 30,400 pCi/L, median 1,399 pCi/L), areas underlain by the Sterling Suite were not significantly different (range 700 to 27,300 pCi/L, median 1,595 pCi/L), however, the areas underlain by the Scituate Suite had significantly higher levels (range 1,600 to 83,000 pCi/L, median 5,895 pCi/L) (Table 3, Plates 2 and 3). In plates 2 and 3, both surficial and bedrock wells show a dramatic increase in radon concentration across the Scituate Igneous Suite contact. In surficial material wells underlain by both the Esmond and Scituate Suites, radon concentrations increased with increasing depth and proximity to the bedrock surface, with the bedrock wells having the highest radon concentrations. Shallow surficial wells had a median radon level of 977 pCi/L, wells close to bedrock a median value of 1,389 pCi/L, and bedrock wells a median concentration of 5,353 pCi/L in the Esmond Suite. Median radon levels of the shallow surficial, deep surficial close to bedrock, and bedrock wells in the Scituate Suite were 2,464 pCi/L, 3,602 pCi/L, and 19,057 pCi/L, respectively. However, in the surficial material above the Sterling Plutonic Suite (found only in the Upper Wood aquifer) there was a decrease with depth in the surficial material, the bedrock wells still showed the higher values. Median radon concentrations of the shallow surficial, surficial close to bedrock, and bedrock wells in the Sterling Plutonic Suite were 1,839 pCi/L, 1,064 pCi/L, and 5,926 pCi/L, respectively.

Table 3. Median Radon levels (pCi/L) by underlying bedrock geology.

Underlying Bedrock (average uranium content-ppm)	Well Type shallow surficial	surficial close to bedrock	all surficial	bedrock	all wells
Scituate (4.1)	2464 (n=9)	3602 (n=5)	3015 (n=14)	19057 (n=9)	5895 (n=23)
Sterling (3.3)	1839 (n=7)	1064 (n=13)	1101 (n=20)	5926 (n=7)	1595 (n=27)
Esmond (1.9)	977 (n=15)	1389 (n=11)	1107 (n=26)	5353 (n=14)	1399 (n=40)

Looking at radon levels between the aquifers, the Chipuxet and Upper Wood (not including bedrock) aquifers had the lowest readings (Table 4). The median radon levels for shallow surficial, deep surficial, and bedrock wells in the Queen-Usquepaugh aquifer were 2,809 pCi/L, 4,749 pCi/l, and 15,225 pCi/L, respectively. In the Upper Wood aquifer, the median radon concentrations for the shallow surficial, surficial close to bedrock, and bedrock wells were 1,905 pCi/L, 1,073 pCi/L, and 17,277 pCi/L, respectively. Median radon levels found in the Chipuxet aquifer in shallow surficial, deep surficial, and bedrock wells were 958 pCi/L, 1,389 pCi/L, and 4,697 pCi/L, respectively.

Table 4. Median Radon levels (pCi/L) by aquifer.

Aquifer	Well type shallow surficial	surficial close to bedrock	all surficial	bedrock
Queen-Usquepaugh	2809 (n=6)	4749 (n=6)	3223 (n=12)	15225 (n=9)
Upper Wood River	1905 (n=11)	1073 (n=14)	1216 (n=25)	17277 (n=9)
Chipuxet	958 (n=14)	1389 (n=9)	1092 (n=23)	4697 (n=12)

Water Chemistry

Chemical composition of the ground-water samples are included in Tables 5, 6, and 7. In order to define the background chemistry of each of the aquifers, wells with excessive anthropogenic inputs (conductivity above 200 µS/cm, chloride above 30 mg/L, and nitrate above 20 mg/L) were not included in the chemical interpretation. Concentrations above these levels shows excessive contamination from road salt runoff, fertilizers, and septic leachate. Charge balance errors were calculated for the analyses, and samples with errors of 10% or more were excluded. The samples that were not included were well numbers 1, 2, 19, 21, 23, 25, 29, 31, 33, 34, 38, 39, 41, 45, 60, 66, 68, 70, 72, and 87.

There exist distinct chemical differences between the surficial materials ground water and the bedrock ground water within the three aquifers. Some significant distinguishing characteristics are higher pH, fluoride, and silica, values in the bedrock well water as compared to the surficial materials well water. Median concentrations of selected constituents in the Upper Pawcatuck aquifers are included in Table 8. When these waters are plotted on trilinear diagrams (hydrochemical facies diagrams), the chemical differences between bedrock and surficial wells become apparent (Figures 5, 6, and 7). In trilinear diagrams, the dissolved ionic constituents are plotted as percentages of the total milliequivalents per liter of cations or anions, creating a convenient way in which to represent the composition of most natural waters. The bedrock wells are dominated by HCO_3 (most greater than 40% of anions) and Ca (most greater than 40% of cations) and fall in the Ca + HCO_3 field. The surficial wells, on the other hand, are dominated by higher chloride (most greater than 40% of anions) and Na and K (most greater than 40% of cations) values and therefore plot in the corresponding fields. The deep surficial wells that plot in the bedrock field show evidence of greater chemical evolution and bedrock mixing.

Table 5. Well data for Queen-Usquepaugh ground-water sampling sites (in mg/L, except as noted).

Well	**screened material**	**Well**	**well**	**depth to**	**bedrock**	**Temperature**	**Conductivity**	**pH**	**dissolved oxygen**	**Radon**	**Alkalinity**	**Uranium**
#	/yield (Gallon/min.)	Type	depth (ft)	bedrock	type*	(C)	(µS/cm)			(pCi/L)	(as $CaCO_3$)	(ppb)
1	sand and gravel/.1	surf-shal	20	30	Eag	9.00	95.80	4.40	6.00	2581	0.44	0.40
2	fine sand/12	surf-shal	12	19	Sg	7.80	226.00	4.36	8.75	3037	2.86	1.00
3		surf-shal	12	15	Sg	4.90	39.50	5.25	8.80	3408	2.86	0.31
4		surf-shal	10	15	Sg	4.20	46.00	4.37	11.70	436	2.64	0.28
5	sand and gravel/.25	surf-shal	10	10	Sg	6.80	42.60	4.22	9.30	15421	1.10	1.01
6	sand and gravel	surf-shal	12	15	Sg	5.00	52.50	5.01	5.70	1609	1.32	0.31
7	sand	surf-deep	77	100	Eag	9.50	42.40	5.08	6.90	682	6.82	0.19
8	sand and gravel	surf-deep	58	60	Sg	7.00	78.60	5.50	9.80	10655	1.54	0.71
9		surf-deep	35	50	Sg	6.80	109.80	5.61	9.00	2434	4.18	0.88
10	fine sand/1.5	surf-deep	25	25	Sg	4.00	104.00	4.41	9.90	3602	7.92	0.34
11	sand and gravel	surf-deep	60	65	Sg	5.00	70.70	5.21	4.30	5895	10.78	0.19
12	sand and gravel	surf-deep	20	25	Eag	8.00	77.50	5.32	6.45	6752	19.80	14.29
13	2	bedrock	185	15	Eag	9.00	114.10	5.38	7.40	13906	22.00	5.19
14		bedrock	162	25	Sg	8.50	80.80	7.05	9.80	7994	7.92	0.20
15		bedrock	400	61	Sg	7.70	137.00	6.33	4.90	20018	38.72	5.29
16	15	bedrock	280	60	Eag	8.20	104.00	6.94	0.80	16544	40.04	9.70
17	20	bedrock	360	25	Sg	8.20	149.20	5.41	0.70	11302	48.40	1.70
18	55	bedrock	350	28	Sg	6.70	162.90	6.50	8.30	17963	59.84	0.60
19		bedrock	177	25	Sg	7.80	237.00	6.27	7.60	33499	41.80	295.45
20	0.25	bedrock	85	25	Sg	6.00	157.80	5.84	3.50	82860	39.60	0.67
21		bedrock	200	20	Sg	7.80	453.00	5.25	8.50	8461	2.20	1.06

* Eag-Esmond Sg-Scituate Hva- Sterling

Table 5 continued. Well data for the Queen-Usquepaugh ground-water sampling sites (in mg/L, except as noted).

Well #	F	Cl	Br	NO_3	PO_4	SO4	Na	K	Mg	Ca	Fe (total dissolved)	Mn	SiO_2
1	0.13	11.08	0.02	19.96	nd	5.37	8.16	1.15	0.97	3.41	0.10	nd	12.90
2	0.27	23.42	nd	48.66	nd	18.45	16.30	6.93	1.94	12.36	nd	0.34	16.09
3	0.11	4.45	nd	0.46	nd	6.79	3.12	0.47	0.44	1.77	nd	nd	10.33
4	0.10	7.89	0.02	0.22	0.02	6.26	4.33	0.26	0.55	1.74	0.09	nd	7.63
5	0.76	4.66	0.01	0.67	nd	6.82	3.10	0.34	0.49	1.34	nd	nd	10.29
6	0.41	5.87	0.01	1.19	nd	7.41	4.07	0.34	0.53	1.88	nd	nd	9.45
7	0.11	6.43	0.02	1.29	nd	2.58	4.91	0.52	0.31	1.36	nd	nd	24.81
8	0.09	11.52	0.02	2.40	0.01	8.63	7.98	0.70	0.89	3.04	0.02	nd	12.35
9	0.13	17.05	0.03	2.18	nd	15.86	10.81	0.80	1.32	4.80	0.04	nd	10.51
10	0.11	11.62	0.02	11.74	nd	6.96	6.60	1.49	1.15	6.60	nd	nd	8.72
11	0.10	6.08	0.03	1.55	nd	9.33	5.61	0.54	0.95	3.41	1.11	0.10	11.58
12	0.75	4.78	0.03	0.18	nd	6.50	4.81	0.69	0.51	7.66	0.02	nd	10.68
13	0.51	9.86	0.01	4.30	nd	8.59	7.93	0.73	1.20	9.27	0.03	nd	15.55
14	0.12	12.17	nd	0.39	<.01	8.27	7.80	0.84	0.98	3.25	0.03	nd	17.36
15	1.33	9.72	0.03	0.97	nd	9.93	8.43	0.96	1.68	15.57	nd	nd	16.69
16	1.29	3.48	0.01	0.82	0.04	1.22	8.26	0.69	1.42	9.41	nd	nd	17.27
17	3.52	4.28	0.01	0.18	nd	8.58	14.72	1.24	0.97	14.79	nd	0.79	30.07
18	2.95	4.31	0.01	0.01	nd	5.92	14.66	0.54	1.47	18.05	0.02	0.25	25.67
19	0.39	15.16	0.04	40.93	0.01	6.31	11.34	1.24	3.19	23.26	nd	nd	22.57
20	3.41	12.89	0.02	0.02	nd	5.95	9.94	1.28	0.94	10.97	5.72	2.64	32.79
21	0.62	121.56	0.04	6.58	nd	9.41	68.50	1.57	1.40	6.26	0.61	0.31	9.57

Table 6. Well data for the Upper Wood ground-water sampling sites (analyses in mg/L, see table 5 for annotations).

Well #	screened material /yield (gal/min)	Well Type	well depth (ft)	depth to bedrock	bedrock type	Temp (C)	conductivity	pH	dissolved oxygen	Radon (pCi/L)
22	sand and gravel	surf-shal	20	80	HVa	10.80	104.00	4.20	5.00	2804
23	sand and gravel	surf-shal	15	80	HVa	14.90	172.20	4.93	6.45	943
24	sand and gravel	surf-shal	23	80	HVa	10.00	94.70	4.85	3.60	1839
25	sand and gravel	surf-shal	10	50	HVa	12.50	347.00	4.99	3.50	1905
26	sand	surf-shal	20	50	HVa	10.00	93.00	4.65	1.50	1121
27	gravel/10	surf-shal	35	70	HVa	10.50	70.80	4.98	3.07	663
28	sand and gravel/15	surf-shal	25	45	Sg	9.80	68.90	5.48	9.40	2464
29	sand and gravel/5	surf-shal	20	60	HVa	10.90	341.00	6.60	10.40	2003
30	sand and gravel	surf-shal	18	45	Sg	11.90	61.70	5.28	1.30	1611
31	sand/10	surf-shal	15	25	Sg	13.90	201.00	6.03	0.30	2992
32	sand	surf-shal	16	20	Sg	11.90	53.00	4.95	2.80	1997
33	sand	surf-deep	30	40	Sg	10.00	301.00	5.18	9.30	3218
34	sand/9	surf-deep	55	60	HVa	9.10	143.00	5.58	8.70	734
35	sand	surf-deep	35	45	HVa	10.00	64.80	5.92	11.10	1595
36	sand and gravel	surf-deep	32	70	HVa	10.50	83.30	5.11	9.60	783
37	sand and gravel	surf-deep	96	100	HVa	12.00	102.00	4.91	0.60	1216
38	sand and gravel	surf-deep	65	65	HVa	11.00	201.00	5.98	10.50	1064
39	sand and gravel	surf-deep	30	70	HVa	10.50	184.00	4.23	8.20	841
40	sand	surf-deep	100	110	HVa	9.50	133.00	4.98	15.00	2500
41	sand and gravel	surf-deep	35	50	HVa	10.40	280.00	5.28	2.40	977
42	sand and gravel	surf-deep	50	60	HVa	8.50	152.00	4.91	11.00	1081
43	sand and gravel/11	surf-deep	60	60	HVa	9.00	110.00	4.92	11.00	1146
44	sand and gravel/9	surf-deep	39	60	HVa	12.20	85.10	4.37	10.10	831
45	sand	surf-deep	36	70	HVa	9.00	287.00	5.18	6.95	991
46	sand	surf-deep	130	130	HVa	9.40	55.20	7.37	10.40	2459
47		bedrock	140	35	HVa	11.00	165.00	6.82	2.65	3049
48	40	bedrock	200	40	Sg	8.90	139.60	6.81	7.75	19057
49	2	bedrock	410	60	HVa	10.80	113.00	7.15	10.50	5700
50		bedrock	97	60	HVa	10.00	97.80	5.69	11.20	4674
51	15	bedrock	71	18	Sg	9.00	131.00	5.34	0.40	39731
52		bedrock	425	130	HVa	10.50	109.80	7.16	3.80	5926
53	6	bedrock	140	120	HVa	9.00	59.60	7.17	7.10	17277
54		bedrock	106	60	HVa	9.70	106.60	5.43	8.50	27311
55	3	bedrock	325	70	HVa	10.00	104.30	5.37	5.80	17785
56	sand and gravel/35	till	20	30	HVA	10.00	74.90	7.07	7.40	10014
57		till	14	20	HVA	13.00	56.60	5.28	8.30	1841
58		till	20	20	Sg	12.00	84.10	4.40	10.70	1383

Table 6 continued. Well data for the Upper Wood ground-water sampling sites (analyses in mg/L, see table 5 for annotations).

Well #	Alkalinity	Uranium	F	Cl	Br	NO3	PO4	SO4	Na	K	Mg	Ca	Fe	Mn	SiO2
22	6.16	0.51	nd	19.59	0.03	5.58	nd	6.96	10.84	1.12	1.07	4.05	nd	nd	10.77
23	4.40	0.25	nd	35.24	0.02	5.72	nd	5.93	20.56	1.03	0.59	5.76	0.01	nd	8.04
24	8.14	0.30	0.08	16.65	0.04	2.49	nd	7.24	10.16	0.79	0.95	3.89	0.02	nd	8.92
25	34.10	0.30	nd	34.91	0.05	72.85	<.01	8.46	25.04	4.73	2.35	27.28	nd	1.44	13.11
26	2.42	0.28	0.07	21.63	0.04	0.05	nd	4.62	10.27	0.95	0.99	3.77	nd	0.25	15.20
27	2.64	0.28	0.23	8.73	0.03	12.75	nd	7.26	5.57	1.27	0.86	4.59	0.02	nd	7.86
28	9.68	0.34	0.11	6.81	0.05	5.89	0.03	6.41	5.48	0.67	0.90	4.14	0.02	nd	10.44
29	7.92	0.59	0.12	69.51	0.03	7.71	nd	8.93	41.99	1.13	1.54	8.67	nd	nd	15.02
30	9.24	0.30	0.15	8.86	0.02	0.24	nd	5.45	6.03	0.82	0.44	2.87	0.47	1.03	9.59
31	13.86	0.30	0.16	45.29	0.02	0.77	nd	3.62	22.77	1.59	1.12	6.97	0.34	1.30	12.14
32	6.16	0.39	0.18	4.19	0.03	0.24	nd	6.26	4.66	0.90	0.37	2.15	1.51	0.10	18.57
33	5.94	0.30	0.11	70.83	0.02	8.40	nd	14.07	46.38	1.98	0.89	5.22	nd	nd	12.40
34	3.08	0.53	0.15	11.62	0.04	38.37	nd	5.74	9.74	2.09	2.29	7.10	nd	nd	14.27
35	11.00	0.35	0.09	3.13	0.04	5.34	nd	6.63	3.79	0.73	0.90	4.31	nd	nd	13.04
36	7.70	0.30	0.10	6.50	0.02	7.92	nd	8.98	4.57	0.77	1.06	5.32	nd	nd	10.63
37	8.36	0.63	0.09	18.63	0.03	0.05	nd	4.04	9.24	0.86	0.79	2.76	4.33	1.84	7.91
38	36.96	0.33	0.13	10.18	0.01	33.56	nd	17.17	26.53	1.24	1.84	9.19	0.03	nd	15.51
39	4.40	0.31	nd	30.75	0.02	25.42	0.18	12.43	17.34	4.39	1.45	11.06	nd	nd	11.86
40	8.14	0.32	0.08	24.93	0.05	nd	nd	8.88	9.64	1.50	0.61	3.06	13.92	0.38	21.59
41	0.44	0.21	0.08	70.04	0.04	0.22	nd	4.61	43.99	0.31	0.42	1.96	2.90	0.54	6.08
42	6.38	0.30	0.13	27.51	0.02	14.79	nd	7.93	14.67	3.03	1.45	6.89	nd	nd	8.44
43	5.28	0.57	0.40	10.99	0.03	18.01	nd	9.89	8.75	1.37	1.21	6.37	nd	nd	15.10
44	4.62	0.30	0.08	14.90	0.02	2.81	nd	7.80	8.37	1.03	0.68	3.26	0.09	nd	7.45
45	16.28	0.30	0.15	21.16	0.03	53.30	nd	19.92	20.97	12.56	1.23	14.66	nd	0.13	16.80
46	14.52	0.77	2.10	3.11	<.01	0.36	nd	2.80	5.15	1.06	0.44	3.72	0.11	nd	22.68
47	23.98	0.31	0.67	23.97	0.04	2.72	0.05	5.99	9.99	2.40	1.39	13.69	0.03	nd	24.24
48	22.00	0.56	0.56	19.41	0.03	2.64	nd	7.61	10.03	1.84	1.21	10.99	nd	nd	24.25
49	26.84	29.62	2.05	6.27	nd	0.80	0.02	8.65	8.80	1.12	0.87	9.25	nd	nd	12.24
50	19.80	0.28	1.02	9.02	0.01	4.73	nd	5.04	7.73	0.86	0.79	7.41	0.04	nd	22.23
51	26.40	0.59	2.77	5.80	0.03	0.11	0.04	14.56	5.42	0.96	1.06	13.84	0.70	0.24	24.25
52	24.64	13.03	2.15	4.81	<.01	nd	nd	9.66	11.95	0.55	0.58	5.73	0.39	nd	12.31
53	17.82	2.32	1.43	3.00	<.01	0.15	nd	2.42	5.74	0.64	0.47	3.76	0.09	nd	21.18
54	19.80	12.38	1.61	12.17	0.02	5.47	nd	2.11	9.59	0.97	0.79	7.57	0.01	nd	16.32
55	32.12	4.80	2.07	3.50	0.02	0.14	<.01	5.95	9.07	0.71	2.55	5.22	0.09	nd	25.72
56	17.38	0.86	0.34	3.90	0.01	1.47	<.01	4.86	5.50	0.94	0.88	3.83	0.01	nd	18.99
57	10.56	0.30	0.09	3.06	0.02	4.48	nd	3.55	4.32	0.82	0.41	2.44	0.03	nd	14.61
58	3.96	0.28	0.44	13.38	0.02	3.49	nd	6.96	6.53	2.09	0.85	3.22	0.41	0.10	11.82

Figure 7. Well data for the Chipuxet ground-water sampling sites (in mg/L, see Table 5 for annotations).

Well #	screened material/yield (gal/min)	Well Type	well depth	depth to bedrock	bedrock type	Temp	Conductivity	pH	Dissolved oxygen	Radon	Alkalinity
59	sand	surf-shal	6.1	90	Eag	7.00	132.00	5.40	4.45	1026	11.22
60	sand and gravel	surf-shal	18	190	Eag	11.10	222.00	5.13	4.20	1202	3.30
61	sand/40	surf-shal	19	180	Eag	9.30	53.00	4.45	7.10	1153	6.60
62	sand	surf-shal	22	190	Eag	10.20	123.00	5.09	3.55	1241	7.70
63	sand and gravel/.1	surf-shal	20	200	Eag	11.60	128.00	4.24	8.30	933	0.22
64	sand and gravel	surf-shal	20	100	Eag	11.10	134.00	4.43	3.50	870	3.74
65	sand and gravel	surf-shal	20	190	Eag	11.40	158.00	4.79	0.90	617	5.72
66	sand and gravel	surf-shal	19	180	Eag	11.20	141.00	4.27	2.90	1092	7.48
67	sand and gravel/.1	surf-shal	18	190	Eag	8.40	103.00	4.10	8.20	533	5.28
68	sand and gravel/.1	surf-shal	23	190	Eag	10.90	202.00	4.17	1.35	877	11.66
69	sand and gravel/.1	surf-shal	14	190	Eag	11.00	92.80	4.53	8.80	977	2.64
70	sand and gravel/.1	surf-shal	20	210	Eag	10.40	269.00	4.04	8.20	520	1.10
71	sand and gravel	surf-shal	22	200	Eag	10.00	175.00	5.27	9.20	1903	0.44
72	sand and gravel	surf-shal	14	190	Eag	9.50	103.50	5.91	3.00	938	4.84
73	sand	surf-deep	150	150	Eag	13.00	122.00	4.47	8.45	1122	6.38
74	sand	surf-deep	37	190	Eag	10.80	172.00	4.76	4.65	1389	3.30
75	sand	surf-deep	35	190	Eag	12.20	89.00	4.38	4.75	1361	1.10
76		surf-deep	65	100	Eag	9.40	54.00	4.59	9.10	1409	3.96
77	sand and gravel	surf-deep	75	100	Eag	9.40	135.00	4.59	8.80	1954	13.20
78	sand	surf-deep	53	190	Eag	11.00	87.00	4.26	0.75	1786	8.36
79	sand	surf-deep	30	80	Eag	10.00	93.30	4.22	8.90	924	4.62
80	sand	surf-deep	28	190	Eag	9.10	107.00	4.10	8.80	558	4.40
81	sand	surf-deep	65	180	Eag	10.00	135.00	6.69	6.10	2010	49.50
82		bedrock	435	80	Eag	10.00	121.00	6.77	8.60	3152	41.36
83	5	bedrock	500	95	Eag	11.00	87.40	7.01	0.75	13562	40.92
84	15	bedrock	125	70	Eag	9.10	62.30	5.24	11.20	9514	19.80
85		bedrock	200	30	Eag	8.00	63.50	4.86	12.00	4777	3.52
86		bedrock	150	18	Eag	9.40	106.00	5.39	6.40	7428	22.00
87		bedrock	150	100	Eag	10.00	321.00	5.59	3.80	4617	16.50
88		bedrock	209	190	Eag	9.50	95.20	5.53	0.70	1171	17.60
89	5	bedrock	350	100	Eag	10.00	74.50	6.65	2.80	30401	23.98
90		bedrock	360	30	Eag	10.20	147.00	5.76	8.50	3674	46.64
91		bedrock	152	18	Eag	9.20	103.00	5.26	6.60	1534	11.44
92		bedrock	120	70	Eag	8.80	55.00	5.06	10.70	3692	3.96
93		bedrock	500	190	Eag	11.00	132.00	6.95	0.40	5929	37.40
94		till	90	90	Eag	8.50	54.10	4.71	12.20	3760	12.76
95		till	12	20	Eag	9.70	41.40	3.85	8.70	2952	1.98

Table 7 continued. Well data for the Chipuxet ground-water sampling sites (in mg/L, see table 5 for annotations).

Well #	Uranium	F	Cl	Br	NO3	PO4	SO4	Na	K	Mg	Ca	Fe	Mn	SiO2
59	0.13	nd	13.48	0.03	3.12	nd	22.95	4.54	2.25	2.44	11.13	nd	nd	15.56
60	0.24	nd	33.49	0.05	25.37	nd	19.02	20.27	3.94	2.67	8.47	0.03	0.10	12.40
61	2.78	0.05	6.81	0.03	0.19	nd	5.27	5.82	0.55	0.53	1.84	0.03	nd	14.64
62	0.27	nd	11.79	0.04	10.36	nd	19.53	7.48	2.15	1.79	8.45	0.02	nd	12.57
63	0.20	0.08	22.16	0.04	16.61	nd	8.56	15.06	2.72	0.59	3.46	nd	nd	7.17
64	0.19	0.09	15.03	0.05	10.04	nd	17.71	5.54	14.21	1.94	4.06	0.01	0.17	10.42
65	0.62	0.07	25.59	0.05	15.07	nd	18.95	12.19	3.26	2.11	10.44	0.13	0.13	14.53
66	0.28	nd	13.22	0.05	21.35	nd	15.98	8.60	3.52	1.37	9.57	nd	nd	7.64
67	0.25	nd	19.92	0.05	8.94	nd	14.91	9.10	2.96	1.23	7.65	nd	nd	12.25
68	0.20	0.07	35.08	0.04	29.64	nd	17.85	32.30	5.88	0.82	4.33	nd	0.31	10.40
69	0.27	0.09	16.85	0.03	2.66	nd	9.28	9.36	1.89	0.54	3.59	nd	nd	8.62
70	0.35	0.07	49.29	0.06	32.73	nd	12.18	32.37	3.49	1.22	9.30	0.04	0.13	9.29
71	0.19	0.08	18.44	0.05	16.44	nd	27.10	8.13	5.66	3.41	9.37	nd	nd	12.95
72	0.20	0.09	13.93	0.04	21.95	nd	12.31	7.22	3.69	1.96	8.53	0.09	nd	17.89
73	0.26	nd	7.87	0.04	8.32	nd	24.25	5.44	0.72	2.14	8.70	0.05	nd	13.66
74	0.30	0.06	21.79	0.05	13.86	nd	21.89	13.59	3.89	2.38	6.53	0.03	nd	14.67
75	0.18	0.10	8.82	0.02	3.61	nd	12.44	4.03	1.83	0.88	3.51	nd	nd	11.39
76	0.27	nd	8.94	0.03	0.63	nd	7.06	5.75	0.49	0.61	1.94	0.02	nd	12.26
77	0.45	0.07	8.62	0.08	12.42	0.03	17.15	7.36	1.58	2.43	8.55	nd	nd	16.22
78	1.41	0.07	12.74	0.04	1.71	0.04	9.49	9.27	1.36	0.86	3.27	0.05	nd	11.59
79	0.28	nd	16.70	0.05	2.48	nd	15.31	8.44	1.66	1.85	4.24	0.03	nd	9.25
80	0.19	nd	14.98	0.03	7.33	nd	14.47	7.57	3.85	0.96	5.31	0.06	0.10	10.24
81	3.67	0.84	8.77	0.03	3.37	nd	6.71	9.21	1.67	7.00	12.54	0.01	nd	14.85
82	15.00	0.37	4.67	0.03	0.70	nd	5.97	8.05	1.47	1.74	10.53	nd	nd	14.93
83	2.45	1.26	4.63	<.01	nd	0.06	3.01	11.86	0.60	0.59	8.30	nd	nd	15.74
84	0.31	0.26	4.92	0.03	0.03	0.18	0.82	6.66	0.53	0.91	3.09	0.03	nd	18.17
85	0.93	0.08	8.88	0.03	0.63	nd	7.97	5.78	0.98	0.71	2.16	0.02	nd	11.24
86	17.78	0.87	11.83	0.03	1.67	nd	11.33	9.74	0.93	0.67	9.83	0.02	nd	12.92
87	3.24	0.17	25.12	0.11	29.57	nd	60.45	13.95	2.69	5.96	26.74	0.17	nd	22.85
88	0.19	0.10	8.83	0.03	0.04	nd	8.91	7.14	1.13	0.46	4.26	8.20	0.13	25.24
89	3.33	0.49	4.89	0.02	nd	0.17	1.22	7.83	1.06	1.14	2.64	0.19	nd	17.03
90	4.00	0.97	8.34	0.02	1.83	nd	7.80	13.06	1.00	1.50	12.55	nd	0.61	16.75
91	0.32	0.10	12.77	0.03	4.60	0.01	10.68	13.95	0.83	1.13	4.50	0.18	0.20	14.16
92	0.31	0.08	7.78	0.03	0.45	nd	7.60	4.87	0.66	0.63	1.98	0.04	nd	13.30
93	7.33	0.62	9.31	0.01	0.02	nd	9.69	11.44	1.26	1.63	10.54	1.18	0.18	12.58
94	0.42	0.08	3.94	0.01	nd	0.02	5.62	6.11	0.76	0.48	2.37	0.02	nd	22.35
95	0.31	0.12	5.07	nd	0.06	nd	7.16	3.62	0.40	0.42	1.09	nd	nd	7.79

Table 8. Concentrations of selected constituents in Upper Pawcatuck aquifers.

Median		**Chemical**	**Parameters**	**(mg/L)**					
Values		**pH**	**alkalinity**[1]	**Ca**	**SiO2**	**F**	**Mg**	**Na**[2]	**cond**[3]
Queen-Usquepaugh	shallow surficial (n=4)	4.69	1.98	1.76	9.87	.26	.51	3.6	44.3
	deep surficial (n=6)	5.27	7.37	4.1	11.13	.11	.92	6.1	78.05
	all surficial (n=10)	5.15	3.52	2.46	10.42	.11	.54	4.86	61.6
	bedrock (n=7)	6.33	39.6	10.97	17.36	1.33	1.2	8.43	137
Upper Wood	shallow surficial (n=7)	4.95	6.16	3.89	10.44	.13	.9	5.97	70.8
	deep surficial (n=8)	4.95	7.92	4.01	11.83	.1	.84	5.85	93.55
	all surficial (n=15)	4.95	7.7	3.89	10.63	.1	.9	5.97	85.1
	bedrock (n=9)	6.81	23.98	7.57	22.23	1.61	.87	7.73	109.8
Chipuxet	shallow surficial (n=9)	4.53	5.28	7.65	12.57	.08	1.79	5.9	128
	deep suficial (n=9)	4.47	4.62	5.31	12.26	.07	1.85	7.34	107
	all surficial (n=18)	4.5	4.95	5.92	12.42	.08	1.82	5.9	122.5
	bedrock (n=11)	5.53	22	4.5	14.93	.37	.91	8.05	95.2

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[1] mg/L $CaCO_3$.

[2] corrected for anthropogenic contamination by eliminating equivalent Na moles where Cl is in excess of 15 mg/L.

[3] µS/cm.

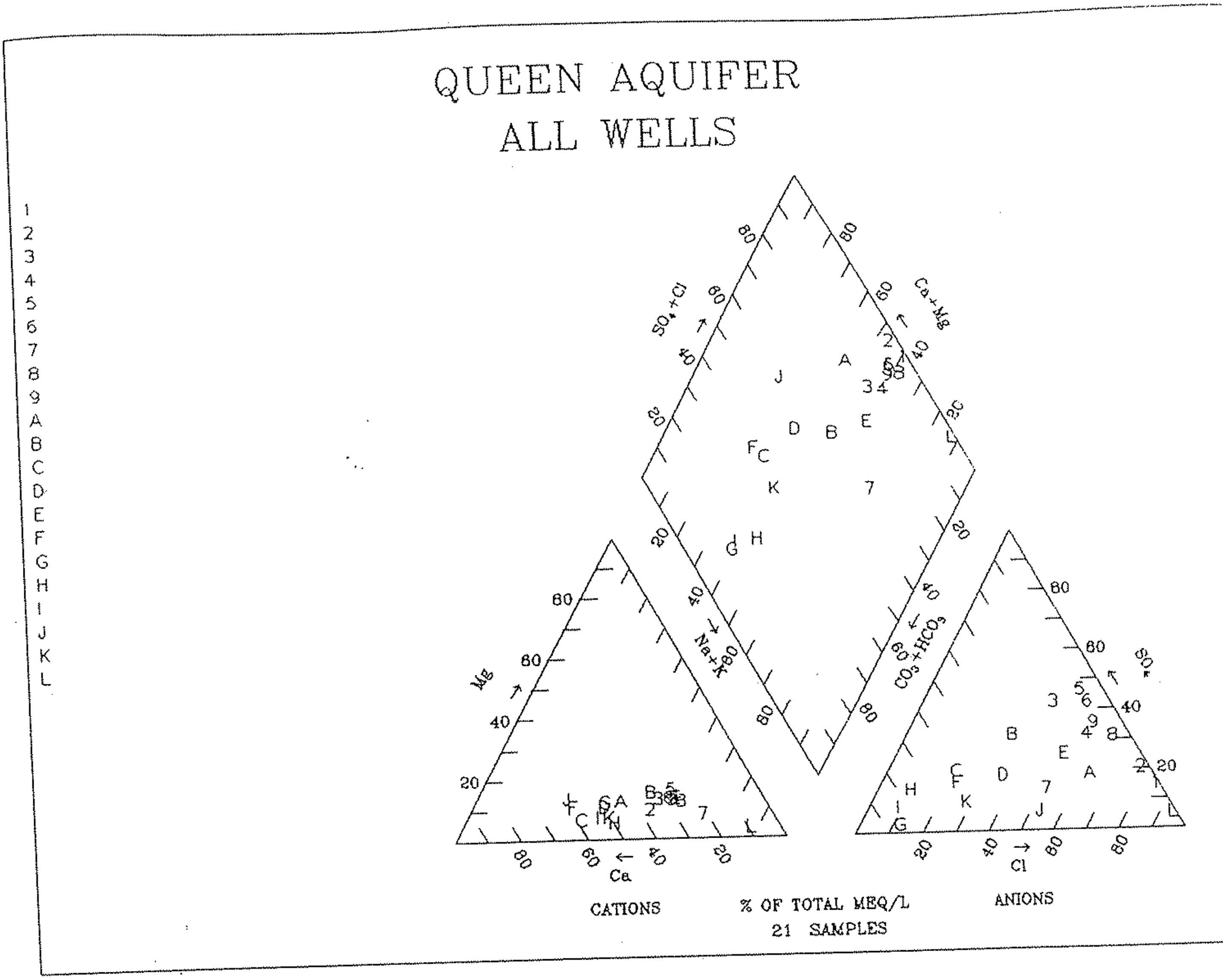


Figure 5. Trilinear diagram of ground water in the Queen-Usquepaugh aquifer.

* 1-6 shallow surficial wells
7-C surficial wells close to bedrock
D-L bedrock wells

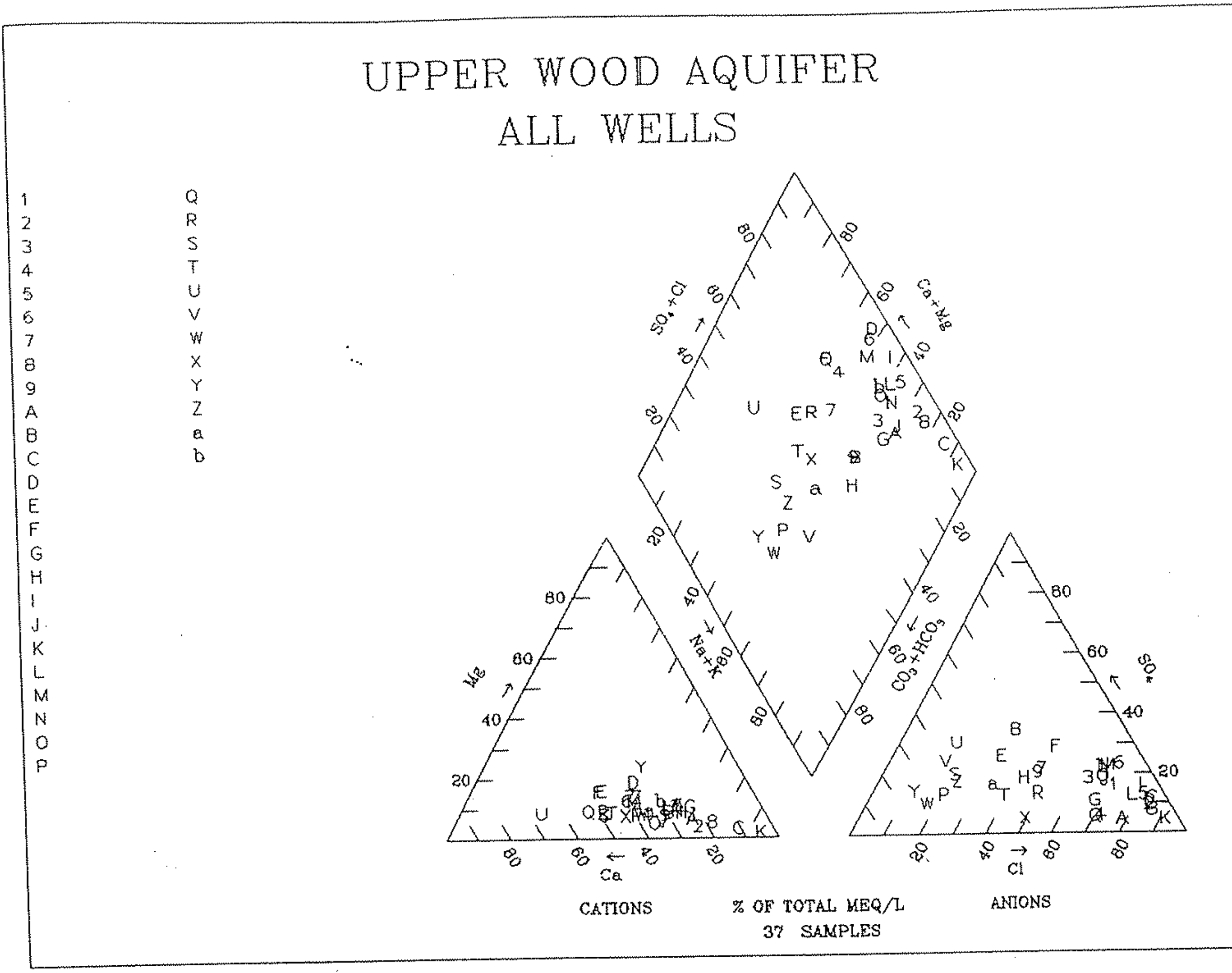


Figure 6. Trilinear diagram of ground water in the Upper Wood aquifer.

* 1-B shallow surficial wells
C-P surficial wells close to bedrock
Q-Y bedrock wells
Z-b till wells

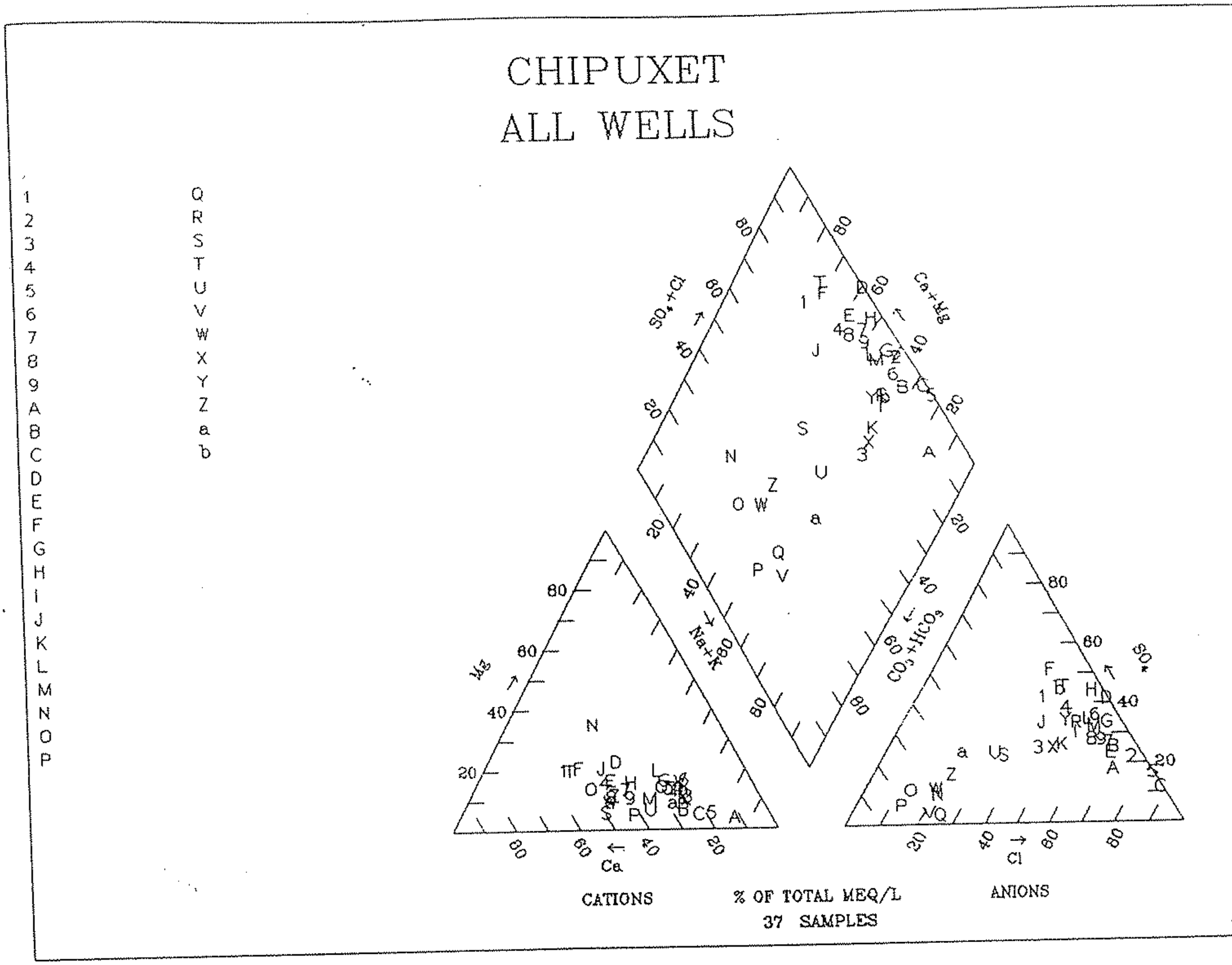


Figure 7. Trilinear diagram of the ground water in the Chipuxet aquifer.

* 1-E shallow surficial
F-N surficial wells close to bedrock
O-Z bedrock wells
a-b till wells

Distinctive chemical characteristics of the aquifers include lower fluoride values in both bedrock and surficial wells and higher magnesium values in surficial materials wells in the Chipuxet than in the other two aquifers. Magnesium comes from biotite, and the highest amount of biotite is found in the Esmond Suite, 4%, the other two aquifers have less than 2%. The Queen-Usquepaugh aquifer is distinguished by higher calcium and alkalinity in its bedrock aquifer relative to the other two aquifers. These parameters show greater chemical evolution in the Queen-Usquepaugh bedrock aquifer. The Upper Wood, on the other hand, has higher alkalinity in its surficial materials aquifer, and higher silica and fluoride values in its bedrock aquifer than the Chipuxet and Queen-Usquepaugh aquifers. The Upper Wood surficial materials wells are more chemically evolved than the other two aquifers. The two bedrock types that contain apatite (the source for fluoride) are the Scituate and Sterling Suites, both of which underlay the Upper Wood aquifer. The Chipuxet is underlain by the Esmond Suite which does not contain apatite, and the Queen-Usquepaugh is also underlain by the Esmond Suite, as well as the Scituate Suite.

Almost all of the bedrock samples have alkalinities greater than .0004 moles as $CaCO_3$,, while the surficial wells exhibit alkalinities less than .0004 moles as $CaCO_3$. This is due to the fact that hydrogen from carbonic acid (H_2CO_3) is consumed during the weathering reactions of alumino-silicate minerals to produce bicarbonate (HCO_3). Bicarbonate is a major contributor to alkalinity, therefore, alkalinity is one of the indicators of geochemical evolution. Both the Chipuxet and Queen-Usquepaugh aquifers exhibit increasing alkalinities with depth into the suficial material, and then further into bedrock.

Within the aquifers themselves, variations are seen between the surficial materials wells. In the Queen-Usquepaugh surficial wells, alkalinity, calcium, silica, magnesium, and sodium increase from shallow to deep surficial close to bedrock. Alkalinity and silica increase slightly from shallow surficial to deep surficial in the Upper Wood aquifer. However, in the Chipuxet, a decrease in calcium and an increase in sodium is seen from the shallow surficial to the deep surficial wells close to bedrock.

Uranium concentrations were greater in the bedrock aquifers than the surficial materials aquifers. Median uranium concentrations in the surficial and bedrock wells were .33 ppb (n=10) and 1.7 ppb (n=7) in the Queen-Usquepaugh, .32 ppb (n=15) and 2.32 ppb (n=9) in the Upper Wood, and .27 ppb (n=18) and 2.45 ppb (n=11) in the Chipuxet. The Queen-Usquepaugh had slightly lower uranium concentrations in its bedrock aquifer than the other two bedrock aquifers.

Discussion

As expected from other studies, no statistical relationship was found between radon levels and uranium concentrations in the ground-water samples. The solubility of uranium is a function of oxidation-reduction conditions in the aquifer and is therefore not expected to parallel radon concentrations (because radon is a noble gas). Figure 8 shows the relationship between uranium and iron in ground water. Because uranium is more mobile in oxidizing conditions, high levels of uranium (greater than 2 ppb) are only found in waters with less than 2 mg/L iron. The source of radon in ground water is the uranium in the solid phase, not dissolved uranium. The higher radon levels (in and above the Scituate Suite wells) correlate with the higher uranium content in the underlying bedrock. Furthermore, as also seen from previous studies, ground water from bedrock wells yields higher concentrations of radon than that from surficial material wells (Wanty et al, 1993). This may be a function of uranium availability in the surficial materials, the higher porosity of the sedimentary aquifers as opposed to fractured ones, or it may be a function of the efficiency of radon transfer to the water as uranium decays in the aquifer materials. Uranium is found in accessory minerals in the crystalline bedrock of the study area. This uranium is either disseminated within the grain, or has been mobilized to the edges of the grains, resulting in concentrated radon on the edges of the grains. As radon decays, alpha recoil is responsible for moving the radon in the rock into the adjacent ground water (Wanty et al 1993). Therefore, the siting of these uranium-bearing minerals is very important as well as the flow rate of the ground water through the material.

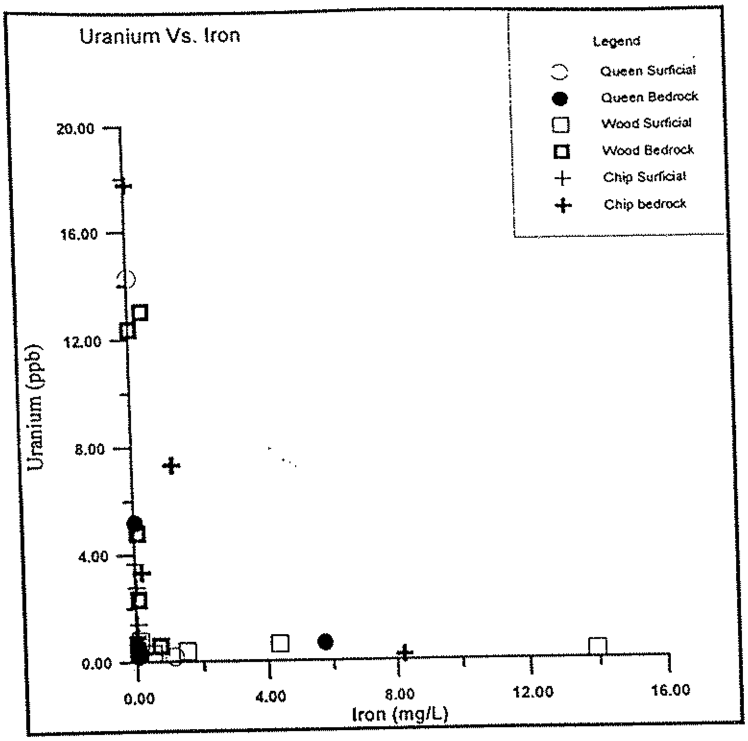
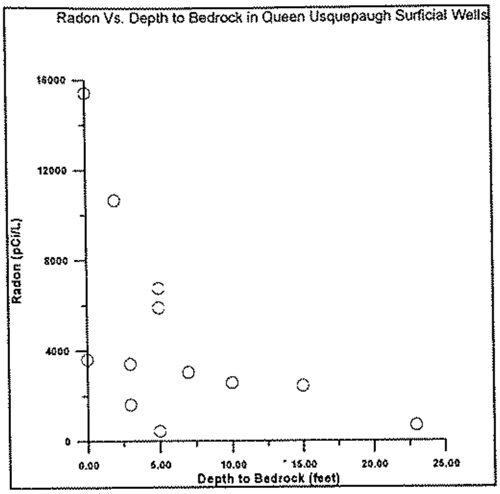


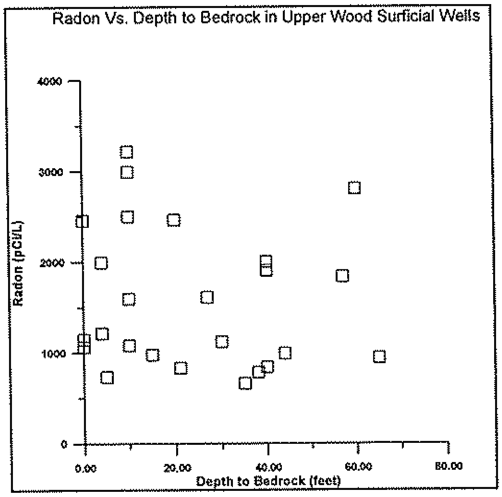
Figure 8. Uranium Versus Iron for different water-bearing zones in the Chipuxet, Queen-Usquepaugh, and Upper Wood River Basins.

Based on the limited sample size used here, there was no relationship between radon levels in the surficial materials aquifers and the eTh and eU concentrations in the regolith. The median uranium content of the three surficial materials aquifers were less than 2.5 ppm. Both the Scituate and Sterling Suites had uranium contents greater than 3 ppm. However, the uranium content of the Esmond Suite bedrock was 1.9 ppm. Because much higher radon levels are seen in the bedrock wells drilled in the Esmond Suite than in the surficial material above it which actually contains more uranium, the higher flow rate of ground water through the surficial materials aquifer as opposed to the flow through the bedrock fractures and perhaps the more favorable siting of uranium in the bedrock aquifer, seem to be the dominant factors in determining radon concentration of the ground water.

When comparing radon versus depth to bedrock in the surficial materials wells, greater radon levels are found in wells that are within 20 feet of the bedrock surface (Figure 9). There is no correlation seen between radon and depth from the well bottom to bedrock in the Chipuxet aquifer because the depth to bedrock is greater than 20 feet for all surficial wells sampled.

Because only one third of the wells had recorded well yields, and most of them were qualitative estimates by the well drillers, well yield data was insufficient to create a quantitative comparison between the amount of flow through an aquifer and radon levels. In previous studies of radon and hydraulic aperature, differences in radon concentration within well pairs were found to be attributed to differences in hydraulic aperature alone (Pete Folger, written communication) and inverse correlations were seen between dissolved radon and well yield (Wanty et al, 1993). In this study, evidence of this relationship is also seen. Two of the bedrock wells sampled in this study, numbers 17 and 20, were located in the same bedrock material but had very different radon concentrations. Well 20 was not as deep and had a much lower yield (.25 gallons per minute as opposed to 20 gallons per minute) than well 17. The radon level in well 20 was significantly higher (82,860 pCi/L) than well 17 (11,302 pCi/L). The radon in well 17 was diluted by the greater volume of water in the fracture resulting in a dramatically lower radon concentration.





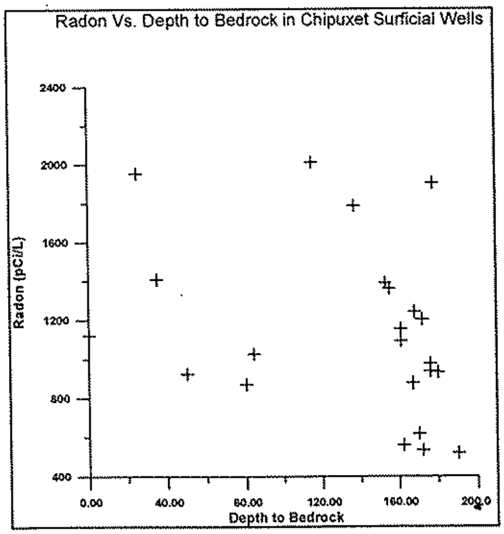


Figure 9. Radon versus depth to bedrock in the Pawcatuck River Basin surficial wells.

There is a general relationship between radon and fluoride concentrations (Figure 10). Ground water with fluoride concentrations greater than 1 mg/L is likely to have radon concentrations above 10,000 pCi/L. The rocks in this study that contained apatite (the fluoride-bearing mineral) also contained the most uranium (Sterling and Scituate Suites). Therefore, rocks that contain apatite are likely to contain more uranium-bearing minerals.

The chemistry of ground water in the Pawcatuck river basin is affected by several processes: mineral dissolution, hydrolysis, redox reactions, and ion exchange. Furthermore, anthropogenic input can also influence the chemistry of ground water (fertilizer for instance). As recharge water percolates downward through the aquifer materials, carbonic acid (from carbon dioxide gas in the atmosphere reacting with water to form carbonic acid) reacts with the material in the aquifer (water-rock reactions), and chemical weathering takes place. The weathering products produced from the aluminosilicate minerals in this aquifer are clay (kaolinite), cations, dissolved silica, and bicarbonate. Figure 11 shows a correlation between alkalinity represented as % meq of the major anions (chloride and sulfate) and radon. Bedrock ground water with alkalinity values greater than 40 % are likely to have radon levels greater than 10,000 pCi/L. The age of the water in bedrock aquifers is much older than surficial aquifers, therefore, as a result of contact, the water is more chemically evolved. The radon concentration, however, is attributable to local contact with the water because radon has such a short half-life, so long residence time does not produce higher radon concentrations. Therefore, this is not a causative relationship between elevated radon and alkalinity.

Different radon levels are seen in waters with very similar chemical signatures, the Upper Wood and Queen-Usquepaugh deep surficial materials wells for example. The Queen-Usquepaugh deep surficial materials wells have much higher radon levels (4,749 pCi/L as compared to 1,073 pCi/L in the Upper Wood), even though the alkalinity, calcium, silica, fluoride, and sodium median values are almost equal. This suggests textural advantages such as the favorable siting of uranium in the Queen-Usquepaugh aquifer material or differences in flow rate influencing radon levels. On the other hand, waters with different chemical signatures (like the Upper Wood and Chipuxet deep surficial materials wells having very different alkalinity, calcium, magnesium, and sodium values) are producing similar radon levels, 1,073 pCi/L and 1,389 pCi/L, respectively. This implies that residence time and water evolution are a factor in water chemistry but not radon level of ground water. Instead, well yield and uranium-siting would be the controlling factors.

Summary and Conclusions

All wells sampled yielded radon levels above the proposed EPA limit of 300 pCi/L and many were more than an order of magnitude greater. Although the EPA will probably adopt a standard that is less rigorous than 300 pCi/L, this study reveals that much of the ground water in southern Rhode Island has elevated radon levels that may be cause for concern.

Bedrock aquifers yield higher concentrations of radon than surficial materials aquifers. This relationship is both related to the lower well yields in bedrock aquifers as compared to surficial materials aquifers, and the availability of uranium-bearing minerals in both settings. Higher radon values were discovered in areas where the underlying bedrock contained the most uranium (Scituate Suite) because the source uranium is the solid phase and not the dissolved species.

In both the Queen-Usquepaugh and Chipuxet aquifers, radon concentrations in the surficial materials aquifer varied with respect to proximity to the bedrock surface. The water chemistry data suggest that vertical mixing is occurring between the surficial materials wells and bedrock wells in the Queen-Usquepaugh and the Chipuxet aquifers. Therefore, there is either discharge of radon-bearing ground water from the underlying bedrock aquifer into the surficial material, or the deeper surficial material has a greater capacity for radon production (uranium-siting). Radon values in the Queen-Usquepaugh surficial materials

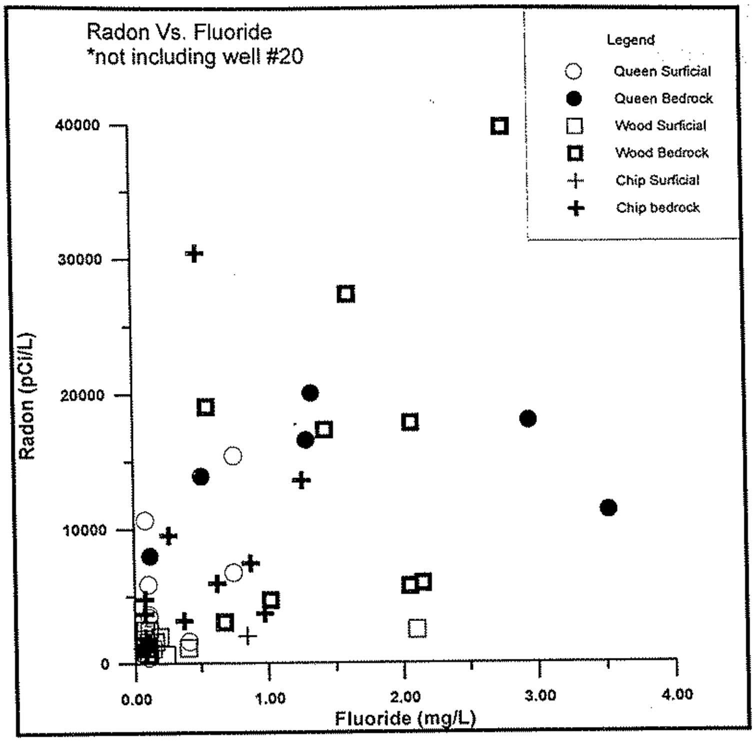


Figure 10. Radon versus fluoride concentrations.

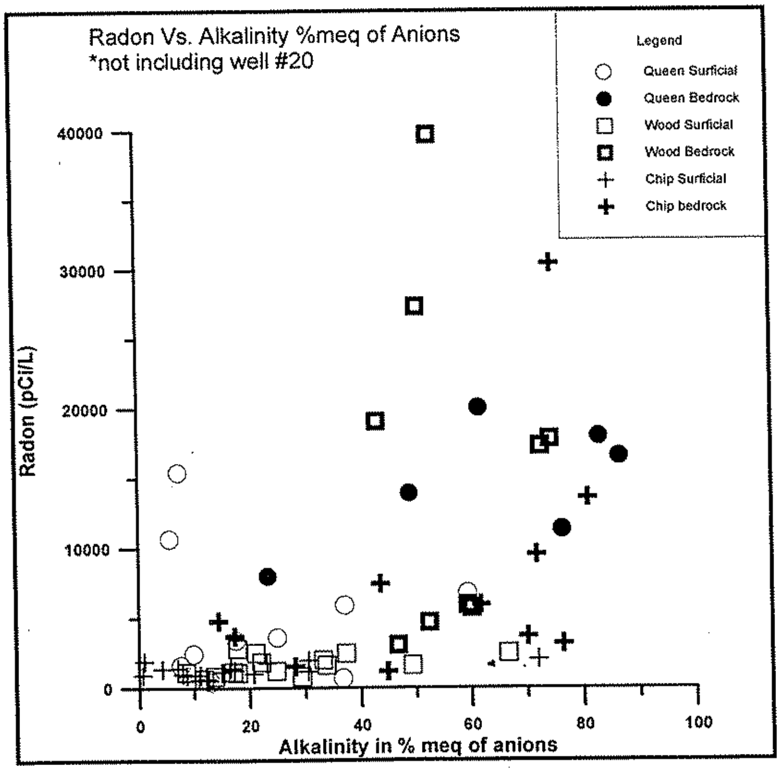


Figure 11. Radon versus Alkalinity.

groundwater are much greater than radon values in the surficial materials aquifers of the other two. Both the Queen-Usquepaugh and Upper Wood bedrock aquifers have similar radon levels, however, the Chipuxet bedrock aquifer yields much lower radon values.

Water chemistry does not play an important role in the determination of radon concentrations. However, some chemical parameters can provide some insight as to the uranium content of the bedrock. Higher radon values correlated with high fluoride in the ground water because the bedrock suites that contain the mineral apatite are likely to have more uranium-bearing minerals. Also, greater radon levels are found in wells that are within 20 feet of the bedrock surface.

The reasons why radon concentrations are higher in one well as opposed to another cannot be isolated to one specific reason. However, the higher flow rate of ground water through the surficial materials aquifer as opposed to the flow through the bedrock fractures and perhaps the more favorable siting of uranium in the bedrock aquifer, seem to be the dominant factors in producing higher radon concentrations in bedrock wells as opposed to surficial wells within an aquifer. Differences in radon concentrations between aquifers are also caused by uranium-siting and well yield, but the uranium content of the underlying bedrock also plays a key role in radon concentrations of the ground water.

Factors controlling radon distribution are so complex that it is impossible to establish a specific model to predict radon levels in the ground water. Information needed to distinguish between these factors would be actual well yields and samples of both the bedrock and surficial material to evaluate textural differences (for surficial wells) and the siting of uranium in these locations.

This investigation has shown that radon is a concern for ground-water users within the Pawcatuck River Basin, Rhode Island. Although it is not possible to make detailed predictions on radon concentrations in ground water, this study shows that bedrock ground water users in the Queen-Usquepaugh and Upper Wood aquifers can expect relatively high levels of radon in their ground water (10,000 pCi/L to 85,000 pCi/L), while bedrock ground water users in the Chipuxet can expect relatively low levels (less than 10,000 pCi/L). Those users that withdraw ground water from surficial materials aquifers are at a lower risk for elevated radon levels in their ground water than bedrock ground water users.

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Appendix A: Well Survey

The University of Rhode Island, Kingston, RI 02881-0807
Department of Geology

Dear Homeowner,

We are conducting a study of the water in the Pawcatuck River Basin. This study is supported by the Rhode Island Water Resources Center. We are investigating the relationship between ground-water quality and geology. As part of this study, a number of private wells in the area will be sampled. We are asking for help from homeowners around the Wood River, to develop a data base for our study. If you have answers to any of the following questions, please return them in the self-addressed, stamped envelope we have provided. If your well is included in the study, you will receive a copy of the laboratory results with the complete chemical analysis

Is your house served by a well? (YES , NO) (circle one)

Date of well construction? ____________

Type of well construction? (dug, drive point, drilled) (circle one)

Depth of well? ____________

Type of pump? (submersible pump in the well, vacuum pump in your house) (circle one)

The drillers name? ____________

Well yield? ____________ Water bearing material? ____________

Do you have any problems with your water? (iron, taste, odor, other)

Do you use your water for drinking purposes? (YES , NO) (circle one)

Do you have a water treatment device? (filter, water softener, iron removal, other)

Has your home or well been tested for radon? ____________

Please draw us a quick sketch of your house and well location, in the box provided.

Could we have permission to sample your well?

signature: ____________

name:

address:

phone #:

If we have your permission, we will contact you to set up a convenient time for you, to sample your well. If you have any questions, please contact Dr. Anne Veeger at the University of Rhode Island, 792-2187.

Thank you for your cooperation,

Nicole C. Ruderman

Graduate Student: Univ. of R.I.

The University of Rhode Island is an affirmative action and equal opportunity employer.

Appendix B: Sampling Techniques

Using the homeowner's well pump, ground-water samples were collected after 3-well volumes had been evacuated from each well, and the pH, temperature, and electrical conductivity had stabilized. The pumping rate, type of pump (submerged for deep wells or vacuum for shallow wells), water level (if possible to obtain), temperature, electrical conductivity, pH, dissolved oxygen, color, odor, and turbidity were recorded during the time of collection. A field sheet is provided in Appendix C. The samples were stored in a cooler and later stored in the U.R.I. Department of Geology, Hydrogeology laboratory refrigerator to await analysis. Five hundred milliliter samples were collected for anion analysis, 250 milliliter samples were collected for cation analysis, 60 milliliter samples were collected for uranium analysis, and 20 milliliter samples were collected for radon analysis. The cation, anion, and uranium samples were filtered through a 0.45 µm filter in order to remove particulate matter, and stored in high-density polypropylene bottles. Samples collected for cation analysis were treated with hydrochloric acid and samples collected for uranium analysis were treated with nitric acid to maintain the dissolved constituents. Water levels were measured in wells with accessible casings using an electric tape.

FISCAL YEAR 1994 PROGRAM REPORT

CALVIN P.C. POON, DIRECTOR

WATER RESOURCES RESEARCH INSTITUTE
THE UNIVERSITY OF RHODE ISLAND

FISCAL YEAR 1994 PROGRAM REPORT

Rhode Island Water Resources Research Institute
University of Rhode Island
Rhode Island

FISCAL YEAR 1994 PROGRAM REPORT
Grant No. 14-08-0001-2044

for

U.S. Department of the Interior
Geological Survey

by

Water Resources Center
University of Rhode Island
Kingston, RI 02881

Calvin P.C. Poon, Director

July 1995

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ABSTRACT

The objectives of the FY-94 Rhode Island Water Resources Research Institute Program are (1) to identify critical policy and management issues of water resources in the State and in the New England region, (2) to conduct research in order to generate information useful to address the issues and to solve the problems, (3) to transfer the information to potential users throughout the State and New England region, (4) to educate the public about water quality protection, and (5) to train both graduate and undergraduate students in water resources research. Current and anticipated state and regional water problems are aquifer pretection in relation to turf farming management, increased cost of drinking water supply resulting from the Safe Drinking Water Act Requirements in water quality monitoring, water quality aspects of wetlands, radon removal from drinking water, toxic metal removal and recovery for waste minimization and pollution prevention as an alternative to pollution discharge followed by treatment of wastewater, water management policy in relation to water right/water allocation, and information dissemination on water quality management such as stormwater overflow control and aquifer management in Rhode Island.

The FY-1994 program addressed many of these issues and problems. Residents in southern Rhode Island in recent dry summers (1987, 91, 93) located downstream from turf farms, nurseries, and vegetable farms claimed that irrigation withdrawals were responsible for diminishing stream flows and the drying up of sink holes and other small water bodies. Several state agencies are eager to develop a statewide water policy. Extensive data collection on surface and groundwater resources, seasonal pattern of water supply, water demand, economic value of water in alternative uses, have been and are being conducted as

well as extensive discussions with agencies and water users have been carried out. A model for the water supply and demand will be developed from which opportunities for reallocating water resources according to economic and other criteria will be identified. The information will be useful for the development of water rights and water allocation policy in the State. Turf culture (rsidential, commercial, institutional and recreational) has come under criticism as an environmentally risk land use whenever groundwater protection is important. Therefore it is important that managers of turf understand the best cultural practices for minimizing nutrient release from turf areas. It was found that good quality Kentucky bluegrass turf can be maintained with annual nitrogen application of not more than 1 lb Nitrogen/1000 ft_2(less than 50 lbs N per acre). Small amount of nitrogen application in the spring is better than higher application in the fall. a good root growh was able to absorb all nitrate during the winter-spring period. Most pretreatment standards of sewage treatment facilities of cities and towns require less than 1 mg/l of silver of industrial discharge. The photo/x-ray process industries can treat their wastewater using conventional metal replacement and/or electrolytic recovery technique to achieve this standard. However a recently proposed silver limit of 0.029 mg/l for the Narragansett Bay Commission Sewage Treatment Facility cannot not be achieved. Laboratory synthesized MnO_2 ,activated casrbon and ion exchange were studied for their silver removal capacity. MnO_2 was found to be highly effective in silver removal, better tahn activated carbon. The fine mesh make both MnO_2 and activated carbon difficult to use. Anionic ion exchange matrial with macroporous structure such as Amberite IRA-68 and Bio-Rad AG1-X8 were found to be able to remove silver to meet the new standard. Also the ion exchange column could be regenerated with chemical solutions with 72 to 90% silver recovery. Therefore onsite silver recovery is feasible which is better alternative than off-site recovery. Onsite recovery eliminates the manifest requirement under the Resources Conservation and Recovery Act. A large number of private drinking water wells contain radon at a concentration significantly higher than the USEPA proposed 300 pCi/l limit. Analyzing the geology and radon, uranium, Ca, Mg, Na, K, Fe, Mn, Si, F, Cl, NO_3 , PO_4 , and SO_4 of the water, no correlation was found to exist between dissolved uranium and radon concentration. The higher radon concentrations correspond to the bedrock containing the most uranium, and groundwater from bedrock wells yields higher concentrations of radon than that from surficial material wells. Riparian forest buffer strips cn be used for the mitigation of P present in runoff. However, it was found that within the same soil catena, soils with different drainage characteristic exhibit very different capacity to retain P. The specific equilibrium P concentration for well drained soil, poorly drained soils, and very poor drained soil are respecively found to be 1.0 mg/l, 3.8 mg/l, and 0.39 mg/l. This spatial variation of P removal capacity has to taken into consideration in modeling or designing of P removal by riparian forest buffer strips.

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WATER PROBLEMS AND ISSUES OF RHODE ISLAND

Agricultural water withdrawals from major river systems in southern Rhode Island were the focus of heated debate during the unusually dry summers of 1987 and 1991. Residents located downstream from turf farmss, nurseries, and vegetable farms claimed that irrigation withdrawals were responsible for diminished stream flows and the drying up of sink holes and other small water bodies. The state's Department of Environmental Management held several meetings to address the concerns of local residents in 1987, but the agency has not yet developed a statewide policy regarding water rights, or the allocation of water resources. The inevitable scarcity of water during future drought years will cause similar conflicts among users of surface water and groundwater resources in Rhode Island, unless an appropriate allocation scheme is designed and implemented.

Several agencies and user groups are eager to develop a statewide water policy. The Office of Statewide Planning, the Department of Environmental Management, the Division of Agriculture within DEM, and others have expressed interest in research that will benefit through a better understanding of the economic and hydrologic impacts of surface water and groundwater withdrawals on competing users of water resources. Farmers will benefit through more precise description of the economic and hydrologic impacts of agricultural water use in Rhode Island. An appropriate water rights system will allocate water effriciently and equitably during periods of shortage, to ensure that competing users are able to maintainn economically imporatant activities with minimal disruption.

Land development in southern New England is of such intensity that most areas are or soon will be subjected to some level of use, Shallow aquifers, especially those representing sole source water supplies, need special protection but the land overlying them is often highly valued for residential or commercial development. It is important to identify those land uses which constitute the least threat to these sensitive areas. Turf culture (residential, commercial, institutional and recreational) has come under much media criticism as an environmentally risky land use wherever ground water protection is important. This has influenced land use planning policy in spite of an ever growing body of research which shows turf to be a relatively effective gound cover forminimizing both nitrate and pesticide leaching to ground water.

While turf may constitute an environmentally sound ground cover high value aquifer systems, it is important that managers of turf and those responsible for protecting ground water resources understrand the best cultural practrices for minimizing nutrient release from turf areas. Such knowledege will maximize the protective functions of turf and permit policy makers to assure the public that effective safeguards for the preservation of water quality are being implemented.

Groundwater with Radon has been associated with increased risk of stomach cancer and an increased risk of lung cancer related to the inhalation of radon outgassing from sinks, showers and other indoor water uses. Many measurements of radon concentration in Rhode Island groundwater exceed 1,000 pCi/l, well in excess of the USEA proposed 300 pCi/l MCL. Groundwater is the only viable source of drinking water in Washington County, Rhode Island. Given the potential hazard associated with radon, a systemic assessment of radon in the groundwater reservoirs of the State is needed to provide detailed information to state agencies, water suppliers and the general public.

The Narragansett Bay Commission (NBC) has a treatment program to limit the amount of toxic chemical discharge into the NBC sewer lines. Currently, a significasnt number of "non-significant" users defined by NBC as those with dischage flow rate less than 5,000 gpd have not yet obtained a wastewater discgarge permit. The silver bearing wastes from the "non-significant" users of the photo/x-ray processing industries are largely discharged into NBC sewers with no silver removal/recovery. The present silver discharge limitation to the NBC's Field's Point Treatment Facility will be reduced from 0.43 mg/l maximum daily and 0.24 mg/l 10-day average to a uniform concentration limit of 0.029 mg/l. This concentration of 0.029 mg/l of silver is set by RI Department of Environmental Management (RIDEM), based on a revised calculation of NBC industrial pretreatment limitations for the Field's Point Treatment Facility in 1933, using the Headworks Loading Allocation Method as well as the RIDES permit. The RIDES permit on silver is based on both the acute and chronic toxic study of silver in Narragansett Bay.

Technologies for silver recovery/removal from x-ray and photo processing wastes have been developed and used for a long time. Metallic replacement process with steel wool cartridges for silver deposition and electrolytic process for plating out silver on to a cathode as silver flakes are two conventional systems used for silver recovery/removal from fixer solutions. Fixer solutions contains high concentrations of silver from 2,000 up to 10,000 ppm. Both the steel wood and eletrolytic technologies remove the bulk of silver from the fixer solution, and leave from 5 to 100 ppm of silver in the solution. The mixture of the desilvered fixer solution combined with the developer solution (containing very little silver) and the final wash (0.2 to 5.0 ppm silver) contains from 1 to 50 ppm of silver discharged to the drain. Some electrolytic systems in the market clains 95 to 97% silver recovery with good amperage and voltage control so that a significant percentage of the desilvered fixer can be recycled for use in a closed loop. Both the electrolytic system and the metallic replacement system have been well developed and, in combination, can recover 99% of silver from the fixer solution. This technology is recognized by USEPA as the Best Demonstrated Applied Technoloty (BDAT) by various environmental agencies. To recovery/remove silver from the desilvered fixer/developer solution/final wash mixture, however, requires the ion exchange technology. By selecting the proper ion exchange material and use an adequate amount in the proper condition, silver concentration can be reduced to a low level. Obviously the economics of an ion exchange system is dictated by the amount and the ion exchange capacity of the ion exchange material and the replenishing rate of new ion exchange material after the exchange capacity is depleted. The technology can be very expensive for removing silver down to 0.029 ppm, and it would be cost prohibitive for small shops. There is a need to develop a new process that can be cost effective as well as reliable in meeting the new dicharge limit regulation. Such a technology would be greatly beneficial to the photo/x-ray processing industry, RIDEM, as well as NBC.

Elevated phosphorus (P) concentrations in surface waters have the potential to compromise the quality and availability of drinking water in New England. Eutrophication resulting from high P inputs into fresh water lakes has been linked to the formation of trihalmethanes (THMs) in drinking water (Palmstrom et al. 1988). THMs are potential human carcinogens and their presence in drinking water poses a public health threat. Problems with eutrophication and high THM levels in drinking water already exist in Rhode Island. For example, the water supply reservoirs of Aquidneck Island are all eutrophic as a result of nonpoint source pollution inputs from surrounding land uses. This has resulted in total THM levels in drinking wter that are frequently in violation of the 0.01 mg/l standard. The current upper limit for total THM levles in finishing drinking water is 0.1 mg/l; however, the USEPA has proposed new regulations that would lower this limit to 0.08 mg/l beginning in 1996. A lower THM standard is likely to pose a difficult challenge to public water utilities that depend on eutrophic surface water supplies, of which there are a significant number in the state. Controlling the sources of DOC in natural waters may prove to be an effective alternative to costly in-plant treatment for DOC removal. The main precursors of THMs in surface waters are humic substances, algal and bacterial cells and their metabolites, and macrophytes. Of these, only the levels of THM precursors resulting from increased primary production, i.e., increases in biomass of algae and aquatic macrophytes, are likely to respond to watershed management practices aimed at controlling non-point source P pollution of surface waters; in Rhode Island these include storm water runoff from highways, gardening and agricultural practices, and construction activities.

Riparian forest strips are landscape features that include both upland and wetland areas and are believed to be important in mitigation of P present in runoff. Riparian areas, because of the flatter slopes and high surface roughness, tend to accumulate sediment-bound P that originates from upland areas. A portion of this P is readily mineralized to ortho-phosphate and leached by rainfall into the reparian soils. Quantitative data on the P mitigation capacity of wetlands is of particular importance in the state of Rhode Island, where they consitute 20% of the land-use within a 100-m buffer strip around freshwater bodies, with adjacent reparian forests making up another 40%. Wetlands are generally perceived as water quality enhancers as a result of nutrient attenuation, yet there is little quantitative information regarding this function, It was fouind that wetlands may act as either sources or sinks of P depending on hydrologic characteristics. Phosphorus within the surface soils of riparian areas can be moved offsite by two different hydrologic pathways: (1)by leaching to the saturated zone and subsequent transport by groundwater flow, and (2) by return flow, i.e., upland groundwater that seeps to the surface in riparian areas during periods of elevted groundwater, such as during the "wet" season or following prolonged periods of rainfall. The importance of return flow to overland runoff in non-urban watersheds has been well documented in New England and has generated much interest in "partial area hydrology", the concept that reparian areas may contribute an unusually large proportion of overland flow from non-urban watersheds. The process of return flow can flush solutes such as ortho-P from the surface soils of riparian areas, thereby again subjecting the P to overland transport processes and rapid export to surface water bodies. The large area comprised by wetlands and riparian forests, their proximity to surface water reservoirs, and their potential significance in management of non-pont source P pollution of surface waters point to the need for evaluating the role these landscape features as sources or sinks of P.

PROGRAM GOALS AND PRIORITIES

The research needs on water resources in Rhode Island and in the New England region as identified by the State Advisory Committee and the University Water Resources Coordinating Committee have been:

Water Management

1. Water rights and water allocation policy
2. Evaluation of local and state land use and zoning regulations as well as wellhead protection program on their impacts on water quality protection.
3. Management of wetlands as pollution mitigators
4. Water conservation practices and effects
5. Study of the impacts of the Federal Energy Policy Act on Rhode Island water systems and consumers

Water Quality

1. Mitigating non-point sources of nutrients from runoffs.
2. Silver recovery and management from industries to meet the new discharge limits in Rhode Island.
3. Occurrence and significance of radon in water supplies
4. Role of wetlands in nutrient removal

Surface-groundwater Interactions

1. Assessment of groundwater reservoir capacity and pollution in glacial deposit and bedrock fractures.

Technology Transfer

Individual sewage disposal system, design, site evaluation, management, innovative system design, nutrient loading, model local ordinances, enforcement, public outreach, training for both regulatory and private sector groups. Education, preventive maintenance, evaluation of risks of homeowner practices (lawn care, buffer distances, e.g.) on individual wells and water quality in relation to the Rhode Island designated wellhead protection areas.

Guided by these research needs, the Rhode Island Water Resources Center developed its program goals to meet some of these research needs as well as to transfer the information of water resources research/management/education to the public. Research solicitation was sent out to the public targeting primarily the institutions of higher education in Rhode Island. Based on the responses and the quality of the proposals submitted, three research projects and one information transfer project that meet the research needs developed for the FY-1994 were selected. In addition to relevance of research needs and technical competency, a reasonable budget was also a criterium in selecting the projects for FY-1994 program support. Two other projects, 02a and 04a, were no cost extension of previous year's research. They continued to receive Office support in FY-1994.

Project 02a, entitled *Designing a System of Water Rights and a* Water *Allocation Policy for*

Rhode Island focused its study on the Wood/Pawcatuck River system in southern Rhode Island which serves agricultural, municipal, and industrial water users. Historical data and existing models of the surface water and groundwater resources in the region were collected. Appropriate water policy identified for the Wood/Pawcatuck watershed which is a peak-loading problem includes a system of water trading during dry periods, an incentive program to encourage efficient water use, and compensation to water users who voluntarily reduce withdrawals druing dry periods. Other options such as variable water rights and insurance programs to replace revenues lost during periods of water shortage have been identified. An economic optimization model has been developed. It determines the optimal allocation of water among competing users. The model examines sub-basins within the watershed, to permit analysis of policy alternatives that may emphasize key differences among sub-basins.

The second project, Project 02, entitled Minimum Maintenance Turf Management for Aquifer Protection, studied the growth of Kentucky bluegrass with different nitrogen loading from 0 as a control to 1, 2, and 3 lbs N/1000 ft^2/yr, in the form of urea, CORON (liquid methylene diurea product), compost (Earthgro lawn food, 8-2-4). The control plot was included to monitor natural seasonal changes in soil mineralization of organic nitrogen and normal fluctuations in soil water nitrate levels. Sodded in April 1994, all plots grew well despite the significant difference of N loadings. However the turf fertilized in N overload with 2 lbs N/1000 ft^2 grew well throughout despite a drought. The other plots recovered fully in summer. The plot received small amounts of N in the spring exhibited better quality than the fall fertilized plot. Nitrate analysis of the water sample showed that extensive root growth occured during the winter-spring season and the grass was capable of absorbing all nitrogen mineralized at that time.

Project 03 entitled Manganese Dioxide Adsorption for Silver Removal/Recovery compared the silver removal from both pure $AgNO_3$ solution and from photo processing water containing primarily $Ag(S_2O_3)^{-3}$ and organo-silver complexes, using MnO and activated carbon as well as ion exchange material. Different forms of MnO_2 were synthesized in the laboratory for use since pure MnO_2 minerals commercially available were found to be ineffective in Ag removal. Two types of synthesized MnO_2: MnO_2(HCL) and MnO_2 (HCl and KNO_3) were found removing Ag better than activated carbon GRC-22 and BL-pulverized. The highest Maximum Adsorption Capacity, Xm, was found to be 193 mg of Ag/gram of MnO_2 for $AgNO_3$ solution and 138 mg Ag/gram of activated carbon GRC-22. For photo processing water, the respective Xm values were 91.7 and 42.8 mg Ag/gram of sorbent. Ion exchange columns are effective in Ag removal which is not practical for industrial use without onsite Ag recovery. Photo processing water (bleach/fixer mixture treated with electrolytic technique and further diluted with rinse water, Ag concentration at 37 mg/l) can be applied up to 630 bed volumes before a breakthrough of 0.029 mg/l Ag occurs. The column can be regenerated with 30% $NH_4S_2O_3$ or 4N NH_4Cl to recover 72 to more than 90% of Ag so that the column can be used repeatedly in treatment/regeneration cycles.

Project 04a, entitled *Radon in the Groundwater Reservoir of Southern Rhode Island: a Field Assessment,* collected water samples from 100 private wells in the Upper Wood, Queen-

Usquepaugh, and the Chipuxet River Basin aquifers. Field analyses included temperature, pH, Eh, electrical conductance, and dissolved oxygen. Laboratory analysis included radon, uranium, alkalinity, Ca, Mg, Na, K, Fe, Mn, Si, F, Cl, NO_3, PO_4, and SO_4, conducted in the USGS National Water Quality Laboratories in Denver, and Lakewood, Colorado as well as in the Department of Geology's Hydrogeology Laboratory of the University of Rhode Island. All well samples yielded radon levels above the proposed EPA limit of 300 pCi/l and many were more than an order of magnitude greater. The finding indicates no correlation exists between dissolved uranium and radon concentration. The higher radon concentrations correspond to the bedrock containing the most uranium, and groundwater from bedrock wells yields higher concentrations of radon than that from surficial material wells. Users that withdraw groundwater from surficial material aguifers are at a lower risk for elevated radon levels in their goundwater.

Project 04, entitled *Potential for Mitigation of Non-point Source Phosphorus Pollution in Riparian Forest Soils*, measured the specific equilibrium P concentration (EPC) values of soils in the Peckham Farm site, Kingston, Rhode Island in a riparian forest zone. Comparing the EPCo values exist among soil drainage class within a soil catena suggesting that riparian forest soils have different capacities to remove P from runoff. As a buffer zone, areparian forest would vary significantly in its interaction with P depending on the soil drainage class of a particular soil catena.

The level of funding and sources for various projects including the information transfer activities are listed in Table 1.

Table l. Sources and Levels of Funding FY-1994

Project	**Level**	**Source of Funding Ending May 31, 1995**
02a, Designing a System of Water Rights and a Water Allocation Policy of R.I.	No cost extension office support	University of Rhode Island
02, Minimum Maintenance Turf Management for Aquifer Protection	$18,928 38,849	USGS URI
04a, Radon in the Groundwater Reservoirs of Southern Rhode Island: A Field Assessment	No cost extension office support	URI
03, MnO Adsorption for Silver Removal/Recovery	$18,650 39,030	USGS URI
04,Potential for Mitigation of Non-point Source P in Riparian Forest Soils	$19,168 38,766	USGS URI
22, Information Transfer Activities	$17,421 33,123	USGS URI
01, Center Administration	$26,360 52,239	USGS URI
FY-1994 Total Funding	$100,527 202,007	USGS URI

SYNOPSIS

Project Number: 02

Start: 6-1-94
End: 5-31-95

Title: Minimum Maintenance Turf Management for Aquifer Protection

Investigator:
Richard J. Hull
Plant Sciences Department
University of Rhode Island
Kingston, RI 02881

Focus categories: GW; NC; NPP; NU; WQL

Congressional District: 2nd RI

Descriptors: Ground water pollution; Nitrates; Land application; Organic Wastes; Aquifer; Fertilizers; Turfgrasses

Problem and research objectives:

Land development in southern New England is of such intensity that most areas are or soon will be subjected to some level of use. Shallow aquifers, especially those representing sole-source water supplies, need special protection but the land overlying them is often highly valued for residential or commercial development. It is important to identify those land uses which constitute the least threat to these sensitive water resources. Turf culture (residential, commercial, institutional and recreational) has come under much media criticism as an environmentally risky land use wherever ground water protection is important. This has influenced land use planning policy in spite of an ever growing body of research which shows turf to be a relatively effective ground cover for minimizing both nitrate and pesticide leaching to ground water.

While turf may constitute an environmentally sound ground cover over high value aquifer systems, it is important that managers of turf and those responsible for protecting ground water resources understand the best cultural practices for minimizing nutrient release from turf areas. Such knowledge will maximize the protective functions of turf and permit policy makers to assure the public that effective safeguards for the preservation of water quality are being implemented. Most research has concentrated on quantifying the discharge of pollutants into ground water. This study will define fertilizer management strategies for turf culture which are most protective of ground water quality.

Research supported by the RIWRRC over the past six years has generated a substantial data base of monthly nitrate concentrations in soil water under intensively managed lawn turf. This information, along with annual nitrogen budgets generated for turf-soil ecosystems in Rhode Island and elsewhere, provides the basis for modifying turf fertility management so as to minimize nitrogen use. The objectives of this research are:

1. To minimize nitrogen fertilizer use on turf by applying it only when soil nitrogen supplies are not adequate to maintain turf quality. Emphasis will be placed on spring and early summer applications with less use in the fall.
2. To compare fertilizer sources for their ability to deliver nitrogen in the amount and at a rate required by turfgrasses. Readily available and slow release organic nitrogen sources will be compared.
3. To determine if good quality Kentucky bluegrass turf can be maintained with annual nitrogen applications of not more than 1 lb N/1000 sq-ft (less than 50 lbs. N per acre).

Methodology:

The plot area utilized for this research is located on the Turfgrass Research Farm of the Rhode Island Agricultural Experiment Station at Kingston, RI. The soil type is an Enfield silt loam (Coarse loamy over sandy skeletal, mixed, mesic, Typic Dystrochrept). The site had been in turf for the past 25 years but not utilized for experimentation since 1989. In early April, 1994, existing sod was killed by a topical application of glyphosate and the dead turf removed with a sod cutter. The site was limed and prepared for sodding. Commercially grown Kentucky bluegrass (*Poa pratensis* L.) sod was installed on April 26, 1994. Past experimentation has shown Kentucky bluegrass to be least efficient in recovering nitrate from the soil and the most demanding of fertilizer nitrogen. If Kentucky bluegrass turf can be maintained at 1 lb N/1000 sq-ft/year, the same can be done with any cool-season turfgrass.

Suction cup lysimeters were installed in each plot at a depth of two feet on June 1. Seven nitrogen fertility treatments were initiated on June 20 as summarized below:

N source	Rate	Time & amount of application
	lbs N/1000 ft^2/yr	
Urea	3	June - 1/3; Nov. - 2/3
Urea	1	April - 1/2; June - 1/4; Sept. - 1/4
CORON	1	April - 1/2; Sept. - 1/2
CORON	1	April - 1/2; June - 1/4; Sept. - 1/4
Compost	1	April - 1/2; June - 1/2
Compost	1	April - 1/2; June - 1/4; Sept. - 1/4
Control	0	

The 3 lb urea-N treatment simulated conventional fertility management for a home lawn. CORON is a liquid methylene diurea product, 28% N by weight of which about 30% is urea and 70% is controlled release polymerized material. In our research, it has supported good quality turf, provided little leachable nitrate, and is the sort of nitrogen formulation popular with lawn maintenance companies. The compost used was Earthgro Lawn Food with an analysis of 8-2-4. It consists mostly of composted leaves and poultry manure fortified with $NaNO_3$. Its 8% nitrogen is about 50% water soluble and 50% insoluble. It is typical of commercially available 'organic' lawn fertilizers and in our research has supported good quality turf but tends to leach some nitrate. These nitrogen sources represent the spectrum of materials currently used in lawn fertilizers and should provide a realistic assessment of minimum fertility turf management. In this study, most fertilizer is applied in the spring when soil nitrate concentrations are lowest and absorption by grass roots is greatest. Low applications in September are intended to enable grass to recover more quickly from summer injury caused by drought, high temperatures, insect predation and human activity. An unfertilized control plot was included to monitor natural seasonal changes in soil mineralization of organic nitrogen and normal fluctuations in soil water nitrate levels.

During 1994, soil water samples were collected on nine dates; the first on June 7 and the last on December 28. These were analyzed for nitrate-N and the results used to estimate nitrate leaching. All plots were scored for visual quality on four dates during the 1994 growing season. Clippings were harvested on four dates. They were oven dried, ground to pass a 30-mesh screen and analyzed for total Kjeldahl nitrogen. Nitrogen recovered in clippings is a nondestructive means of estimating nitrogen absorption by roots and transport to shoots.

Principal findings and significance:

This project is continuing through the 1995-96 year with funding from the RIWRRC. Consequently what is presented here can only be viewed as a progress report. This research realistically will require three to four years to test the minimum fertilizer hypothesis on which this project is based.

The experimental site was sodded on 26 April 1994 using commercially grown Kentucky bluegrass sod grown less than 500 meters from the site on the same soil type. The spring season was dry and the irrigation system at the Turf Farm was inoperative until early July. Although the sod was hand watered several times following installation, some drying and turf injury was noted. This resulted in somewhat lower turf quality ratings than would be normal for recently established sod. However, by late summer and early fall, all initial injury had recovered and the turf entered the winter in excellent condition. Quality differences attributed to fertilizer treatments were not detected during the 1994 season.

By mid-April 1995, turf fertilized in November with 2 lbs N/1000 ft^2 exhibited a rich green color and resumed growth while the other plots remained brown and showed little signs of growth. By mid-May, however, the other plots had commenced growth and quality differences among treatments was not evident. By early June, turf that had received small amounts of nitrogen in the spring exhibited good quality and was slightly better than the fall fertilized turf. It is evident that quality differences are emerging during the 1995 growing season.

Water samples collected during 1994 showed a marked increase in nitrate content as the growing season progressed. However, this trend was observed in the unfertilized plots as well as those receiving nitrogenous fertilizers. Evidently, nitrogen applied just prior to harvesting the sod in April was mineralized and lost during the first growing season. Limited root growth during the dry summer months probably restricted the ability of the turf to absorb nitrate and prevent it from leaching beneath the root zone. By November, 1994, soil water nitrate-nitrogen levels in excess of 10 mg/L were recovered from most plots including the unfertilized controls. By April, 1995, soil water nitrate-nitrogen did not exceed 0.3 mg/L in any plot from which water samples were obtained. Apparently, extensive root growth occurred during the winter-spring season and the grass was capable of absorbing all nitrogen mineralized at that time. Hydraulic flow through turf has not as yet been calculated for 1994 so nitrate leaching losses can not be estimated at this time.

Clipping samples harvested during 1994 have been processed but total Kjeldahl nitrogen analysis has not been completed as of this writing. These are currently under way and results will be available for the August completion report.

The objectives of the 1994 season were fulfilled in that the experimental area was established, fertility treatments were initiated and preliminary data were obtained. The 1995 season should provide the first valid assessment of the minimum nitrogen fertility concept for turf management.

Utilization of Results:

Since this research is currently only in its second year, utilization by industry or commercial practice is premature. However, the stage has been set for the concept being tested in this research to be applied to commercial turf management. Articles published in regional and national newsletters have alerted turf managers to the prospect of greatly reduced nitrogen fertility in turfgrass culture (see publication list). As results emerge from this project, they will be released to the commercial sector along with the theoretical bases on which minimum nitrogen turf management is predicated. The channels have been developed to expedite this information transfer.

Additional Funding:

While the RIWRRC is the primary source of funding for this research, other funding sources have been explored. These include:

1. Earthgro Corp. - $4,000 received during 1994 along with fertilizer materials to support nitrogen efficiency research.

2. Coron Corp. - $500 received in support of nitrate leaching research as well as a supply of Coron methylene urea fertilizer.

3. RI Agricultural Experiment Station - $2,000 in operating funds for research on nitrogen use efficiency in turf management.

4. Fertilizer materials have also been provided by Milorganite Corp. and by Vigoro Industries, Inc.

5. Research grants to support greatly expanded aspects of this project have been submitted to the U.S. Golf Association, TruGreen-ChemLawn, Corp. and the U.S. Department of Agriculture - Competitive Grants Program. The USDA proposal is still pending. The others were not funded although our proposals made the final cut in both cases.

SYNOPSIS

Project Number: 02a

Title: **Designing a System of Water Rights and a Water Allocation Policy for Rhode Island.**

Investigators: **Dennis Wichelns, University of Rhode Island**
Thomas F. Weaver, University of Rhode Island

Focus Categories: **ECON, AG, WU, IG**

Congressional District: **Second**

Descriptors: **Water rights, economics, irrigation, policy analysis**

Problem and Research Objectives

Agricultural water withdrawals from major river systems in southern Rhode Island were the focus of heated debate during the unusually dry summers of 1987, 1991, and 1993. Residents located downstream from turf farms, nurseries, and vegetable farms claimed that irrigation withdrawals were responsible for diminished stream flows and the drying up of sink holes and other small water bodies. The state's Department of Environmental Management held several meetings to address the concerns of local residents in 1987 and staff members have worked with farmers to address water management issues during the recent dry summers. However, the agency has not yet developed a statewide policy regarding water rights, or the allocation of water resources during periods of shortage. The inevitable scarcity of water during future drought years will cause similar conflicts among users of surface water and groundwater resources in Rhode Island, unless an appropriate allocation scheme is designed and implemented.

Several agencies and user groups are eager to develop a statewide water policy. The Office of Statewide Planning, the Department of Environmental Management, the Division of Agriculture within DEM, and others have expressed interest in research that will result in the formation of an appropriate policy.

State agencies will benefit through a better understanding of the economic and hydrologic impacts of surface water and groundwater withdrawals on competing users of water resources. Farmers will benefit through more precise description of the economic and hydrologic impacts of agricultural water use in Rhode Island. An appropriate water rights system will allocate water efficiently and equitably during periods of shortage, to ensure that competing users are able to maintain economically important activities with minimal disruption.

The goal of this research is to determine the appropriate policy for allocating water during periods of shortage in southern Rhode Island. At present, there is limited information available regarding the impact of water withdrawals on stream flows and groundwater in the region. There is also a lack of information describing the incremental value of water to farmers, industries, and residents in southern Rhode Island. However, information describing the various components of water supply and demand, and the impact of water withdrawals on the amount of water available for alternative uses, is required in order to develop an efficient allocation policy. This information will be developed in this study and an economic analysis will be performed to examine policy alternatives.

Methodology

The Wood/Pawcatuck River system is an important watershed in southern Rhode Island, serving agricultural, municipal, and industrial water users with a relatively reliable supply of high-quality surface water and groundwater. During recent drought years, however, both the volume and quality of water in the system were diminished and complaints among water users were filed with the state's Department of Environmental Management. This river system is chosen for analysis because several current studies are developing useful data and because the water resource issues in the watershed are very representative of the critical issues facing Rhode Island at this time.

The water supply and demand situation for the Wood/Pawcatuck River system has been examined using historical data (to the extent available) and existing models of the surface water and groundwater resources in the region (eg. Gold, et al., 1988). The frequency distribution of the water supply has been examined, using daily weather data to describe the seasonal pattern of water supply in the system.

Competing demands on the Wood/Pawcatuck River system have been examined using available data describing water withdrawals from the system. Many water users in the watershed have been interviewed, to determine the components of water demand, and to learn about the role of water use in agricultural production, recreation, and industry. This information is required to estimate the direct economic value of water in alternative uses. Economic information is used to evaluate the tradeoffs that must be considered when total supply of water in the region is less than the sum of competing demands.

Water demand and supply relations will be combined in a water balance simulation model of the Wood/Pawcatuck River system. Existing irrigation scheduling programs will be used when appropriate to simulate daily water demands. The complete model will permit prediction of periods when water demands will most likely exceed water supply. Opportunities for reallocating water resources according to economic and other criteria will be identified by comparing the relative values of water in competing uses. This information will be used to develop the components of an appropriate system of water rights and a water allocation policy for the region.

Faculty and graduate students in the Department of Resource Economics at the University of Rhode Island will conduct the research for this study. Specialists in the University's Departments of Natural Resource Science, Civil Engineering, and Geology will be contacted for assistance with technical information and physical system modeling. Scientists in the U.S. Geological Survey will be called on for similar assistance and to provide data describing stream flows and groundwater depths in the Wood/Pawcatuck River system. The expected linkages among surface water and groundwater resources in the region will be described as completely as possible, given the available data and the hydrologic models developed to date.

Principal Findings and Significance

Major water users in the Wood/Pawcatuck water system include agricultural operations (primarily turf farms and nurseries), golf courses, industries, local residents (water supply and recreation), and municipal water companies. Water is also required, in stream, to maintain a healthy aquatic environment. The sum of water demands on the system can exceed water supply during conditions of low stream flow. This usually occurs during short, dry periods, during June through September. Water demands are often strong, during these months, due to the same weather conditions that cause a reduction in water supply. Water shortages are best described by examining daily data depicting water flow and withdrawals, because the periods of shortage are often very brief and may not be evident in monthly data.

The water supply and demand problem in the Wood/Pawcatuck watershed can be described as a peak-loading problem, in which constraints occur only during a small portion of the year. Appropriate water policies or a system of water rights will address the peak-loading problem, while not restricting water use during periods of the year when supply exceeds demand. For example, a system of water trading during dry periods, an incentive program to encourage efficient water use, or compensation to water users who voluntarily reduce withdrawals during dry periods are appropriate policies. Other policy options include a system of variable water rights, adoption of best management practices, and insurance programs to replace revenues lost during periods of water shortage.

An economic optimization model that includes water demand and supply relations, and information describing the relative value of water in alternative uses has been developed. Data for constructing the model include daily weather conditions and river flows, information gathered from water users, and data describing population growth rates and development patterns in the region. The goal of the model is to determine the optimal allocation of water, among competing users, when water supply is less than the sum of water demands. The model examines sub-basins within the watershed, to permit analysis of policy alternatives that may emphasize key differences among sub-basins.

The model is being used to examine the economic impacts of alternative public policies for addressing water shortages in the Wood/Pawcatuck watershed. Results will describe the relative advantages of alternative policies for addressing water shortages that occur during relatively short time periods. The economic impacts on competing users will be described, to determine the benefits and costs that are imposed on users by alternative policies.

Results can also be used to describe incentives that may be offered to water users, to encourage their participation in public programs to allocate water efficiently during drought periods. The social benefits that are generated by implementing public policies to encourage efficient allocation of water will be compared to the economic values that are generated in the absence of public policy, to determine the gains from policy intervention. If these gains exceed the social costs of policy intervention, then the net returns to intervention will be positive. Other goals of public policy, including income distribution, environmental protection, employment, and growth should also be considered when evaluating the full impact of policy alternatives.

SYNOPSIS

PROJECT NUMBER: 03

TITLE: Manganese Dioxide Adsorption for Silver Removal/Recovery

INVESTIGATORS: Calvin P. C. Poon, Dept. Civil/Environmental Engineering, Univ. of Rhode Island, Kingston, RI 02881
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FOCUS CATEGORIES: **TRT**

CONGRESSIONAL DISTRICT: **SECOND**

DESCRIPTORS: Silver, manganese dioxide, adsorption, ion exchange, activated carbon, industrial wastes

PROBLEMS AND RESEARCH OBJECTIVES:

Silver bearing wastewaters are discharged to sewer systems from various types of industries. A recent survey of the number of firms in Rhode Island discharging silver bearing wastes into the Narragansett Bay Commission (NBC) sewage system indicates 122 firms of printing and photo or x-ray processing, 16 metal plating firms, and 1 firm in glass manufacturing. Photo/x-ray processing firms typically discharge to sewers their spent fixer solution and rinse water after some type of silver recovery such as metallic exchange, electrolytic recovery, or ion exchange. The silver in the waste is mostly in the form of silver thiosulfate, $Ag(S_2 0_3)^{-3}$. Some silver in the wastes is in the form of organic-silver complex. In plating, silver bearing waste streams are discharged to sewer system as spent rinse solutionns. The silver in the solution consists primarily of silver cyanide complexes. For glass manufacturing operation, silver is used to "frost" light bulbs. The form of silver in the waste is not exactly known. Judging from the reported mumber of firms invloved and the amount of silver in their wastes, the major contributors are the photo/x-ray processors.

The USEPA has designated 5 mg/l or more of silver as "hazardous". Many sewer authorities simply adopted 5 mg/l as the discharge limit. Based on local situation considering the sensitivites of aquatic life to silver toxicity in the receiving water area, many sewer authorities adopt much lower silver concentration in their pretreatment standards. The current pretreatment standards for the NBC system is 0.43 mg/l maximum daily and 0.24 mg/l 10-day average. This will be reduced to a uniform concentration limit of 0.029 mg/l of silver. Neither metal exchange nor electrolytic recovery alone is sufficient to meet this standard. Even in combination, the treatrment system, recognized by USEPA as the Best Demonstrated Applied Technology (BDAT) with a 99% silver recovery cannot produce an effluent with 0.029 mg/l of silver. Ion exchange technology can be applied successfully to meet this standard. However it is expensive and generally requires the shipment of exhausted ion exchange columns offsite for silver recovery. Regeneration onsite, if feasible, could reduce or eliminate manifest and liability as well as cost. In addition, internal recycling of silver can be incorporated into the photo/x-ray process..

The research objectives of this project are to (1) synthesize MnO_2 crystals as adsorbent for silver removal, (2) study the adsorption kinetics, (3) study the possible regeneration of silver from MnO_2 , (4) compare the silver removal and regeneration by MnO_2 with other materials such as ion exchange and activated carbon.

METHODOLOGY:

1. Silver bearing wastewaters were collected from various photo/x-ray processors in Providence and Cranston areas for analysis.

2. Gelman filter type A/C(0.1 to 40 um) was used to separate particulates and soluble form of silver from the samples, and Sep-Pak C_{18}RPLC cartridge was used to separate the inorganic silver from the organic-silver complex, using methanol as the eluent.

3. Perkin-Elmer AA 3030 (flame) and AA 5100 (graphite tube) were used for silver analysis.

4. δ-MnO_2 was synthesized using (a) $KMnO_4$ and HCl according to Healy et al, 1966, and (b) δ-MnO_2 synthesized using $KMnO_4$, H_2O_2 and NaOH according to B. T. Anderson, et al, 1972. δ-MnO_2 also was synthesized (c) using $KMnO_4$, H_2O_2, and KOH, and (4) using $MnSO_4$, $KMnO_4$ according to EPA, (e) α-MnO_2 was prepared by soaking δ-MnO_2(Healy) or δ-MnO_2(EPA) in 2% KNO_3 solution at 70° C for 24 hours.

5. Activated carbon GRC-22, 12x30 mesh or grinded to 200 mesh, and BL-pulverized (200 mesh) were used for silver adsorption study.

6. Ion exchange resins Amberite IRA-68, and Bio-Rad AG1-X8 were used, both anionic form, for silver removal.

7. Silver solutions and selected sorbents were put in bottles on a shaker table for adsorption study at room temperature.

8. Both mini-columns (10-ml holding capacity) and burettes (50-ml and 25-ml) were used as ion exchange columns. The mini-columns are Poly-Prep Chromatograph columns equipped with 50-ml capacity reservoir and both the 50-ml and 25-ml plastic burettes were

equipped with a constant head reservoir for silver bearing solution supply.

9. For column studies, the flow rate was in general 0.4 bed volume per minute and regeneration using 30 % ammonium thiosulfate or 4 N NH_4Cl at a backflow rate of 0.4 bed volume/min for a total of 10-bed volume.

PRINCIPAL FINDINGS AND SIGNIFICANCE:

Preliminary adsorption or ion exchange studies were used to screen the types of material with good silver removal potential for later experiments. Among those studied, the following are the best ones MnO using Healy et al method designated as MnO_2(HCl), MnO_2 Healy et al modified or EPA modified designated as MnO_2 (HCl and KNO_3), IRA-68 and Bio-Rad anionic resins, Calgon GRC-22 and BL-pulcerized activated carbon, all exhibited high silver removal capacities, in the vicinity of 0.06 mg Ag removal per gram of absorbent or per gram of ion exchange resin. The initial removal rate was approximately 0.06 mg/g-hr.

Isotherm study was carried out in two parts (a)using photo/x-ray processed wastewaters, and (b)using pure $AgNO_3$ solution. The Langmuir adsorption kinetic equation was used for data fitting as follows:

$$\frac{1}{\mathbf{Xeq}} = \frac{1}{\mathbf{Xm\ K}}\left(\frac{1}{\mathbf{Ceq}}\right) + \frac{1}{\mathbf{Xm}}$$

The maximum adsorption capacity, **Xm** (mg Ag/g) and **K** value (1/mg of Ag) which is a measure of energy of sorption related to the heat of sorption, for each isotherm study are recorded as follow:

Medium	**Solution**	**Xm(mg/g)**	**K (1/mg)**
δ-MnO_2(HCl)	Photo process, RA-4 solution Initial Ag conc 330 mg/l pH = 7.55	91.74	0.0058
GRC-22 12x30 mesh	Photo process, RA-4 solution Initial Ag conc 330 mg/l pH = 7.55	42.77	0.0129
δ-MnO_2(HCl)	$AgNO_3$ solution Initial Ag conc 200 mg/l pH adjusted to 7.0	192.76	1.13
α-MnO_2(HCl + KNO_3)	$AgNO_3$ solution Initial Ag conc 200 mg/l pH adjusted to 7.0	138.06	0.066
GRC-22 200 mesh	$AgNO_3$ solution Initial Ag conc 200 mg/l pH adjusted to 7.0	165.62	0.266
BL-pulcerized 200 mesh	$AgNO_3$ solution Initial Ag conc 200 mg/l pH adjusted to 7.0	110.64	0.172

The result indicates that using relatively high concentration of silver, 200 to 330 mg/l, all sorbents have high sorption capacity. Silver removal from pure silver solution as $AgNO_3$ was much higher than Ag bearing photo processing wastes because the latter contained organics and other contaminants. The pH adjustment step was necessary for the $AgNO_3$ solution study because two similar experiments without pH adjustment (pH 0.95 to 2.12) indicated much lower silver sorption (**Xm** = 78.55 mg/g for MnO_2 (HCl) and 27.85 mg/g for GRC-22 activated carbon).

Mini-column and burette column studies were carried out using different types of ion exchange material and photo-processing RA-4 wastewater(treated bleach-fixer solution combined with rinse water)

Column	**Ion Exchanger**	**Initial Ag Conc.** mg/l	**Breakthrough at 0.029 mg/l bed volume**	**Regenerant upflow**	**Ag Recovery**
Mini	IRA-68 No pretreat	37.7	150	30% $NH_4S_2O_3$	70.76
Mini	IRA-68 4% H_2SO_4 treat	38.86	570	same as above	83.14
Mini	Bio-Rad No pretreat	37.8	630	same as above	99.57
Mini	Bio-Rad 9 N HCl treat	38.8	605	same as above	88.79
Buret 50 ml	IRA-68 4% H_2SO_4treat	37.0	610	same as above	72.42
Buret 25 ml	Bio-Rad No pretreat	37.0	600	same as above	-----
Mini	Bio-Rad	37.0	630	4N NH_4Cl	89.40

The result indicates that many sorbents and ion exchanges can be successful in silver removal. The principal findings are:

1. Removal of silver from pure $AgNO_3$ solution was much higher than from silver containing photo processing wastewater because of the presence of organic and other chemical compounds in the processing waste.

2. Both activated carbon GRC-22 and BL-pulverized(200 mesh) effectively removed silver from photo processing wastewater. Although activated carbon adsorption is normally used as a

pretreatment column preceeding ion exchange columns, the data in this study show that carbon along, particularly GRC-22 200-mesh, is as good as ion exchange material. Therefore carbon can be a stand alone treatment system. The practical problem with carbon at 200-mesh is that it is too fine to be used in columns. GRC22 at 10x30 mesh can be used in columns, but at a lower sorption capacity which is reduced to about one-third of the sorption capacity at 200 mesh. At 10x30 mesh size, the carbon serves best as a pretreatment unit ahead of the ion exchange columns.

3. Columns of MnO_2, either HCl or HCl+KNO_3 form, is very effective and better than activated carbon in silver removal. The maximum sorption capacity is as high as 192 mg Ag/g of MnO_2 . Similar to activated carbon used in this study, the 200-mesh size is too fine for column application.

4. IRA-68, an anionic resin with a macroporous structure is very effective in silver removal. The large openings allow the large organic-silver compounds to have access to the resin surface. With pretreatment of the rsin using 4% H_2SO_4 , an average close to 600 bed volume of Ag containing wastewater at 33 mg/l concentration per cycle can be processed before a breakthrough at 0.029 mg/l occurs. Regeneration with 30% $NH_4S_2O_3$ or 4N NH_4Cl can be successful, with 72 to 83% silver recovery from the ion exchange column. Bio-Rad AG1-X8 is another resin which is slightly more effective than IRA-68 in silver removal. On the average, 615 bed volumes of Ag waste at 33 mg/l per cycle can be processed before the breakthrough occurs. A regeneration with $NH_4S_2O_3$ or NH_4Cl with 88 to 99% silver recovery was successful. However Bio-Rad is much more expensive which prohibits its use in industrial application for silver removal/recovery. Because of the simple regeneration procedure, all photo/x-ray processing facilities that use ion exchange columns can practice recycle/reuse of silver onsite without having to remove the columns offsite for silver recovery. Offsite recovery is much more expensive and increases the liability of mishandling in manifest.

The research will continue which includes more ion exchange column study and possible silver recovery from activated carbon and MnO_2. Using H_2O_2 as a disinfectant in ion exchange columns has been found to be very destructive to the silver removal capacity. Using formaldehyde a disinfectant will be invcestigated. Finally a treatment train using activated carbon and ion exchange columns will be studied.

PROGRESS REPORT

Project Number: 04

Start: June 1, 1994

End: November 31, 1995

Title: POTENTIAL FOR MITIGATION OF NON-POINT SOURCE PHOSHPORUS POLLUTION IN RIPARIAN FOREST SOILS

Focus Categories: Non-Point Pollution, NPP

Congressional District: 2

Descriptors: Water Quality Riparian Land Phosphorus Removal Soil Chemistry Nonpoint Pollution Sources Soil Absorption Capacity

Problem and research objectives:

Phosphorus is the limiting nutrient for primary productivity in many lakes. Increased P loading into freshwater bodies from agricultural runoff and domestic and industrial sewage leads to accelerated eutrophication. This rapid change to more productive conditions often creates serious environmental problems, including oxygen depletion within the water column, which affects biota adversely, and extremely elevated levels of dissolved organic carbon, which are precursors of trihalomethanes (THMs) in chlorinated drinking water. THMs are known to be carcinogenic in humans. Prevention of P pollution of freshwater bodies is therefore an important approach to a improve water quality, both from a limnological and a public health perspective.

Riparian forest strips are transition zones between upland and wetalnd areas and are blelieved to be important in mitigation of P present in runoff. Thus, they can potentially act as filters of non-point source P pollution for surface waters. Water quality management relies on nutrient loading models to predict the effects of non-point source P pollution from different land uses on freshwater bodies. These models assume that all land uses are sources of P. As such, they do not incorporate the effects of these buffer zones -- such as riparian forest strips -- on P loading. These models also do not take into account the spatial and temporal variability in the ability of the soils and landscape features to function as sources or sinks of P.

Because of their proximity to surface water reservoirs, the large area wetlands and riparian forests comprise in Rhode Island, and because of their potential significance in water quality management, it is important to evaluate the ability of these landscape features to act as sources or sinks of P.

The objectives of the present study are:

1. To evaluate riparian forest soils for their capacity to retain or release P within different soil drainage classes.
2. To evaluate the correspondence of P retention or release with soil physical and chemical properties.
3. To quantify the spatial and temporal variability in P removal and release capacity of riparian forest soils.

<u>Methodology:</u>

The research is being conducted at a site at Peckham Farm (Kingston, RI), where a riparian forest zone with well-defined soil drainage classes has been identified. Three hundred spatially-referenced samples were taken in May of 1995 -- 100 from each of three soil drainage classes: moderately well, somewhat poorly, and poorly drained. The litter layer was removed and the top 5 cm was sampled with a 90 cm^3 core. Bulk density, organic matter content, soil moisture, and pH were determined for each sample point. P retention or release was evaluated by using P-adsorption isotherms. Isotherms were prepared by weighing 0.5 grams air-dried soil into a 20-ml vial and adding 0, 1, 3, 5, or 7 mg phosphate/L solution. The vials were then shaken in the dark in a reciprocal shaker for 24 h. The equilibrated solution was filtered through a Whatman No. 42 filter and analyzed for phosphate concentration using an RFA 300 Rapid Flow Analyzer. Isotherms were created for each sample point using the amount of P sorbed at each specific equilibrium P concentration (EPC). The EPC_0 value is defined as the solution concentration at zero sorption: a low EPC indicates high P retention capacity. For each sample point, an EPC_0 value was calculated.

Principal findings and significance:

Moderately well drained soils had a mean EPC of 1.0 mg P/L with a coefficient of variation (CV) of 83%. Somewhat poorly drained soils had the lowest buffering capacity in the catena with a mean EPC of 3.8 mg P/L, and a CV of 211%. Poorly drained soils had the highest buffering capacity with a mean EPC of 0.39 mg P/L and a CV of 73%. The high coefficients of variation suggest that spatial variability is high within a particular soil drainage class.

Differences in EPC_0 values among soil drainage class within a soil catena clearly suggest that riparian forest soils have different capacities to remove phosphorus from runoff. As such, the ability of these landscape features to intercept

P before it reaches adjacent freshwater bodies will likely be dependent on the area of a particular soil type and the contact time of runoff water with the soil -- riparian forest buffer zones cannot be considered as homogeneous landscape features when considering their interactions with P.

Current research efforts are being directed at evaluating the spatial dependence of P removal capacity of the different soils and evaluation of the mechanisms responsible for P sorption in these different soil drainage classes. Future work will be focused on assessing the site-to-site variation in P removal capacity of riparian forest soils as well as the temporal variation in this capacity.

SYNOPSIS

PROJECT NUMBER: 4ª

START: June 1, 1993

END: May 31, 1995

TITLE: Radon in the ground-water reservoirs of southern Rhode Island: a field assessment

INVESTIGATORS: Anne I. Veeger, O. Don Hermes, and Nicole C. Ruderman
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FOCUS CATEGORIES: GW, HYDGEO, HYDROL, RAD, WQL

CONGRESSIONAL DISTRICT: Second

DESCRIPTORS: Groundwater hydrology, groundwater quality, hydrogeology, radioactive isotopes, water chemistry

PROBLEM AND RESEARCH OBJECTIVES:

The Unites States Environmental Protection Agency (USEPA) has determined that elevated levels of radon gas in indoor air is the second leading cause of lung cancer, cigarette smoking being the number one cause. Approximately 1 to 7 percent of radon-related deaths are the result of radon that is released from well water during normal household activities. Because of the potential health threat of radon, the USEPA originally proposed a maximum contaminant level (MCL) of 300 pCi/L for radon in drinking water (Federal Register, July 18, 1991). This MCL was not accepted by Congress and is currently under revision.

Radon-222 (^{222}Rn) is a radioactive isotope with a half-life of 3.8 days. It is produced during the decay of uranium-238 to lead-206. Because of its short half-life and the relatively slow flow of ground water, ^{222}Rn is not transported great distances in aquifers. Therefore, when high levels of ^{222}Rn are found in ground water, its source, uranium, must be present in the surrounding rock or sediment. Previous studies of the crystalline rocks underlying the state have found significant amounts of uranium (Nevins, 1991). Furthermore, unconsolidated material derived from the uranium-bearing bedrock has been deposited in the bedrock valleys of Rhode Island during the retreat of the last ice sheet. Therefore, the potential for high levels of radon exists in wells in surficial material as well as in the underlying bedrock.

Ground water is the drinking water source for approximately 24% of Rhode Island as a whole, and 100% of southern Rhode Island. Previous research in Rhode Island has discovered elevated levels of radon in ground water from bedrock wells. However, no work has been done to evaluate the occurrence of radon in the surficial material aquifers, which are the highest yielding aquifers in the state. This study focuses on the distribution of ^{222}Rn in surficial aquifers and its relation to radon and uranium distribution in the underlying bedrock. The study area includes three of the major ground-water reservoirs in the Pawcatuck River Basin, Rhode Island: the Upper Wood, the Queen-Usquepaugh, and the Chipuxet.

The field assessment was completed in one year and included the following objectives:

- measurement of ^{222}Rn levels and chemical composition of ground water in wells screened in glacial material as well as bedrock; and
- determination of the variability of ^{222}Rn within the three-dimensional framework of the aquifer;

The interpretive phase of this study, completed in the second year, includes the following objectives:

- evaluation of the factors controlling ^{222}Rn levels, for example: uranium content in the underlying bedrock, depth to bedrock, and chemical evolution of the ground water; and
- development of a conceptual model for the distribution of ^{222}Rn in the aquifers of the Pawcatuck River Basin, Rhode Island.

METHODOLOGY:

Site Selection and Sample Collection

Ground-water samples were collected from private wells in the Upper Wood, Queen- Usquepaugh, and the Chipuxet River basin aquifers. Surveys were sent to homeowners throughout these three river basins asking for well depth and a description of the aquifer material. One hundred wells were chosen on the basis of this survey and the underlying bedrock. Ground-water samples were collected only after 3-well volumes had been evacuated from each well and pH, temperature, and electrical conductivity had stabilized. Standard water sampling and preservation techniques were used. Field analyses included temperature, pH, Eh, electrical conductance, and dissolved oxygen. Ground-water samples were collected for the following laboratory analyses: radon, uranium, alkalinity, calcium, magnesium, sodium, potassium, iron, manganese, silica, fluoride, chloride, nitrate, phosphate, and sulfate.

The radon samples were analyzed within three days of collection at the United States Geological Survey (USGS) National Water Quality Laboratory in Denver, Colorado. The uranium analyses were completed at the USGS National Water Quality Laboratory in Lakewood, Colorado. All other analyses were performed in the University of Rhode Island, Department of Geology, Hydrogeology Laboratory.

A Gad-6 gamma-ray spectrometer measured the gamma-ray emissions from the regolith material throughout the study area. These data were used to calculate %K (potassium), eU (uranium), and eTh (thorium) content of the surficial materials.

PRINCIPAL FINDINGS AND SIGNIFICANCE:

Geology

These three aquifers are unconsolidated aquifers of glacial origin deposited in bedrock valleys during the retreat of the late Wisconsin ice sheet. These deposits consist of fine to coarse sand and gravel, with some silt, derived from granitic igneous and metamorphic rocks to the north. The aquifers vary in thickness ranging from less than 50 feet of saturated thickness to greater than 150 feet of saturated thickness in the deepest portions of the bedrock valley. The sediment was deposited in a glaciofluvial/glacio-lacustrine environment resulting in strongly heterogeneous aquifer materials.

The Upper Wood River aquifer is underlain by the Sterling Plutonic Suite Granite Gneiss and the Scituate Igneous Suite Granite. The Queen Usquepaugh aquifer is underlain by the Esmond Plutonic Suite Granite Gneiss and the Scituate Igneous Suite Granite. The Chipuxet is underlain solely by the Esmond Plutonic Suite Granite Gneiss. The uranium-bearing minerals found in the bedrock are zircon, allanite, sphene, and monazite. The average uranium content of the Esmond Gneiss is 1.9 ppm, Sterling Gneiss is 3.3 ppm, and Scituate Granite is 4.1 ppm (Nevins, 1991).

There was no significant difference between the measured eU concentrations of the regolith of the three aquifers (median values were 2.24 ppm for the Queen-Usquepaugh, 1.9 ppm for the Upper Wood, and 2.37 for the Chipuxet). However, the eTh concentrations of the regolith did vary between the three aquifers. The Queen-Usquepaugh had the highest eTh median, 11.03 ppm, while the Upper Wood and the Chipuxet were lower, 9.67 ppm and 9.7 ppm, respectively.

Radon Distribution

Wells (both surficial and bedrock) in areas underlain by the Esmond Suite had the lowest radon content (range 500 to 30,400 pCi/L, mean 3,900 pCi/L, median 1,385 pCi/L), areas underlain by the Sterling Suite were not significantly different (range 700 to 27,300 pCi/L, mean 4,050 pCi/L, median 2,459 pCi/L), however, the areas underlain by the Scituate Suite had significantly higher levels (range 1,600 to 83,450 pCi.L, mean 13,900 pCi/L, median 6,945 pCi/L). In surficial material wells underlain by both the Esmond and Scituate Suite, radon concentrations increased with increasing depth and proximity to the bedrock surface. However, in the surficial material above the Sterling Plutonic Suite (found only in the Upper Wood aquifer) there was no increase with depth.

In areas underlain by the Esmond Suite, shallow surficial wells averaged 1,100 pCi/L, wells close to bedrock 1,800 pCi/L, and bedrock wells 8,600 pCi/L. In areas underlain by the Scituate Igneous Suite, shallow wells averaged 2,600 pCi/L, wells close to bedrock 9,500 pCi/L, and bedrock wells 28,900 pCi/L. In areas underlain by the Sterling Suite both the shallow surficial and deep surficial wells close to bedrock had about the same radon levels, 1,600 pCi/L and 1,300 pCi/L, respectively, and bedrock wells averaged 11,600 pCi/L. No statistical relationship was found between radon levels and uranium concentrations in the ground-water samples. However, the higher radon levels correlate with the higher uranium content in the underlying bedrock. Furthermore, the higher radon levels in the surficial material aquifer (underlain by the Scituate Igneous Suite) corresponded with the higher eTh concentrations in the regolith above the Scituate Igneous Suite, mean 10.74 ppm. The mean eTh concentrations in the areas underlain by the Esmond and Sterling Suites were 9.68 ppm and 9.83 ppm, respectively. There was no correlation between radon and eU values.

Looking at radon levels between the aquifers, the Chipuxet and Upper Wood aquifers had the lowest readings. The surficial material ground water in the Upper Wood had a median radon level of 1,216 pCi/L, and the Chipuxet had a median of 1,092 pCi/L. The median radon level of the Queen-Usquepaugh surficial material ground water was significantly higher at 3,222.5 pCi/L. A difference between aquifers can also be seen in the median bedrock ground water radon levels. The Queen-Usquepaugh and Upper Wood bedrock aquifers had the highest medians, 15,225 pCi/L and 17,277 pCi/L, respectively, while the Chipuxet bedrock ground water had a median radon level of only 4,697 pCi/L.

Water Chemistry

There exist distinct chemical differences between the surficial materials ground water and the bedrock ground water within the three aquifers (refer to table 1). Some significant distinguishing characteristics are higher pH, fluoride, calcium (except in the Chipuxet), silica, sodium, conductivity (except in the Chipuxet), and alkalinity values in the bedrock well water as compared to the surficial materials well water. Distinctive chemical characteristics of the aquifers include lower fluoride values in both bedrock and surficial wells and higher magnesium values in surficial materials wells in the Chipuxet than in the other two aquifers. The Queen-Usquepaugh aquifer is distinguished by higher calcium and alkalinity in its bedrock aquifer relative to the other two aquifers. The Upper Wood, on the other hand, has higher alkalinity in its surficial materials aquifer, and higher silica and fluoride values in its bedrock aquifer than the Chipuxet and Queen-Usquepaugh.

Summary and Conclusions

All wells sampled yielded radon levels above the proposed EPA limit of 300 pCi/L and many were more than an order of magnitude greater. Although the EPA will probably adopt a standard that is less rigorous than 300 pCi/L, this study reveals that much of the ground water in southern Rhode Island has elevated radon levels that may be cause for concern. Radon concentrations in the surficial materials varied with respect to proximity to bedrock surface in both the Queen-Usquepaugh and Chipuxet aquifers. Either the deeper surficial material in these two aquifers has a greater capacity for radon production (due to higher uranium content or a more favorable siting of uranium in the aquifer materials) or there is discharge of radon-bearing ground water from the underlying bedrock aquifer into the surficial material. Chemical analysis suggests that mixing is occurring between the surficial and bedrock aquifers in the Queen-Usquepaugh and Chipuxet aquifers, which could have an impact on the radon levels in the deeper surficial material.

Table 1-Concentrations of selected constituents in Upper Pawcatuck aquifers:

Chemical Parameters		Median	Values			
(mg/L)	Queen surficial	Queen bedrock	Wood surficial	Wood bedrock	Chipuxet surficial	Chipuxet bedrock
pH	5.15	6.33	4.95	6.81	4.5	5.53
alkalinity[1]	3.52	39.6	7.7	23.98	4.95	22.0
calcium	2.46	10.97	3.89	7.57	5.92	4.5
silica	10.42	17.36	10.63	22.23	12.42	14.93
fluoride	.11	1.33	.1	1.61	.08	.37
magnesium	.54	1.2	.9	.87	1.82	.91
sodium[2]	4.86	8.43	5.97	7.73	5.9	8.05

The finding that no correlation exists between dissolved uranium and radon concentrations in ground water is consistent with that of other studies. The solubility of uranium is a function of redox conditions in the aquifer and is therefore not expected to parallel radon concentrations (because radon is a noble gas). As expected, high radon concentrations in ground water correspond to the underlying bedrock containing the most uranium and the regolith containing the higher eTh values. Furthermore, ground water from bedrock wells yields higher concentrations of radon than that from surficial material wells. This may be a function of uranium availability in the surficial materials or it may be a function of the release rate of radon to the water as uranium decays in the aquifer materials. In some instances, chemical parameters (higher fluoride and alkalinity values) are linked to higher radon concentrations in the ground water. This suggests that source material does play some role in the distribution of radon in an aquifer. Also, different radon levels are seen in waters with very similar chemical signatures, the Upper Wood and Queen-Usquepaugh deep surficial materials wells for example. The Queen-Usquepaugh deep surficial materials wells have much higher radon levels, suggesting textural advantages such as the favorable siting of uranium in the Queen-Usquepaugh aquifer material or differences in flow rate influencing radon levels. On the other hand, waters with different chemical signatures (like the Upper Wood and Chipuxet deep surficial materials wells) are producing similar radon levels. This implies that residence time and water evolution are a factor in water chemistry but not radon level of the ground water.

This investigation has shown that radon is a concern for ground-water users within the Pawcatuck River Basin, Rhode Island. Although it is not possible to make detailed predictions on radon concentrations in ground water, this study shows that bedrock ground-water users in the Queen-Usquepaugh and Upper Wood aquifers can expect relatively high levels of radon in their ground water (10,000 pCi/L to 90,000 pCi/L). However, those users that withdraw ground water from surficial material aquifers are at a lower risk for elevated radon levels in their ground water.

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[1] mg/L CaCO3

[2] corrected for anthropogenic contamination by eliminating equivalent Na moles where Cl is in excess of 15 mg/l.

COOPERATIVE ARRANGEMENTS

The Water Resources Center at the University of Rhode Island has two advisory committees, namely the State Advisory Committee and the University Water Resources Coordinating Committee. The member ship has been changed in the past year, reflecting the recent interest and availability of water resources experts in Rhode Island.

State Advisory Committee

Combs, Walter	Dept. of Health
Falcone, Willaim	Water Resources Board
DeLima Virginia	U.S. Geological Survey
Mark, Eugene	
Meyer, Henry	Kingston Fire District
Miller, Scott	Office of System Planning, Dept. of Adm.
Rose, Vincent	Save the Bay
Salomon, Erich W.	Armbrust Chain Co.
Scott, Elizabeth	Office of Environmental Coordination
Stuart, Everett	U.R. Dept. of Agriculture
Szymanski, Edward	Dept. of Environmental Management
Varin, Daniel W.	Dept. of Administration
Weygand Robert A.	Lieutenant Governor

The state advisory Committee is consisted of leading water resources officials of the state and federal agencies as well as representatives from prominent citizen groups and manufacturers.

The other committee is the University Coordinating Committee, consisting of faculty members of the University of Rhode Island from various colleges and the director of the Sea Grant program. Each member has a significant contribution to academic and research programs related to water in the area.

University Coordinating Committee

Cain, J. Allen	Professor & Head of the State Geologist Office
DeLuise, Frank	Professor, Mechanical Engineering
Frohlich, Reinhard K.	Professor Geology
Gold, Arthur	Professor
Miller, Robert H.	Dean, College of Resources Development
Nixon, Scott	Professor, Coordinator of Sea Grant Program
Calvin P.C. Poon	Professor, Environmental Engineering

The two committees discussed water resources issues and research priorities for the FY-1994 State Water Research Institute Program. As a result of the discussion and suggestions from the committee members, the research priorities were established as listed on pages 7,8 of this report. Both committees also reviewed and ranked research proposals, made comments and suggestions of proposal alterations. They also served as points of contact to collect and to disseminate information to various groups of audience.

Project 02 worked closely with U.S. Department of Agriculture, Soil Conservation Service, U.S. Geological Survey subdistrict Office in Providence, Rhode Island, Department of Environmental Management, to collect and discussion of data in order to identify the important issues and to formulate an appropriate methodology.

Project 03, by nature of its work, had close cooperation with the U.S. Environmental Protection Agency, the Pollution Prevention Section of the Narragansett Bay Sewage Commission of Rhode Island, and the Photo/x-ray processing industries in Rhode Island for their advices and sampling.

Project 04, worked closely with US Department of Agriculture, Soil Conservation Service. USGS, and Department of Health of R.I. in Rhode Island.

PUBLICATIONS

1. **Referred Scientific Journal**	**Supporting Section 104 Project No.**
Hesketh, E. S., R. J. Hull, and A. J. Gold 1995,*Estimaing Non-gaseous Nitrogen Losses from Established Turf.* Jour. Turfgrass Managment, 1:17-30	02-(FY-94)
Liu, H., R. J. Hull, and D. T. Duff, 1995 Comparing Cultivars of Three Cool-Season Turfgrasses for Potassium Uptake Kinetics and Potassium Recovery in the Field. J. Plant Nutrition, 18:467-485	02-(FY-94)
Liu, H., R. J. Hull, and D. T. Duff, 1995 Comparing Cultivars of Three Cool-Season Turfgrasses for Phosphate Uptake Kinetics and Phosphorus Recovery in the Field, J. Plant Nutrition, 18:523-540.	02-(FY-94)
2. **Book Chapters**	
Hull, R. J., S. R. Alm, and N. Jackson, 1994 Toward Sustainable Lawn Turf. in A.R. Leslie (ed). Handbook of Integrated Pest Management for Turf and Ornaments. Lewis Pub., Boca Raton, Fl. PP.3-15	02-(FY-93)
3. **Dissertations**	
Ruderman, N. C., in prep, Hydrogeologic Controls on the Occurrence and Distribution of Radon-222 in Glacial aquifers, M.S. thesis, Dept. of Geology, University of Rhode Island, Kingston, RI.	04a-(FY-94)
4. **Water Resources Research Institute Reports**	
Hull, R. J., P. M. Goffman, and H. Liu, 1993 Controlling Nitrate Contamination of Groundwater Following Fall Fertilization of Turf, RIWRRI, University of Rhode Island, 40 p	02-(FY-93)
Poon, C P. C., and J. McCaughey, 1995 Progress report, Silver Removal/Recovery from Photo Processing Wastewaters.	03-(FY-94)

Wicheln, D.,and T. Weaver, 1995 02a-(FY-94)
Completion Report, Designing a System of Water
Rights and a Water Allocation Policy for
Rhode Island

Amador, J. 1995 04-(FY-94)
Progress report, Potential for Mitigation of Non-
Point Source Phosphorus Pollution in Riparian
Forest Soils

Veeger, A, O. Don Hermes, 1995 04a-(FY-94)
Completion Report, Radon in the Groundwater Reservoirs
of Southern Rhode Island: a Field Assessment.

5. Conference Proceedings

Hull, R. J., 1994 02-(FY-94)
Increasing Nitrogen Use Efficiency by Turfgrasses. in
Proceedings of the 3rd Annual Rutgers Turfgrass Sym.
Jan. 21-22, Rutgers Univ., New Brunswick, NJ. P. 12-13

6. Others

Lyons, J. B., J.H. Gorres, and J. A. Amador, 1995 04-(FY-94)
Spatial Distribution Patterns of P Retention and
Release in Riparian Wetland Forest Soils, Agronomy
Abstracts

Hull, R.J., and H. Liu, 1993, Nitrogen Losses from 02-(FY-94)
Well Fertilized Lawn Turf, Turf Notes 4(2):1-8, New
England Cooperative Extension, Mary Owen (ed), Univ.
Mass, Worcester, MA.

Hull, R. J., 1994, Nitrogen Fate:What Happens to It and 02-(FY-94)
Where Does It Go? Turf Grass Trends 4(9):1-10., J. Haber
(ed), Washington, D. C.

Hull, R. J., 1995, Problem or Myth? Nitrate Leaching from 02-(FY-94)
Turf. Turf Grass Trends 5(2):1-9, J. Haber (ed), Washington
D. C.

Hull, R. J., and J. A. Amador, 1994, Fall Nitrogen Use 02-(FY-94)
Efficiency by Turf, RI Turfgrass Field Day Field Book
63:5-7, Univ. of Rhode Island, Kingston, RI

Hull, R.J., 1994, Minimum Maintenance Turf Management for Aquifer Protection, RI Turfgrass Field Day Field Book 63:8-10, Univ. of Rhode Island, Kingston, RI.

02-(FY-94)

TRAINING ACCOMPLISHMENTS

Academic Level

Field of Study	Under-graduate	Master's Degree	Ph.D. Degree	Post-Ph.D.	TOTAL
Engineering - Environmental		1			1
Geology		1			1
Natural Resources Science		1			1
Natural Resources Economics		1			1
Plant Science	2				2
Total	2	4			6

FISCAL YEAR 1995

PROGRAM REPORT

WATER RESOURCES RESEARCH INSTITUTE
THE UNIVERSITY OF RHODE ISLAND

FISCAL YEAR 1995 PROGRAM REPORT

Rhode Island Water Resources Research Institute
University of Rhode Island
Kingston, Rhode Island

FISCAL YEAR 1995 PROGRAM REPORT
Grant No. 14-08-0001-2044

for

U.S. Department of the Interior
Geological Survey

by

Water Resources Center
University of Rhode Island
Kingston, RI 02881

Calvin P. C. Poon, Director

July 1996

The activities on which this report is based were financed in part by the Department of the Interior, U.S. Geological Survey, through the Rhode Island Water Resources Center.

ABSTRACT

The objectives of the Rhode Island Water Resources Institute program for the recent years has been (1) to identify critical policy and management issues of water resources in the State and in the New England region, (2) to conduct research in order to generate information useful to address the issues and to solve the problems, (3) to transfer the information to potential users throughout the State and New England region, (4) to educate the public about water quality protection, and (5) to train both graduate and undergraduate students in water resources research. Current and anticipated state and regional water problems are aquifer protection in relation to turf farming management, increased cost of drinking water supply resulting from Safe Drinking Water Act Requirements in water quality monitoring, water quality aspects of wetland, radon removal from drinking water, the fate of phosphorus in riparian wetland forest, hazardous material removal/recovery as part of the pollution prevention program as well as contaminated site remediation, and information dissemination on geophysical techniques and economics in groundwater survey.

The FY-1995 program address many of these issues and problems. Eutrophication of freshwater bodies due to elevated phosphorus inputs is of increasing concern within Rhode Island. Riparian forested buffers are regarded as sinks of nonpoint source pollution and essential to protecting water quality in freshwater bodies. The potential for phosphorus removal was investigated using the equilibrium P concentration at zero sorption (EPC_0). Soil properties and EPC_0 were determined for 3 draining classes in a riparian forest. Mean EPC_0 and soil property values were different between drainage classes. EPC_0 means were different in May and November. For somewhat poorly drained soils, the forest appeared to become a source of P in the fall. The potential for P removal diminished rapidly as Fe, Al concentrations fell below a critical level. For remediation of petroleum contaminated sites, landfarming is an effective technology for soil decontamiantion. The process can be accomplished in a period of several weeks to several months. The soil at the site may have to be amended with nutrients supplement, pH and moisture control, and addition of surfactant. Some detergent may not be effective because of the disinfection property. BioSolve appears to be better than other detergens studied in enhancing the bioremediation process. It is important that managers of turf and those responsible for protecting ground water resources understand the best cultural practices for minimizing nutrient release from turf areas. Soil mineralization of organic nitrogen in the fertilizer probably contribute to elevated soil water nitrate levels. Even the unfertilized plots contain soil water nitrate-nitrogen in excess of 1.0 mg nitrate-N/l (ppm) during late summer and fall. During the spring, nitrate-N levels are consistently less than 1.5 ppm. The higher urea-N treatment is evident by the elevated soil water nitrate levels. The 1.0 lb urea-N/1000 sq-ft application in mid-June results in a Nitrate-N concentration in soil water of 16 ppm the following July. Silver removal/recovery is important to the photo/X-ray processing industries for regulation compliance and for resources recovery reasons. At high silver concentrations, electrodeposition can be cost effective. At low concentrations, ion exchange process has to be used. A method of sulfuric acid treatment of the resin can prolong the useful life of the resin by going through the exchange/acid fixation cycles repeatedly. The exchange capacity of the resin IRA-68 can be increased 40 times or more. The effluent, at about 20 mg/l Ag, has to be diluted with tap water for further ion exchange treatment to reduce the Ag to 0.029 mg/l breakthrough concentration. Pollution

minimization and pollution prevention is necessary for the marine trade related industries including boat builders using fiber reinforced plastics and marinas to remain competitive and profitable. Hazardous waste management using solvent substitution, solvent reclamation, process substitution, material substitution, waste collection and recycling etc are found to be practical and cost saving in the production and yet maintaining the quality of the products or service.

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RESEARCH PROJECT SYNOPSES

INFORMATION TRANSFER

WATER PROBLEMS AND ISSUES OF RHODE ISLAND

Eutrophication of fresh water bodies due to elevated phosphorus (P) inputs is of increasing concern within the state of Rhode Island. Ten of the 42 lakes monitored in Rhode Island rank as eutrophic based on median chlorophyll trophic state index values. The increased primary productivity associated with eutrophication affects water quality by increasing concentrations of dissolved and particulate organic carbon, which constitute the main precursors of trihalomethanes (THMs) in surface waters. The USEPA has proposed new regulations that would lower the THMs limit to 0.08 mg/l beginning in 1996. A lower THM standard will pose a difficult challenge tp public water utilities that depend on eutrophic surface water supplies in Rhode Island. Controlling the sources of DOC in natural waters may prove to be an effective alternative to costly in-plant treatment for DOC removal. Controlling the non-point source P pollution of surface limits the primary production of algae and aquatic macrophytes which in turn limits the production of THMs. Riparian wetland areas, because of their flatter slopes and high surface roughness, tend to accumulate sediment-bound P in the runoff. Since wetland acts as either sources or sinks of P depending on hydrologic characteristics, there is a need to evaluate the role of the special landscape features of wetland as sources or sinks of P.

Rhode Island has many sites contaminated with hazardous materials. Almost without exception, the sites have contaminated soils as well as contaminated groundwater. Without decontamination the site cannot be used and the migration of the contaminants will not stop. More contaminants will reach the aquifer resulting in a greater negative impact on the environment. Some simple and cost-effective remediation method that can decontaminate the site for reuse is needed. Land farming can remove or destroy the contaminants in a short period of time. The process should be studied both in the laboratory and field scale and its applicability in Rhode Island can be evaluated.

Land development in southern New England is of such intensity that most areas are or soon will be subjected to some level of use. Shallow aquifers, especially those representing sole-source water supplies, need special protection but the land overlying them is often highly valued for residential or commercial development. While turf may constitute an environmentally sound ground cover over high value aquifer systems, it is important that managers of turf and those responsible for protecting ground water resources understand the best cultural practices for minimizing nutrient release from turf areas. Such knowledge will maximize the protective functions of turf and permit policy makers to assure the public that effective safeguards for the preservation of water quality are being implemented. Most research has concentrated on quantifying the discharge of pollutants into ground water. A study of fertilizer management strategies for turf culture which are most protective of ground water quality is needed.

There is a large number of firms in Rhode Island that discharge silver bearing wastewater. In the Narragansett Bay Commission (NBC) district alone, there are 122 firms of printing and photo or x-ray processing, 16 metal plating, and 1 firm in glass manufacturing discharging silver bearing waste into the NBC sewer system. The US EPA has designated 5 mg/l or more of silver as "hazardous". Many sewer authorities simply adopt 5 mg/l as the discharge limit. However many sewer authorities lower the limit by taking into the consideration of the effect of silver toxicity in the receiving water as well as in the sewage treatment process and sludge quality. The current pretreatment standards for NBC system is 0.43 mg/l Ag maximum daily and 0.24 mg/l on a 10-day average. There is a proposal to lower the standards to a uniform concentration of 0.029 mg/l. Even the combined technology of metal exchange/electrolytic recovery recognized NY US EPA as the Best Demonstrated Applied Technology (BDAT) with a 99% silver recovery cannot produce an effluent with 0.029 mg/l of silver. There is a need to study the ion exchange technology for more efficient silver recovery and at the same time reducing the silver to the proposed level of 0.029 mg/l.

There are numerous boat builders in Rhode Island that use fiber reinforced plastics (FRP). Hazardous wastes and volatile organic compounds (VOCs) are generated in the boat building processes. To reduce the generation of hazardous wastes and VOCs while at the same time maintaining quality control, it is necessary to study various ways such as alternative solvent use, solvent reclamation, process substitution, and material management. The study is part of the effort of state pollution prevention program that is designed to minimize pollution and helps the state industries in their sustainable development.

PROGRAM GOALS AND PRIORITIES

With minor changes from last year's program goal and research priorities, the State Advisory Committee and the University Water Resources Coordinating Committee set the following priorities:

Water Management

1. Evaluation of local and state land use and zoning regulations as well as wellhead protection Program on their impacts on water quality protection.

2. Management of wetlands as pollution mitigators.

3. Water conservation practices and effects.

4. Study of the impacts of the Federal Energy Policy Act on Rhode Island water systems and Consumers

Water Quality

1. Mitigating non-point sources of nutrients from runoffs.

2. Resources recovery and management from industries to meet discharge limits in Rhode Island.

3. Role of wetlands in pollutant removal.

Groundwater and Surface Water-Ground Water Interaction

1. Assessment of groundwater reservoir capacity and pollution in glacial deposit and bedrock Fractures.

2. Geophysical technology and economics in groundwater survey.

Technology Transfer

Education, preventive maintenance, and evaluation of risks of homeowner practices on individual wells and water quality in relation to the Rhode Island designed wellhead protection area, or information transfer of any of the research topics mentioned above.

Table 1. Sources and Levels of Funding, FY-1995

Project	Funding Level	Source of Funding Ending May 31, 1996
02. Riparian Wetland Forest Soils as Sinks and Sources of Phosphorus	$ 10,066 23,197	USGS Univ. Rhode Island
03. Landfarming Technologies for On Site Bioremediation of Hydrocarbon-Contaminated Soils	23,529 46,424	USGS Univ. Rhode Island
04. Wellhead Protection from Nitrate Contamination through Minimum Fertilization of Turf	13,958 29,788	USGS Univ. Rhode Island
05. Silver Removal/Recovery from Photo Imaging Industries	40,000 7,938 5,433	RI Dept. Environ. Manag. Univ. Rhode Island Narragansett Bay Comm.
06. Hazardous Waste Management in Matine Trade Industries--Pollution Prevention	36,000	RI Dept. Environ. Manag. And RI Dept. Economic Development
22. Information Transfer Activities	14,000 31,570	USGS Univ. Rhode Island
01. Center Administration	16,992 31,735	USGS Univ. Rhode Island
FY-1995 Total Funding	$ 78,545 170,652 5,433 76,000	USGS Univ. Rhode Island Narragansett Bay Comm RI Dept. Environ.Manag. And Dept. Economic Development..

Project Summary

Project Number: 2

Start Date: 6-1-1995
End Date: 5-31-1996

Title: RIPARIAN FOREST SOILS AS SINKS AND SOURCES OF PHOSPHORUS: SPATIAL DISTRIBUTION PATTERNS AND MODELING

Investigators: Josef H.Görres
José A Amador
Natural Resources Science Department
University of Rhode Island
Kingston, RI 02881

Focus Category: WL, NU

Congressional District: 2nd RI

Descriptors: Water Quality Riparian Land Phosphorus Removal Soil Chemistry Nonpoint Pollution Sources Soil Absorption Capacity

Rationale and Research Objectives:

Eutrophication of freshwater bodies due to elevated phosphorus inputs is of increasing concern within Rhode Island. Much of the State relies on surface water reservoirs for drinking water and the increased primary productivity results in high organic carbon concentrations which constitute precursors of trihalomethanes (THMs). THMs are potential human carcinogens and their presence in drinking water poses a public health threat.

Riparian forested buffers are regarded as sinks of nonpoint source pollution and essential to protecting water quality in freshwater bodies. In riparian ecosystems plant uptake, microbial assimilation, adsorption and the mechanical removal of sediments from overland flow, participate in the removal of phosphorus originating from agricultural or residential land uses. However, it is also possible that under certain conditions buffer strips may act as sources of phosphorus.

While it is recognized that riparian buffers have large potentials for removing nutrients and protecting water quality, mechanistic nonpoint source loading models treat riparian areas as neutral. There are a number of difficulties that need to be overcome before mechanistic components of phosphorus removal and release in riparian forests can be incorporated into nonpoint source loading models. The first is to identify processes which would explain both removal or release. The second is to measure parameters which describe these processes sufficiently accurately so that an assessment of the removal or release potential of a riparian forested buffer can be undertaken.

The removal or release of phosphorus will most likely occur in the forest floor and the upper most mineral layer. The focus of this project was on soluble phosphorus, so that a measure of adsorption and desorption of phosphorus in soils was a critical component for this project. The variability of soils was considered one of the problems in the estimation of areal means of source or sink parameters.

Our objectives were to

- provide a measure of phosphorus adsorption and desorption
- determine whether a particular drainage class was particularly effective in phosphorus removal
- determine whether spatial dependence needed to be considered in the measurement of adsorption or desorption
- determine whether adsorption and desorption were temporally variable.

Our hypotheses were that

- the potential for phosphorus removal or release varies with Fe and Al ions, and organic matter
- adsorption or desorption differs in different drainage zones
- adsorption and desorption are spatially and temporally variable.

Methodology

A riparian forest located down gradient from an agricultural area was chosen to conduct the research. The forest is on glacial outwash and contains a soil drainage catena. The soil at the site is a Hinkley sandy loam with an average surface slope of 3%. The upland forest is dominated by oak (*Quercus spp.*), grading into a red maple (*Acer rubrum)* swamp.

A plot was established which was 25 m long and 15 m wide. The plot was oriented such that the long side was normal to the gradient. The plot was placed to span three consecutive drainage classes: moderately well, somewhat poorly and poorly drained. The drainage classes were delineated within the plot using soil morphological features. Each drainage class had a width of approximately 5 m. 100 samples were taken in each drainage class in May 1995 and November 1995, giving a total of 300 samples per sampling date. To satisfy geostatistical sampling criteria, the sampling scheme was a nested stratified random design. This design created distances between points that varied from very short (about 5m) to very long (about 25 m) within each drainage class. For the first sampling all points were surveyed to a common origin to allow geostatistical analysis to account for spatial dependence of data.

Soil samples were taken from the top of the mineral soil with cylindrical cores (5 cm diameter and 5 cm length) to obtain a known volume of soil. Subsequently, the soils were weighed and then stored at 4° C. We determined bulk density, soil pH, soil organic matter and soil moisture with standard methods within one week of sampling. Soil samples were homogenized by shaking before determination of soil moisture, soil organic matter and soil pH. Particle size distribution was determined on 50 g of oven dried soil using the hydrometer method. Oxalate-extractable Al and Fe were determined by atomic adsorption spectroscopy.

Phosphorus adsorption isotherms were used to determine the ability of the soil to remove or release phosphorus. To obtain this isotherm, 1 g air dry aliquots of each sample were placed in plastic vials containing 15 ml of PO_4 solution at concentrations of 0, 1, 3, 5, 7 mg P/L. After 24 hours of shaking and filtering the filtrate was analyzed for soluble reactive P colorimetrically. Phosphate was determined by the molybdenum blue method using ascorbic acid as a reductant. Total phosphorus (TP) in solution was determined by chemically oxidizing a portion of the filtrate to phosphate and analyzing colorimetrically. Dissolved organic phosphorus was derived as the difference between ortho-P and TP.

Equilibrium phosphorus concentration (EPC_0) was computed from sorption isotherms obtained with the phosphorus data measured as described in the previous paragraph. This required the computation of sorbed phosphorus with the equation:

$$S_e=(C_i-C_e)$$

where S_e is the amount of phosphorus sorbed, C_i is the initial concentration, and C_e is the concentration of phosphorus in solution after 24 hours of equilibration. Sorption was plotted against phosphorus concentration in solution. EPC_0 is defined as the solution concentration at zero sorption. Regression analysis was used to find this point.

A physical interpretation of EPC_0 is that it represents a reciprocal potential of soil to adsorb phosphorus. The larger EPC_0, the less the ability of the soil to remove phosphorus. If regression analysis does not give a positive slope, nor an x-intercept, i.e. EPC_0 does not exist, the soil is most likely a source of phosphorus.

We used both classical statistics and geostatistics to estimate the mean and variance of EPC_0, and the various soil properties. Normality of data was ascertained using the Kolmogorov-Smirnov (K-S) test. It the data was not normally distributed, non-parametric statistics were used. Unpaired t-test or the Mann-Whitney rank sum test were used, depending on the outcome of the K-S test, to test for seasonal differences in mean soil properties and EPC_0. Kruskall Wallis one-way analysis of variance on ranks was used to assess differences in mean soil properties and EPC_0 between drainage classes. Significant differences were evaluated at the 95% confidence level.

Geostatistical analysis was used for the first sampling date to model the spatial distribution of EPC_0, and soil properties that affect P release/retention. Estimation of areal means with Kriging is a preferred method when the data has a high degree of spatial structure.

Principal Findings and Significance:

Table 1 gives the result of classical statistical tests for soil properties in the three drainage classes and on the two sampling dates. Soil properties are not generally different between sampling dates for the same drainage class. However, between drainage classes on the same sampling date, soil properties are different. This is true not only for organic matter and bulk density but also for the soluble ion contents.

Kriged means for May were not significantly different to the mean values computed with classical statistics and they are not tabulated in this report. No krige analysis was carried out in November.

Table 2 lists the EPC_0 means and standard deviations for moderately well, somewhat poorly and poorly drained soils for May and November 1995. Each drainage class has different EPC_0 values in May and November. For somewhat poorly drained the x-intercept could not determined and sorption values remained below zero (denoted NI in Table 2) in November 1995. The soil in this drainage class was probably a phosphorus source in the Fall. Mean EPC_0 also varied between drainage classes. The best removal potential is in the poorly drained soils. The least potential for phosphorus removal is in the somewhat poorly drained soils.

Our first hypothesis listed above states that we anticipated some interaction between soil ions, organic matter and phosphorus. In Figure 1, EPC_0 is plotted against the sum of oxidized Fe and Al and against % organic matter for the drainage class with the best removal potential (poorly drained). In May and November the soil oxidized ions appear to define a threshold for phosphorus removal. For [Fe] +[Al] > 8, EPC_0 is low and thus the potential for removal of phosphorus is high. For [Fe] +[Al] < 8, EPC_0 appears to increase asymptotically. Low organic matter coincides with low EPC_0 and high organic matter coincides with high EPC_0. The other drainage classes are being investigated in a similar manner.

The graphs in Figure 1 give us confidence in that the more difficult to determine EPC_0 values may be estimated from other soil properties. This would make a successful transfer of this technology to water resource managers more likely.

Utilization of Results:

It is our intend to use the information generated in phosphorus loading models to provide a source or sink estimate for riparian forested buffers. The finding that little can be gained from estimating average EPC_0 values with spatial statistics, in our setting at least, makes a determination of EPC_0 simpler since data points need not be surveyed and the non-standard geostatistical treatment can be omitted.

In a new project we will estimate the EPC_0 averages for riparian forests down gradient from different land uses to determine whether different loadings lead to phosphorus saturation of the soil and consequently to the soil becoming a source of P. The information gained in this project will help us design efficient sampling schemes that take into account the seasonal variation and the variation in drainage class.

Publications Generated:

Dissertation:

Lyons, Jody. 1996. Temporal and Spatial Patterns of P-retention and Release in Riparian Forest Soils."M.S. Dissertation". Department of Natural Resources Science, College of Resource Development, University of Rhode Island, Kingston, Rhode Island.

Conference Proceedings:

Lyons,Jody, Josef Gorres and Jose Amador. 1995. Spatial patterns of P-retention in riparian forest soils. "In" Agronomy Abstracts. American Society of Agronomy, Crop Science Soceity of America, Soil Science Soceity of America, St. Joseph, MI

Table 1: Mean and standard deviation of soil properties for moderately well, somewhat poorly and poorly drained soils in May and November 1995. N = 100 for all soil properties.

Drainage Class	Date		Organic Matter	Bulk Density	pH	Al	Fe
			[%]	[g/cm^3]			[mg/g]
Moderately	May	Mean	33.8a[1,2]	0.37a	3.8a	2.19a	2.16a
Well		Std.	16.8	0.19	0.2	0.61	0.92
	Nov	Mean	35.5a	0.35a	4.1b	2.18a	2.58a
		Std.	15.7	0.13	0.2	0.52	0.92
Somewhat	May	Mean	63.1b	0.2b	3.8a	1.97b	1.63b
poorly		Std.	11.7	0.05	0.2	0.49	0.54
	Nov	Mean	61.9b	0.20b	4.0c	2.04b	1.92b
		Std.	9.9	5	0.3	0.5	0.46
Poorly	May	Mean	59.8c	0.21c	3.7d	5.16c	3.51c
		Std.	7.1	0.04	0.2	1.84	1.17
		Mean	62.3d	0.18d	4.2	5.60c	4.14c
		Std.	8.7	0.07	0.2	1.96	1.51

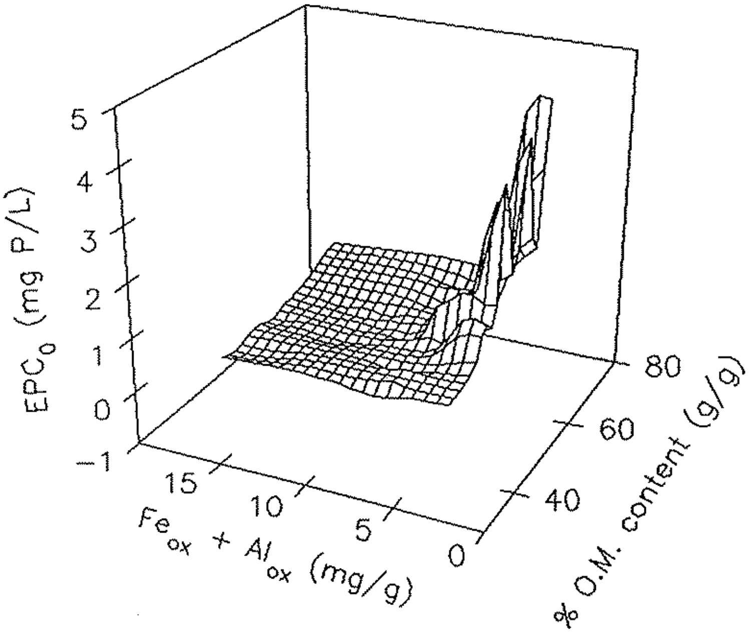
[1] Values within drainage class followed by the same letter within a column are not significantly different

[2] Values between drainage classes for each date followed by the same letter within a column are not significantly different

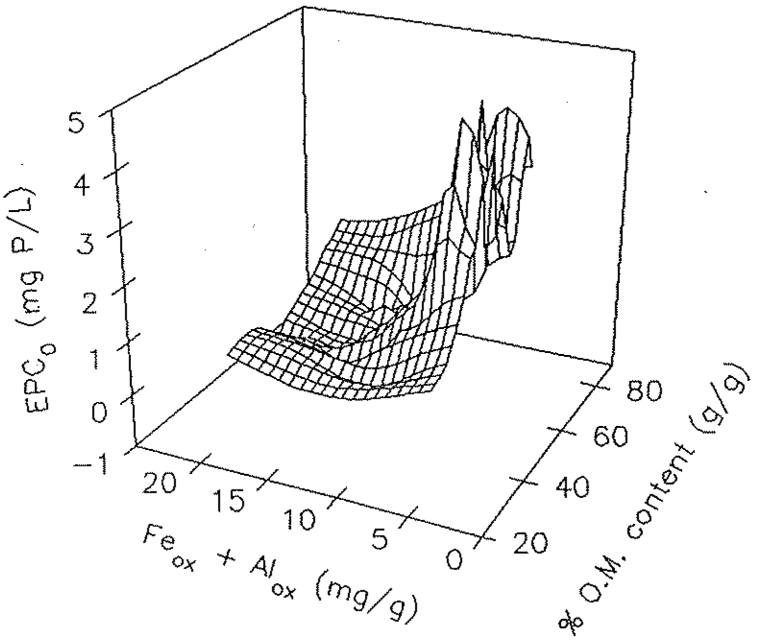
Table 2: Equilibrium phosphorus concentration (EPC_0) at zero sorption for moderately well, somewhat poorly and poorly drained soils in May and November 1995

	Moderately well drained		Somewhat poorly drained		Poorly drained	
Date	May	November	May	November	May	November
			EPC_0	[mg P/L]		
Mean	1.01a[1,2]	1.53b	3.80c	NI[3]	0.52d	1.26 e
Std.	1.35	1.57	1.85	NI	0.98	1.42
n	80	66	61	NI	74	82

1 Values within a drainage class followed by the same letter are not significantly different
2 Values between drainage classes followed by the same letter are not significantly different.
3 NI = no intercept found for EPC_0 determination.



Poorly drained soil in May



Poorly drained soil in November

SYNOPSIS

Project Number : 03

Starting 6-1-95
Ending 5-31-96

Title: Land farming Techniques for On Site Bioremediation of Hydrocarbon-Contaminated Soils: Laboratory and Field-Scale Evaluation

Investigators: Jose A. Amador and Calvin P. C. Poon
University of Rhode Island
Kingston, RI 02881

Focus Categories: NPP TS

Congressional District: 2nd RI

Descriptors: Bioremediation, Petroleum hydrocarbons, Soil farming, Environmental Control, On site treatment, Biodegradation, Pollution prevention

Problem and Research Objectives:

Contamination of air, surface water, sediment, groundwater, and soils with toxic and hazardous chemicals is a potential health and social-economic problem among all industrialized nations today. There are over 1,250 abandoned sites with toxic and hazardous chemicals and wastes in the National Priority List, and the number may potentially increase to over 32,000. There are millions of underground fuel storage tanks in the United States and a significant number of these tanks are leaking. Despite the regulatory efforts to decrease the release of toxic chemicals to the environment, significant environmental contamination has occurred. At the current rate of Superfund site cleanup and the removal of leaking underground storage tanks, the environmental contamination problems will be with us for a long time. In Rhode Island alone, there are 12 Superfund sites eligible for federal cleanup, 82 hazardous waste sites throughout the state requiring public cleanup, and another 220 hazardous privately owned sites. Most of the sites need cleanup to reduce their long term-effects on groundwater pollution. With federal and state mandates to cleanup these sites, soil contamination has to be eliminated so that a contaminated site can be restored to its clean state. A restored site can have significant economic value, e.g., the former Kettle Point Petroleum Products Terminal site will be decontaminated and redeveloped into a condominium development project. Before the site can be redeveloped, soil total petroleum hydrocarbon up to 53,000 ppm and BTEX (benzene-toluene-ethyl benzene-xylene) up to 1690 ppm need to be reduced to 1 ppm BTEX. This can be accomplished by using various chemical, physical, or biological techniques which emphasize the detoxification and destruction of the contaminants rather than the conventional approach of disposal. The selection of technology alternatives depends on the applicability and economics of the technology for the cleanup of a specific site.

Methodology:

This project investigate various techniques of Land farming for soil decontamination of soils polluted with petroleum products, e.g., fuel oil, gasoline, kerosene, and related products. Land farming is a form of on-site bioremediation that relies on aerobic microbial metabolism for the oxidation of the petroleum products. The factors governing the design, operation, and success of Land farming technology include biodegradability of the contaminants, use of indigenous or imported bacterial consortium, control of moisture, pH, nutrient supplements, control of fugitive VOC emissions, and labor requirement.

(1). Laboratory -scale investigation

Contaminated soil samples and clean soil near the site at the Aqua Tank Farm site of the former Naval Air Station at Quonset Point, Rhode Island were obtained. Laboratory-scale optimization of conditions for Land farming can be accomplished initially using static microcosms. The information obtained from these microcosms will then be used to develop optimal conditions for field-scale implementation of the various Land farming techniques.

The indigenous microflora of the contaminated soil was used to accomplish the aerobic biodegradation of the hydrocarbons. The site was contaminated by jet fuel JP-5 and aviation fuel. Because of the poor soil at the site, nutrients in the form of a fertilizer with N to P ratio of approximately 5 times were added to give a organic carbon/N/P ratio of about 100/15/3. Most samples did not require pH adjustment as the measured pH was within a range of 5.8 to 6.8. Outside of this range, lime was added to the soil sample to near neutral pH. The following non-ionic detergents were added to groups of soil samples: Dawn holding 25% by weight of surfactant, Sunlight holding 15% surfactant, Tide holding 25% of surfactant, and BioSolve holding 15% of surfactant. The amount of surfactants in the soil was controlled to 1.0, 1.5, 2.0, 2.5, and 3.0% of soil weight. All soil samples were moisture adjusted to about 60% of the soil's water holding capacity to start the experiment. Mercury chloride was added to the negative control sample in an amount of 1,500 mg/kg of dry contaminated soil. Positive control samples consisted of uncontaminated soil adjacent to the site subject to the same treatment as contaminated soils. The samples were put into sealed glass serum vials as static microcosms and incubated at room temperature. Rates of microbial respiration were determined by measuring changes in CO_2 concentration in the headspace of the vials as a function of time. The laboratory-scale study lasted 5 weeks and was terminated when the CO_2 generation rate diminished and stabilized.

(2) Field-scale investigation

Two windrow soil piles each 18-ft by 4-ft at the base and 3-ft high will be constructed at a jetfuel and aviation fuel contaminated site. Each soil pile will be divided into two portions. One half of the pile will be a control while the others will receive surfactant, nutrient, or moisture control. Gpysum block probe connected to a conductivity meter will be used for field moisture monitoring. Another soil pile 12-ft by 12-ft and 1-ft high simulating area farming will also be constructed. No soil turn over will be attempted for this pile. Again the area soil pile is divided into two halves with one half for control and the other half with additions of surfactant, nutrients, and moisture control. Spatial and temporal samples will be taken to determine the total petroleum hydrocarbon degradation for all soil piles.

Principal Findings and Significance:

In the laboratory-scale study, the CO_2 generation was measured weekly in each of the microcosms. The gas generation expressed in terms of mg of CO_2 per g of soil for each microcosm was compared with a similar microcosm with different surfactant and different surfactant concentration and with the control.

The positive control microcosm, i.e. uncontaminated soil with the same moisture, pH, and nutrient control but without detergent, showed strong bacterial action. Within the range of surfactant used in the experiment, from 1.0 to 3.0 % of the soil weight, it was found that the surfactant inhibited the bacterial action.

For the microcosms with contaminated soils, the surfactant in general enhanced the biodegradation of the hydrocarbon. However Tide appeared to have too much disinfectant in the detergent such that the bacterial action was significantly inhibited. For the other three detergents, surfactant 1.0 to 1.5% appeared to be the optimal concentration for enhancing hydrocarbon biodegradation in soil. At higher concentration, the detergent inhibited the bacterial action. Among these three detergents, Sunlight, Dawn, and BioSolve, BioSolve appeared to be slightly better.

There is a delay in the field scale investigation because of difficulties in gaining site access. Negotiations with federal agencies and state agencies are under way to get approval. Once site access is granted, the field work can be completed in about 8 to 9 weeks.

SYNOPSIS

Project Number: 04

Start: 6-1-95
End: 5-31-96

Title: Wellhead Protection from Nitrate Contamination through Minimum Fertilization of Turf

Investigator:
Richard J. Hull
Plant Sciences Department
University of Rhode Island
Kingston, RI 02881

Focus categories: GW; NC; NPP; NU; WQL

Congressional District: 2nd RI

Descriptors: Ground water pollution; Nitrates; Land application; Organic Wastes; Aquifer; Fertilizers; Turfgrasses

Problem and research objectives:

Land development in southern New England is of such intensity that most areas are or soon will be subjected to some level of use. Shallow aquifers, especially those representing sole-source water supplies, need special protection but the land overlying them is often highly valued for residential or commercial development. It is important to identify those land uses which constitute the least threat to these sensitive water resources. Turf culture (residential, commercial, institutional and recreational) has come under much media criticism as an environmentally risky land use wherever ground water protection is important. This has influenced land use planning policy in spite of an ever growing body of research which shows turf to be a relatively effective ground cover for minimizing both nitrate and pesticide leaching to ground water.

While turf may constitute an environmentally sound ground cover over high value aquifer systems, it is important that managers of turf and those responsible for protecting ground water resources understand the best cultural practices for minimizing nutrient release from turf areas. Such knowledge will maximize the protective functions of turf and permit policy makers to assure the public that effective safeguards for wellhead protection and preservation of water quality are being implemented. Most research has concentrated on quantifying the discharge of pollutants into ground water. This study will define fertilizer management strategies for turf culture which are most protective of ground water quality.

Research supported by the RIWRRC over the past seven years has generated a substantial data base of monthly nitrate concentrations in soil water under intensively managed lawn turf. This information, along with annual nitrogen budgets generated for turf-soil ecosystems in Rhode Island and elsewhere, provide the basis for modifying turf fertility management so as to minimize nitrogen use. The objectives of this research are:

1. To minimize nitrogen fertilizer use on turf by applying it only when soil nitrogen supplies are not adequate to maintain turf quality. Emphasis will be placed on spring and early summer applications with less use in the fall.
2. To compare fertilizer sources for their ability to deliver nitrogen in the amount and at a rate required by turfgrasses. Readily available and slow release organic nitrogen sources will be compared.
3. To determine if good quality Kentucky bluegrass turf can be maintained with annual nitrogen applications of not more than 1 lb N/1000 sq-ft (less than 50 lbs. N per acre).

<u>Methodology:</u>

Experimental design, plot area and treatments: The plot area utilized for this research is located on the Turfgrass Research Farm of the Rhode Island Agricultural Experiment Station at Kingston, RI. The soil type is an Enfield silt loam (Coarse loamy over sandy skeletal, mixed, mesic, Typic Dystrochrept). The site had been in turf for the past 25 years but not utilized for experimentation since 1989. In early April, 1994, existing sod was killed by a topical application of glyphosate [*N*-(phosphonomethyl)glycine] and the dead turf removed with a sod cutter. The site was limed and prepared for sodding. Commercially grown Kentucky bluegrass (*Poa pratensis* L.) sod was installed on April 26, 1994. The sod was grown within 500 yards of the plot site using a commercial blend (Lofts Seed Inc.) consisting of 25% by weight 'Suffolk', 25% 'Sydsport', 25% 'Baron', 15% 'P-104' Kentucky bluegrasses and 10% 'Jamestown II' Chewings fescue. Past experimentation has shown Kentucky bluegrass to be least efficient in recovering nitrate from solution and the most demanding of fertilizer nitrogen. If Kentucky bluegrass turf can be maintained at 1 lb N/1000 sq-ft/year, the same can be done with any cool-season turfgrass.

Seven nitrogen fertility treatments were initiated on June 20, 1994 and maintained to the present. These are summarized below:

N source	Rate lbs N/1000 ft^2/yr	Time & amount applied (lbs.)
Urea	3	June - 1.0; Nov. - 2.0
Urea	1	April - 0.5; June - 0.25; Sept. - 0.25
CORON	1	April - 0.5; Sept. - 0.5
CORON	1	April - 0.5; June - 0.25; Sept. - 0.25
Compost	1	April - 0.5; June - 0.5
Compost	1	April - 0.5; June - 0.25; Sept. - 0.25
Control	0	

The 3 lb urea-N treatment simulated conventional fertility management for a home lawn. Urea is a water soluble, readily available, and inexpensive nitrogen source commonly included in commercial turf fertilizers. CORON is a liquid methylene diurea product, 28% N by weight of which about 30% is urea and 70% is a controlled release polymerized material. In our research, it has supported good quality turf, provided little leachable nitrate, and is the sort of nitrogen formulation popular with lawn service companies. The compost used was Earthgro Lawn Food with an analysis of 8-2-4. It consists mostly of composted leaves and poultry manure fortified with $NaNO_3$. Its 8% nitrogen is about 50% water soluble and 50% insoluble. It is typical of commercially available 'organic' lawn fertilizers and in our research, has supported good quality turf but tends to leach some nitrate. These nitrogen sources represent the spectrum of materials currently used in lawn fertilizers and were intended to provide a realistic assessment of minimum fertility turf management. In this study, most fertilizer was applied in the spring when soil nitrate concentrations are lowest and absorption by grass roots is greatest. Low applications in September are intended to enable grass to recover more quickly from summer injury to the root system caused by drought, high temperatures, insect predation and human activity. An unfertilized control plot was included in each of the four replications to monitor natural seasonal changes in soil mineralization of organic nitrogen and normal fluctuations in soil water nitrate levels.

Nitrate Leaching, Nitrogen Recovery in Clippings and Turf Quality: Suction cup lysimeters were installed in each plot at a depth of two feet on June 1, 1994. Soil water samples were collected monthly, weather permitting, and more frequently during the growing season. These were analyzed for nitrate-N and the results used to estimate nitrate leaching by multiplying the soil water nitrate concentration by leachate volumes calculated from the CREAMS model.

Clippings were harvested on four dates in 1994 and about every two weeks during subsequent seasons from a 10.3 sq-ft area of each plot. They were oven dried, ground to pass a 30-mesh screen and analyzed for total Kjeldahl nitrogen. Nitrogen recovered in clippings is a nondestructive means of estimating nitrogen absorption by roots and transport to shoots and for monitoring the nutritional status of turf.

All plots were scored for visual quality on four dates in 1994 and about once monthly during subsequent growing season. Quality scores constituted a subjective integration of turf color, texture, uniformity and freedom from weeds, disease and other injury.

April applications were made on 13 April 1995 and 1 April 1996. Mid-June nitrogen applications were made on 20 June 1994, 15 June 1995 and 14 June 1996 with the late summer applications made on 1 September 1994 and 1 September 1995. The November applications to the 3 lb. urea-N plots were made on 17 November 1994 and 24 November 1995.

Principal findings and significance:

This project is continuing through the 1996-97 year with funding from the RIWRRC under a different title. Consequently what is presented here can only be viewed as a progress report for the year 1995. This research realistically will require three to four years to test the minimum fertilizer hypothesis on which this project is based.

Turf quality:
Turf quality scores were taken on eight dates in 1995. While the late spring of 1995 presented near normal temperatures and slightly below normal rain fall the summer was warmer than normal and dry (3.5 inches below normal). This resulted in a sharp decline in turf quality during August. However, the return to more normal

conditions in September along with the nitrogen application to three plots, resulted in a marked increase in quality.

Differences among fertilizer materials and times of application were generally significant but not consistent throughout the season. Urea generally produced the highest quality turf but the one-pound rate was often equal to or better than the three-pound rate. Earthgro Lawn Food (compost) treated turf benefited from the early September application and that advantage persisted throughout the season. Coron treated plots exhibited a similar pattern with the 0.5 lb application in September producing a slight advantage over the 0.25 lb treatment. By mid- to late-fall, all plots exhibited good quality turf indicating that soil water nitrogen was more than adequate to meet grass needs. The unfertilized plots demonstrated the capacity for mineralized nitrogen to provide sufficient nitrogen. Only in the spring did these plots rank poorest. Later in the season, unfertilized plots were of higher quality than some receiving nitrogen fertilizer.

These results are from the first full post-establishment season and must be regarded as preliminary.

Soil water nitrate and nitrate leaching:

Soil water samples were collected on 15 dates in 1995 and the nitrate-nitrogen concentrations determined. Because of warmer than normal conditions throughout the summer, soil mineralization of organic nitrogen probably contributed to elevated soil water nitrate levels. Even the unfertilized plots contained soil water nitrate-nitrogen in excess of 1.0 mg NO_3-N/L (ppm) during late summer and fall. During the spring, nitrate-nitrogen levels were consistently less than 1.5 ppm. The higher urea-nitrogen treatment was evident by its elevated soil water nitrate levels. The 1.0 lb urea-N/1000 sq-ft application in mid-June resulted in a nitrate-nitrogen concentration in soil water of 16 ppm the following July.

All 5 g N/m^2 (1.0 lb N/1000 sq-ft) application rates failed to produce soil water nitrate-nitrogen levels in excess of 10 ppm NO_3-N set by the US Public Health Service as the maximim allowed in drinking water. Because of low rainfall during the summer months, nitrate leaching to the 2-ft. depth of the suction lysimeters may have been delayed or not detected even if nitrate levels in the surface soil horizons were relatively high. This may explain why the Earthgro compost plots which received 0.5 lb. N in mid-June did not exhibit elevated soil water nitrate until August. The relatively high nitrate concentrations in soil water of Earthgro Compost treated plots probably is a result of the readily soluble sodium nitrate added to increase the analysis of that product. Even so, the nitrate-N level from those plots rarely exceeded 5.0 ppm.

Nitrate Leaching:

Nitrate leaching was estimated based on soil water nitrate concentrations and net percolation estimated from the CREAMS model. Almost half of the annual precipitation and irrigation was estimated to have percolated through the soil during 1995. This carried with it nitrate-nitrogen ranging from 4.3 g/m^2 for the high rate of urea to 0.6 g/m^2 for the Coron treatment in which most was applied in the spring. This represented quantities equivalent to 29% and 12% of the nitrogen applied, respectively.

Because nitrate concentrations in the soil water were so low in the spring, relatively little nitrate leached during that season. Also, precipitation was low resulting in only 1.6 inches of percolation. The greatest percolation occurred in the fall when soil water nitrate levels were highest. This resulted in nitrate leaching in excess of 1.5 $g N/m^2$ from the Earthgro Lawn Food when half had been applied in early September. The least leachable nitrogen source was Coron which lost less than 25% of that applied.

The leaching levels observed in this study were greater than those noted in other experiments conducted as part of this long-term investigation. In part, this was due to the low nitrogen rates applied. When expressed as a percent of that applied, even low leaching levels may appear large. Also, the high temperatures and dry conditions which characterized the 1995 growing season, probably contributed to rapid and extensive root decline while encouraging mineralization of soil organic nitrogen. This lack of roots reduced nitrate uptake by the turf leaving soil nitrogen vulnerable to leaching. The 1996 season having more normal precipitation and cooler than normal temperatures should promote greater root retention and activity with less nitrate leaching. This appears to be occurring.

Clipping samples harvested during 1995 have been processed and total Kjeldahl nitrogen analysis completed but as of this writing the data have not been analyzed.

Utilization of Results:

Since this research is currently only in its third year, utilization by industry or commercial practice is premature. However, the stage has been set for the concept being tested in this research to be applied to commercial turf management. Articles published in regional and national newsletters have alerted turf managers to the prospect of greatly reduced nitrogen use in turfgrass culture (see publication list). As results emerge from this project, they are being released to the commercial sector along with the theoretical bases on which minimum nitrogen turf management is predicated. The channels have been developed to expedite this information transfer.

Additional Funding:

While the RIWRRC is the primary source of funding for this research, other funding sources have been explored. These include:

1. Earthgro Corp. - $3,000 requested for 1996 along with fertilizer materials to support nitrogen efficiency research.

2. RI Agricultural Experiment Station - $1,500 in operating funds for research on nitrogen use efficiency in turf management.

3. TruGreen-ChemLawn Corp. - $3,000 requested to support 1996 research.

4. Student assistance for the 1996 season is being funded by the URI Turfgrass Foundation.

5. Research grants to support greatly expanded aspects of this project have been submitted to the the U.S. Department of Agriculture - Competitive Grants Program. This proposal is still pending. Grants submitted to the New England Golf Course Superintendents Association and to the Water Resources Research Regional Competition were not funded.

SYNOPSIS

Project Number: 05 Starting: 6-1-95
Ending: 5-31-96

Title: Silver Recovery/Removal from Photo Imaging Industries

Investigator: Calvin P. C. Poon and Rui-guang Guo
University of Rhode Island
Kingston, RI 02881

Focus Categories: TRT

Congressional District: 2nd district

Descriptors: Silver, Adsorption, ion exchange, activated carbon, electrodeposition, Industrial wastes

Problems and Research Objectives:

Silver bearing waste are generated from photo-processing, X-ray processing, metal plating, and printing industries in Rhode Island and elsewhere in United States. The USEPA has designated 5 mg/l of silver as hazardous. However by taking into consideration of the silver toxicity in sewage treatment plant, silver content in sludge, silver toxicity in receiving waters, many sewer authorities have set silver pretreatment standards much lower than 5 mg/l. Currently the Narragansett Bay Commission has set pretreatment standards for silver at 0.43 mg/l maximum daily and 0.24 mg/l 10-day average. There is a proposal to lower the standards to a uniform concentration limit of 0.029 mg/l.

The major form of silver in the photo and X-ray processing wastes is silver thiosulfate. Most industries use metal exchange or electrolytic recovery to recover silver. Neither one of the techniques can remove silver down to less than 50 mg/l. Ion exchange is generally used to lower the silver concentration down to the pretreatment standards. However the ion exchange technology is expensive because of its limited exchange capacity for silver. Methods to increase the silver exchange capacity or using ion exchange technology in combination with other technologies for a more cost effective means o silver recovery is needed.

Methodology:

Silver bearing wastewaters were collected from various photo/X-ray processors in Rhode Island for study. Silver concentration of the wastewater and of the treated effluents of this study was determined by using Perkin-Elmer AA 3030 (flame) and 5100 (graphite tube). Depending on the objective of specific experiments, dissolved, particulate, total, or organo-complex forms of silver were determined. Sep-Pak C_{18}RPLC was used to separate the inorganic silver from the organo-complex form of silver, using methanol as the eluent.

Adsorption isotherm study was carried out for various materials including manganese oxides, activated carbon, and different types of resins. Silver nitrate solution was also studied for comparison of silver removal/recovery using actual silver bearing wastewater collected from industries. The resins giving the most promising results were selected for column study. Some experiments were conducted using the electrodeposition technique. The reactor consists of carbon anodes and stainless steel cathodes. The effluent from the electrodeposition process was then treated, with or without tap water dilution using ion exchange to lower the silver concentration down to 0.029 mg/l. Some experiments include acid fixing of silver onto the resin at breakthrough and the column was reused for silver exchange. The treatment and acid fixing cycles were repeated many times without having to replace the resin column at the end of each breakthrough. This in effect increased the silver recovery onto the column many times over the conventional technique used for ion exchange.

Principal Findings and Significance:

In the isotherm study, the Langmuir adsorption kinetic equation was used for data fitting as follows:

$$\frac{1}{Xeq} = \frac{1}{Xm\ K}\left(\frac{1}{Ceq}\right)+\frac{1}{Xm}$$

The maximum adsorption capacity, **Xm** (mg Ag/g) and **K** value (1/mg of Ag) which is a measure of energy of sorption related to the heat of sorption, for each isotherm study are recorded as follow:

Medium	**Solution**	**Xm(mg/g)**	**K (1/mg)**
δ-MnO_2(HCl)	Photo process, RA-4 solution Initial Ag conc 330 mg/l pH = 7.55	91.74	0.0058
GRC-22 12x30 mesh	Photo process, RA-4 solution Initial Ag conc 330 mg/l pH = 7.55	42.77	0.0129
δ-MnO_2(HCl)	$AgNO_3$ solution Initial Ag conc 200 mg/l pH adjusted to 7.0	192.76	1.13
α-MnO_2(HCl + KNO_3)	$AgNO_3$ solution Initial Ag conc 200 mg/l pH adjusted to 7.0	138.06	0.066
GRC-22 200 mesh	$AgNO_3$ solution Initial Ag conc 200 mg/l pH adjusted to 7.0	165.62	0.266
BL-pulcerized 200 mesh	$AgNO_3$ solution Initial Ag conc 200 mg/l pH adjusted to 7.0	110.64	0.172

The result indicates that using relatively high concentration of silver, 200 to 300 mg/l, all sorbents have a high adsorption capacity. Silver removal from pure silver solution as silver nitrate was much higher than silver from photo processing wastewater.

Mini-column and burette column studies were carried out using different types of resin and photo-processing wastewater (RA-4, a bleach-fixer solution combined with rinse water).

Column	Ion Exchanger	Initial Ag Conc. mg/l	Breakthrough at 0.029 mg/l bed volume	Regenerant upflow	Ag Recovery
Mini	IRA-68 No pretreat	37.7	150	30% $NH_4S_2O_3$	70.76
Mini	IRA-68 4% H_2SO_4 treat	38.86	570	same as above	83.14
Mini	Bio-Rad No pretreat	37.8	630	same as above	99.57
Mini	Bio-Rad 9 N HCl treat	38.8	605	same as above	88.79
Buret 50 ml	IRA-68 4% H_2SO_4treat	37.0	610	same as above	72.42
Buret 25 ml	Bio-Rad No pretreat	37.0	600	same as above	-----
Mini	Bio-Rad	37.0	630	4N NH_4Cl	89.40

The results indicate that either manganese oxides or the powder form of activated carbon can be a stand alone treatment process for silver recovery. However 200-mesh size is too fine to be used in columns. Bio-Rad stands out as the most efficient ion exchange for silver removal in both its exchange capacity as well as ion exchange regeneration (using $NH_4S_2O_3$ 30% solution). However it is very expensive and could be prohibitive for industrial use.

IRA-68 appears to be the best candidate for use even though its silver exchange capacity is less than that of Bio-Rad and IRA-400. A cost-effective way of using the IRA-68 for silver recovery is to apply the silver bearing wastewater at about 300 mg/l of silver and remove it down to about 20 mg/l in columns. When breakthrough occurs, a 4% sulfuric acid solution can be used to fix the silver onto the resins. After the fixation and tap water washing step, the column are ready to start the silver removal step again. This treatment/fix-regeneration cycle can be repeated up to 42 times in our experiments producing an effluent of the same quality, i.e., about 20 mg/l silver. The exchange capacity of silver has been significantly increased from 0.034 to 1.44 g of silver per g of resin. The shop owner, in effect, will be able to ship out a column to the silver refiner once in 3 years or longer instead of once a month provided that fix-regeneration at the shop is carried out. The spent acid contains less than 0.01 mg/l silver which in itself is not a toxic waste based on silver content.

The treated effluent containing 20 mg/l + 5 mg/l silver requires further treatment. As is, the effluent can not be treated using IRA-68 resin columns as efficiently as the photo processing wastewater. Apparently some residue accumulates in the effluent which reduces the treatment efficiency. It was found that some dilution of the effluent with tap water was a prerequisite for a further ion exchange treatment. Currently experiments are carried out to investigate the proper dilution with internal recycle which could consistently produce an effluent at 0.029 mg/l.

A laboratory built electrode position reactor was built with carbon anodes and a stainless steel cathode. The silver content of a strong photo processing solution at about 3000 mg/l can be reduced to approximately 250 to 300 mg/l in 24 hours. The silver recovered on the surface of the cathode can be scrapped off from time to time. This is a cost-effective way to recover silver from a high silver concentration solution. The effluent from the electrodepostion unit can be treated with the IRA-68 resin columns at two stages as described previously. A bench top pilot scale system will be used to carry out the experiments. The system design and operation is targeted to benefit the numerous small photo/X-ray processing shops for silver recovery and in compliance of the silver pretreatment standards in different states.

SYNOPSIS

Project Number: 06

Starting 6-1-95
Ending 5-31-96

Title: Pollution Prevention and Hazardous Waste Management for Marine Trade Industries

Investigators: Calvin P. C. Poon
University of Rhode Island
Kingston, RI 02881

Focus Categories: TS TRT M&S

Congressional District: 2nd District, RI

Descriptors: Marinas, Boat Builders, Pollution Prevention, Pollution Minimization, Solvent Recovery/Substitution, Process Substitution, Material Management,

Problem and Research Objectives:

Fiberglass reinforced plastic(FRP) boat building industry exists in Rhode Island for a long time. FRP production methods have been targeted for improvement because of the resin waste inherent during application, the liberation of volatile organic compounds(VOCs), principally styrene, during application and curing, and the need for large quantities of solvents, usually acetone, to clean spray guns and tools after completion of work. These issues represent regulatory and economic liabilities for the industry. Marinas in Rhode Island provide services to recreational sail and power boaters. Services include engine maintenance, painting, fiberglass repairs, pressure washing, and winterization and storage of vessels. Wastes such as waste oils, absorbents, antifreeze material, solvent, paints, pressure washing wastewater and human wastes from holding tanks are generated in various quantities. The boat building as a reemerging industry and the increasing boating activities in Rhode Island marinas all have a vested interest in reducing the liabilities of the pollution problem before regulatory and economic pressures impede the profitability of their business. In the environment of a sustainable industrial development and remaining profitable, pollution minimization and prevention are highly encouraged by both the regulatory agencies as well as the marine trade organization in the State.

Methodology:

Representative boat builders and marinas in Rhode Island were chosen for the study. The sites were visited including extensive interviews with the facility manager and production engineers. This site visits, coupled with an extensive survey form to be filled in by the facility manager, help to identify all processes that generate hazardous waste, the techniques and technologies to minimize and reduce waste generation, and finally recommend specific technology or process change tailored to each individual company's needs in order to achieve the goal of waste reduction and elimination. The entire process focused on how to reduce hazardous waste and VOCs while at the same time maintaining quality control. To accomplish this goal, we focused our research on alternative solvents, solvent reclamation, process substitution, and material management.

Principal Findings and Significance:

Solvent substitution-----Since acetone is a 100% pure solvent, it will volatilize over time and contribute significantly to VOC production. There are several acetone replacements suitable to many facility operations. (1) *Shipshape* is an organic based solvent with a slow evaporating rate and a high flashpoint, (2)*Thermaclean* is an aliphatic ester with a high flashpoint and can be used in a heated recirculating wash basin, (3)*Green Stuff* is a water based aqueous parts cleaner designed to be used in a heated recirculating wash basin. All substitute solvents are much more expensive. They are used a recirculating basin and should be reclaimed with an in-house still or commercially. Also flash gun or other demanding cleaning job would still require the use of a small amount of acetone or flush gun solvents.

Solvent reclamation-----Both in-house still and commercial distillation process are proven to be economic for acetone and other acetone substitute solvents reclamation. Cost recovery ranges from a few months to a few years depending on the quantity of solvent usage.

High volume low pressure (HVLP) spray technology-----Conventional air spray units currently used may have a transfer efficiency as low as 50%. Since VOC production varies directly with materials usage, any improvement in transfer efficiency decreases VOCs produced and resin required. Since HVLP spray technology can provide transfer efficiency of 70% or higher, this study provides economic and material saving analyses for many facilities.

Pressure fed roller resin dispensing-----Converting from conventional spray to pressure fed rollers for laminating procedures has advantages in material saving and VOC reduction. Although application rates of pressure fed rollers are lower than that of conventional spray technologies, it has been determined in this study that time saving from less cleaning and increased glass content of the finished product make up for the time difference. These rollers have also been determined to reduce the amount of VOCs emitted during lay-up.

Infusion molding-----The infusion molding process has been demonstrated to cut resin required and VOCs produced in the FRP process. Due to initial expenses, the process is only applicable for medium to large boat builders.

Solvent management-----Use of a centralized solvent wash basin is a method for controlling solvent usage. It the basin is covered and employs a tray to allow settling of particulate matter, evaporation reduction and useful solvent life can be optimized. If solvent has to be used at different location, the management should dispense the solvent to each employee in the smallest amount practical, and in a container that can be sealed or at least covered. The amount dispensed should also be consistent with the size of the job at hand, encouraging employee accountability for how the solvent was used.

Pressure washing-----Regulations proposed for implementation by 1999 by the Coastal Resources Management Council(CRMC) would require an 80% reduction of total suspended solids discharge from marina hull maintenance areas. Several commercially available treatment system for pressure washing water have been identified with different capabilities including the removal of suspended solids, metals, and oil.

Recyclable program-----Encouragement of customers to participate in a marina sponsored recycling program can be fostered through easy accessibility to segregated recycling bins.

Secondary containment storage house-----Provide a dedicated storage shed, weather proofed, with an impervious floor and sufficient containment capacity to meet the Code of Federal Regulations requirements. Drop off bins clearly labeled should be provided under a cover directly outside of the storage area to avoid customers' direct access inside of the shed .

INFORMATION TRANSFER

Title: Geophysical Methods for Hydrogeological and Contaminant Hydrology Applications

Principal Investigator:

Reinhard K. Frohlich
Department of Geology
University of Rhode Island
Kingston, RI 02881

Problem and Statement of Needs:

For the first time the information transfer effort is narrowly focused on one specific topic. The goal is to inform leaders and decision makers at the municipal, state, and federal level of government and people in the industry on the usefulness of surface geophysics. Groundwater exploration and the assessment, remediation, and control of pollution is associate with skyrocketing costs and call for reforms similar to those that have been suggested in health care. Much of the work in hydrology is accomplished with test wells and chemical analyses. Geophysical surface methods provide cost-saving potential, and may eliminate the need for some of the more expensive borings and analyses. The report contains descriptions of Geoelectrics, Seismic Refraction, Gravity, and Magnetic Methods, field work and time requirements, equipments, interpretation, and application of these methods. Also included in the report is a comparison of expenses associated with drilling only as opposed to a combination of geophysics and drilling.

The product of this information transfer effort is a booklet of 51 pages with chapters organized as (1)Geoelectrics, (2)Seismic Refraction Method, (3)Gravity, (4)Magnetic Method,(5)References, (6)Recommended Readings, (7)Drilling, Sampling and Geophysical Exploration, and Appendix of Basics of Groundwater and Hydrogeology. The booklet is published for the purpose of bring the results of research in the past in near surface geophysics to those people who would most benefit from them.

COOPERATIVE ARRANGEMENTS

The Water Resources Center at the University of Rhode Island has two advisory committees, namely the State Advisory Committee and the University Water Resources Coordinating Committee. The membership listed below reflects the recent interest and availability of many water resources experts in Rhode Island:

State Advisory Committee

Comb, Walter	RI Dept. of Health
Falcone, William	RI Water Resources Board
Delima, Virginia	US Geological Survey
Mark, Eugene	RI Audubon Society
Meyer, Henry	Kingston Fire District
Millar, Scott	Office of System Planning, RI Dept of Adm.
Rose, Vincent	Save the Bay
Solomon, Eric W.	Ambrust Chain Co.
Scott, Elizabeth	Div. of Water Supply Management, RI DEM
Stuart, Everett	US Dept. of Agriculture
Szymanski, Edward	RI Dept. of Environmental Management
Weygand, Robert A.	Lieutenant Governor

The state advisory committee consists of leading water resources officials of the state and federal agencies as well as representatives from prominent citizen groups and manufacturers.

The other committee is the University Coordinating Committee, consisting of faculty members of the University of Rhode Island from various colleges and the director of the Sea Grant program. Each member has a significant contribution to academic and research programs related to water resources area.

University Coordinating Committee

Cain, J. Allen	Professor and Head of the State Geologist Office
Frohlich, Reinhard K.	Professor of Geology
Gold, Arthur	Professor of Natural Resources Science
Miller, Robert, H.	Dean, College of Resources Development
Nixon, Scott	Professor and Coordinator of Sea Grant Program
Calvin P. C. Poon	Professor of Environmental Engineering

The two committees discussed water resources issues and research priorities for the FY-1995 State Water Research Institute Program. As a result of the discussion and suggestions from the members, the research priority list was prepared and announced to the public as appeared on page 3 of this report. Both committees also reviewed and ranked research proposals, made comments and suggestions for proposal revision. They also serve as points of contact to collect and to disseminate information to various of audience.

Project 02 worked closely with US Department of Agriculture, Soil Conservation Service, USGS, and RI Department of Health.

Project 03 worked closely with RI Department of Transportation, RI Airport Corp., RI Dept. Of Environmental Management, US Army Corps of Engineers, and GZA GeoEnvironmental Inc.

Project 04 worked closely with the US Department of Agriculture, and Soil Conservation Service.

Project 05 worked closely with Division of Environmental Coordination of the RIDEM and firms of the photo processing industry in Rhode Island and Massachusetts.

Project 06 worked closely with the RI Dept. Of Environmental Management, and Dept. of Economic Development, RI Marine Trade Association, and many boat builders as well as marina owners/managers.

PUBLICATIONS

1. Book Chapters

	Supporting Section 104 Project Number
Hull, R. J., 1996 Turfgrasses. In E. Zamski and A. A. Schaffer (Eds) Photosynthate Distribution in Plants and Crops, Source-Sink Relationships, Marcel Dekker, Inc., New York	04(FY-95)

2. Dissertations

Lyons, J., 1996 Temporal and Spatial Patterns of P-retention and Release in Riparian Forest Soils, MS Dissertation, Department of Natural Resources Science, College Of Reources Development, Univ. Of Rhode Island, Kingston, RI.	02(FY-95)
Schultz, K. Douglas, 1996 Pollution Prevention Strategies in the Rhode Island Marine Fiberglass Reinforced Plastic Industry, MS Dissertation, Department of Civil/Environmental Engineering, Univ. of Rhode Island, Kingston, RI.	06(FY-95)

3. Water Resources Research Institute Reports

Gorres, J, and J. A. Amador Completion Report, Riparian Wetland Forest Soils As Sinks and Sources of Phosphorus: Spatial Distribution Patterns and Modeling	02(FY-95)
Hull, R. Completion Report, Wellhead Protection from Nitrate Contamination through Minimum Fertilization of Turf	04(FY-95)
Poon, C. P. C., and J. A. Amador Progress Report, Landfarming Technologies for On Site Bioremediation of Hydrocarbon Contaminated Soils: Laboratory and Field-Scale Evaluation	03(FY-95)

Poon, C. P. C. Progress Report, Silver Recovery/Removal from Photo Imaging Industries	05(FY-95)

4. Conference Proceedings

Hull, R. J., and H. Liu, 1995, Nitrogen Accumulation In a Turf-soil Ecosystem as a Function of N Source And Grass Species, Agronomy Abstracts 87:158	04(FY95)
Jyons, J., J. Gorres, and J. Amador, 1995 Spatial Patterns of P-retention in Riparian Forest Soils. In Agronomy Abstracts, Am. Soc. Agronomy, Crop Science Soc. Of Am., Soil Science Soc. Of Am. St. Joseph, MI.	02(FY-95)
Poon, C. P. C., 1994, Silver Reduction and Recovery For Photo Imaging Industries, Rhode Island Pollution Prevention Conference and Exposition, Providence, RI	03(FY-95)
Poon, C. P. C. And D., Schultz, 1996 Conference on Source Reduction Recommendatioins for Pollution Prevention and Waste Stream Mitigation at Boat Building and Repair Facilities. Bristo, RI	06(FY-95)

6. Others

Hull, R. J., 1995, Minimum Maintenance Turf Management for Aquifer Protection, RI Turfgrass Field Day Field Book 64:5-13, Univ. of Rhode Island, Kingston, RI	04(FY-95)

TRAINING ACCOMPLISHMENTS

Academic Levels

Field of study	Under-graduate	Master's degree	Ph.D. Degree	Post-Ph.D.	Total
Engineering-environmental		2			2
Geology		1			1
Natural Resources Science		2			2
Plant Science			1		1
Total		5	1		6

Technical Completion Report

Wellhead Protection from Nitrate Contamination through Minimum Fertilization of Turf

by
Richard J. Hull and Zhongchun Jiang

1892

WATER RESOURCES RESEARCH INSTITUTE
THE UNIVERSITY OF RHODE ISLAND

The activities on which this report is based were financed in part by the Department of the Interior, U.S. Geological Survey, through the Rhode Island Water Resources Center. The content of this publication does not necessarily reflect the views and policies of the Department of the Interior, nor does mention of trade names or commercial products constitute their endorsement by the United States Government.

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ABSTRACT

In an effort to protect ground water resources in shallow aquifers, research was continued to investigate the potential for minimum fertilizer use in turf maintenance. Since the soils in much of southern New England overlaying shallow aquifers are highly suited for turfgrass culture, either as recreational facilities or commercial sod production, it is critical that the use of fertilizers and pesticides that might leach beneath the root zone be used at minimum rates. Based on research conducted over the past ten years, it seems reasonable that fertilizer-N rates used on turf could be reduced to 1 lb/1000 sq-ft (<50 lbs/acre). This is possible if fertilizers are used so as to supplement nitrogen released in the soil through natural mineralization of organic matter.

Three nitrogen sources were applied to experimental plots of Kentucky bluegrass sod established during the spring of 1994. Fertilizers were applied at two or three times in early spring and early and late summer such that the total amount used was 1 lb N/1000 sq-ft. A 3 lb N/1000 sq-ft and an unfertilized control were included among the seven fertility treatments. Suction lysimeters installed at a two-foot depth extended below the root zone and were used to monitor the nitrate content of soil water throughout the year. Soil water nitrate concentrations together with net water percolation rates were used to estimate nitrate leaching from turf. During the 1995 growing season, grass clippings were sampled on eleven dates and analyzed for total nitrogen. These analyses indicated that the turf generally was obtaining sufficient nitrogen to maintain good growth and quality. While the high nitrogen plots produced more clippings of higher nitrogen content in the spring, no significant differences in nitrogen content were observed during summer and fall. Turf quality was maintained at acceptable levels in all treatments except during August when high temperature and disease caused a quality decline in all plots. By early fall, all plots contained turf of good quality. Nitrate leaching reflected the fertility treatments with the high nitrogen plots leaching more than those receiving 1 lb N/1000 sq-ft. EarthGro Lawn Food (reinforced compost) leached somewhat more nitrate than Coron (methylene urea) mostly because of the sodium nitrate present in the former material. These preliminary results suggest that quality turf can be grown with nitrogen rates of 1/3 to 1/4 those normally recommended. This research is being continued through 1995-96.

Wellhead Protection from Nitrate Contamination through Minimum Fertilization of Turf

INTRODUCTION

The use of land in southern New England is of such intensity that most areas are or soon will be subjected to some level of development. Shallow aquifers, especially those representing sole-source water supplies, need special protection but the land overlying them is often highly valued for residential or commercial development. It is important to identify those land uses which constitute the least threat to these sensitive water resources. Turf culture (residential, commercial, institutional and recreational) has come under much media criticism as an environmentally risky land use wherever ground water protection is important (Jenkins 1994). This has influenced land use planning policy in spite of an ever growing body of research which shows turf to be a relatively effective ground cover for minimizing both nitrate and pesticide leaching to ground water (Cohen et al. 1990; Petrovic 1990; Kenna 1995).

If turf is an environmentally sound ground cover over high value aquifer systems, it is important that managers of turf and those responsible for protecting ground water resources understand the best cultural practices for minimizing nutrient release from turf areas. Such knowledge will maximize the protective functions of turf and permit policy makers to assure the public that effective safeguards for wellhead protection and preservation of water quality are being implemented. Most research has concentrated on quantifying the discharge of pollutants into ground water. This study helps define fertilizer management strategies for turf culture which are most protective of ground water quality.

This research was developed from the substantial base of data on nitrate recovery and discharge in turf which we have generated over the past decade. While our studies have emphasized worse case situations in order to determine the potential for nitrate leaching, we have learned much about the seasonal patterns of soil water nitrate flucuations and the annual cycle of nitrogen demand by turfgrasses. Based on such information, we are convinced that a turf fertilization program can be devised which will utilize about 25% of the nitrogen commonly applied to turf with little or no decline in turf quality.

This research is an evaluation of several approaches to achieving this marked reduction in nitrogen use and hopfully one or more strategies will emerge as successful and can be recommended to turf managers.

RESEARCH OBJECTIVES

The research reported here is from the first post-establishment year of a study which has the following three objectives.

1. To minimize nitrogen fertilizer use on turf by applying it only when soil nitrogen supplies are not adequate to maintain turf quality. Emphasis is being placed on spring and early summer applications with less use in the fall.

2. To compare fertilizer sources for their ability to deliver nitrogen in the amount and at a rate required by turfgrasses. Readily available and slow release organic nitrogen sources are being compared.

3. To determine if good quality Kentucky bluegrass turf can be maintained with annual nitrogen applications of not more than 1 lb N/1000 sq-ft (less than 50 lbs. N per acre).

METHODOLOGY

Experimental Design: The plot area utilized for this research is located on the Turfgrass Research Farm of the Rhode Island Agricultural Experiment Station at Kingston, RI. The soil type is an Enfield silt loam (Coarse loamy over sandy skeletal, mixed, mesic, Typic Dystrochrept). The site had been in turf for the past 25 years but not utilized for experimentation since 1989. In early April, 1994, the existing sod was killed by a topical application of glyphosate [*N*-(phosphonomethyl)glycine] and the dead turf removed with a sod cutter. The site was limed and prepared for sodding. Commercially grown Kentucky bluegrass (*Poa pratensis* L.) sod was installed on April 26, 1994. The sod was grown within 500 yards of the plot site using a commercial blend (Lofts Seed Inc.) consisting of 25% by weight 'Suffolk', 25% 'Sydsport', 25% 'Baron', 15% 'P-104' Kentucky bluegrasses and 10% 'Jamestown II' Chewings fescue. Past experimentation has shown Kentucky bluegrass to be least efficient in recovering nitrate from solution (Liu et al. 1993) and the most demanding of fertilizer nitrogen. If Kentucky bluegrass turf can be maintained at 1 lb N/1000 sq-ft/year, the same can be done with any cool-season turfgrass.

Seven nitrogen fertility treatments were initiated on June 20, 1994 and maintained to the present. These are summarized below:

N source	Rate lbs N/1000 ft^2/yr	Time & amount applied (lbs.)
Urea	3	June - 1.0; Nov. - 2.0
Urea	1	April - 0.5; June - 0.25; Sept. - 0.25
CORON	1	April - 0.5; Sept. - 0.5
CORON	1	April - 0.5; June - 0.25; Sept. - 0.25
Compost	1	April - 0.5; June - 0.5
Compost	1	April - 0.5; June - 0.25; Sept. - 0.25
Control	0	

The 3 lb urea-N treatment simulated conventional fertility management for a home lawn. Urea is a water soluble, readily available, and inexpensive nitrogen source commonly included in commercial turf fertilizers. CORON is a liquid methylene diurea product, 28% N by weight of which about 30% is urea and 70% is controlled release polymerized material. In our research, it has supported good quality turf, provided little leachable nitrate, and is the sort of nitrogen formulation popular with lawn maintenance companies. The compost used was Earthgro Lawn Food with an analysis of 8-2-4. It consists mostly of composted leaves and poultry manure fortified with $NaNO_3$. Its 8% nitrogen is about 50% water soluble and 50% insoluble. It is typical of commercially available 'organic' lawn fertilizers and in our research, has supported good quality turf but tends to permit some nitrate leaching. These nitrogen sources represent the spectrum of materials currently used in lawn fertilizers and were intended to provide a realistic assessment of minimum fertility turf management.

In this study, most fertilizer was applied in the spring when soil nitrate concentrations are lowest and absorption by grass roots is greatest (Hull et al. 1993). Low applications in September are intended to enable grass to recover more quickly from summer injury to the root system caused by drought, high temperatures, insect predation and human activity. An unfertilized control plot was included in each of the four replications to monitor natural seasonal changes in soil mineralization of organic nitrogen and normal fluctuations in soil water nitrate levels.

The early spring applications of 0.5 lbs. N/1000 sq-ft were made on April 13, 1995. All mid-June nitrogen applications were made on June 15, 1995 which included all treatments except the Coron early spring/late summer and the unfertilized controls. The late summer applications were made on September 1 and the late fall application of 2 lbs. urea- N/1000 sq-ft to the high nitrogen plots was made on November 24, 1995. Plots were hand irrigated with about 0.25 inches of water within one to two hours of the time fertilizer was applied. In 1996, the early spring applications were made on April 1 and the late spring treatments on June 14.

Nitrate Leaching, Nitrogen Recovery in Clippings and Turf Quality: Suction cup lysimeters were installed in each plot at a depth of two feet on June 1, 1994. Lysimeters consisted of a ceramic cup 0.88 inch OD by 2.75 inches long mounted on a 21 inch long PVC pipe 0.8 inch OD. The ceramic cups were obtained from Soilmoisture Equipment Corp., Santa Barbara, CA and rated for standard flow rate. During installation, cups were set in a slurry of silica flour to insure good contact with the soil matrix. When the lysimeters were evacuated to -0.8 bars, 10 to 50 mL of soil water were drawn into the cup over a two hour period.

During 1995, soil water samples were collected on 15 dates which encompassed the entire year. These were analyzed for nitrate-N by passing a water sample through a cadmium/copper reduction column and analyzing the resulting nitrite spectrophotometrically (Keeney and Nelson 1982). The results were used to estimate nitrate leaching by multiplying the soil water nitrate concentration by leachate volumes calculated for each precipitation event identified from soil and meteorological data using the hydrologic component of the CREAMS model (Smith and Williams 1980). Soil water sampling and analysis are continuing throughout 1996.

Clippings were harvested on 11 dates during the 1995 growing season from a 10.3 sq-ft area of each plot. Clippings were oven dried, ground to pass a 30-mesh screen and analyzed for total Kjeldahl nitrogen according to Easton (1978). Nitrogen recovered in clippings is a nondestructive means of estimating nitrogen absorption by roots and transport to shoots and for monitoring the nutritional status of turf. Clippings are being harvested at biweekly intervals throughout the 1996 season.

All plots were scored for visual quality on eight dates during the 1995 growing season. Quality scores constituted a subjective integration of turf color, texture, uniformity and freedom from weeds, disease and other injury. Perfect turf was assigned a score of 9 while dead turf would be scored at 1. A score of 6 or higher indicates acceptable turf quality. Plots are being scored throughout the 1996 growing season.

RESULTS AND DISCUSSION

This project is continuing through the 1996-97 year with funding from the RIWRRC under a different title. Consequently what is presented here can only be viewed as a progress report for the year 1995. The results from the year of establishment (1994) were reported in an earlier completion report (Hull 1995). This research realistically will require three to four years to test adequately the minimum fertilizer hypothesis on which this project is based.

Turf quality:

Turf quality scores were taken on eight dates in 1995 (Table 1.). While the late spring presented near normal temperatures and slightly below normal rain fall the summer was warmer than normal and dry (3.5 inches below normal). This resulted in a sharp decline in turf quality during August. However, the return to more normal conditions in September along with a nitrogen application to three plots, resulted in a marked increase in quality.

Table 1. Quality scores of Kentucky bluegrass turf fertilized with three nitrogen sources at three rates.

Nitrogen source	Yearly rate	Months applied	Quality scores*					
			May	June	July	Aug.	Sept.	Average
	lb/1000 sq-ft	mo.						
Urea	3	6 & 11	8.0	7.8	8.2	4.5	7.8	7.3
Urea	1	4, 6 & 9	8.0	7.0	7.2	5.1	8.0	7.1
Coron	1	4 & 9	7.6	6.2	6.1	5.4	7.5	6.6
Coron	1	4, 6 & 9	7.2	6.5	6.2	4.6	7.2	6.3
Compost	1	4 & 6	7.1	6.5	5.8	4.2	7.2	6.2
Compost	1	4, 6 & 9	7.6	7.0	7.6	5.1	7.8	7.0
Control	0	-	6.9	6.0	5.6	5.2	7.5	6.2

* Quality scores: 9=perfect turf, 1=dead turf; based on 8 scorings averaged by month.

Differences among fertilizer materials and times of application were generally significant but not consistent throughout the season. Urea generally produced the highest quality turf but the one-pound rate was often equal to or better than the three-pound rate. Earthgro Lawn Food (compost) treated turf benefited from the early September application made in 1994 and that advantage persisted throughout the season. Coron treated plots exhibited a similar pattern with the 0.5 lb application in September producing a slight advantage over the 0.25 lb treatment. By mid- to late-fall, all plots exhibited good quality turf (data not shown) indicating that soil water nitrogen was more than adequate to meet grass needs. The unfertilized plots showed the capacity for mineralized soil organic nitrogen to meet their nutritional needs. Only in the spring did these plots rank poorest. Later in the season, unfertilized plots were of higher quality than some receiving nitrogen fertilizer.

These results are from the first full post-establishment season and must be regarded as preliminary.

Soil water nitrate and nitrate leaching:

Soil water samples were collected on 15 dates in 1995 and the nitrate-nitrogen concentrations are summarized in Table 2. Because of warmer than normal conditions throughout the summer, soil mineralization of organic nitrogen probably contributed to elevated soil water nitrate levels. Even the unfertilized plots contained soil

Table 2 Soil water nitrate-N concentrations from Kentucky bluegrass turf plots fertilized with three N sources on three dates.

Nitrogen source	Rate	Nitrate-nitrogen**								
		Feb.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.
	lbs/1000 sq-ft	mg NO_3-N L^{-1}								
Urea-L*	3	3.8	0.5	0.5	1.3	16.4	11.8	6.2	6.2	6.9
Urea-E	1	0.2	-	0.8	0.8	0.8	2.7	1.9	2.4	4.8
Coron-L	1	0.1	0.4	0.9	1.1	0.1	4.2	3.2	2.4	3.0
Coron-E	1	0.3	0.4	0.6	0.9	0.6	2.0	1.1	1.5	1.1
Compost-L	1	0.7	0.4	0.7	1.4	2.7	2.6	1.8	3.8	7.0
Compost-E	1	0.3	0.4	0.8	0.6	1.0	6.9	3.3	3.1	2.7
Control	0	0.6	0.5	0.9	0.5	0.6	1.9	1.0	1.4	1.2

* L = Some fall application; E = Mostly spring applied nitrogen.

** Bases on 15 sampling dates averaged by month.

water nitrate-nitrogen in excess of 1.0 mg NO_3-N/L (ppm) during late summer and fall. During the spring, nitrate-nitrogen levels were consistently less than 1.5 ppm. The higher urea-nitrogen treatment was evident by its elevated soil water nitrate levels. The 1.0 lb N/1000 sq-ft application in mid-June resulted in a nitrate-nitrogen concentration in soil water of 16 ppm during July.

All 1.0 lb N/1000 sq-ft application rates failed to produce soil water nitrate-nitrogen levels in excess of 10 ppm NO_3-N set by the US Public Health Service as the maximim allowed in drinking water. Because of low rainfall during the summer months, nitrate leaching to the 2-ft. depth of the suction lysimeters may have been delayed or not detected even if nitrate levels in the surface soil horizons were relatively high. This may explain why the Earthgro compost plots which received 0.5 lb. N in mid-June did not exhibit elevated soil water nitrate until August. The relatively high nitrate concentrations in soil water of Earthgro Compost treated plots probably is a result of the readily soluble sodium nitrate added to increase the analysis of that product. Even so, the nitrate-N level from those plots rarely exceeded 5.0 ppm.

Nitrate Leaching:

Nitrate leaching was estimated based on soil water nitrate concentrations and net percolation estimated from the CREAMS model (Table 3). Almost half of the annual precipitation and

Table 3 Estimated seasonal nitrate-N leached from Kentucky bluegrass turf plots fertilized with three N sources on two dates.

Nitrogen source	Rate	Nitrate-N leached 1-3	4-6	7-9	10-12	Total	% of applied
	lbs N/1000 sq-ft	mg NO_3-N m^{-2}					
Urea-L*	3	659	34	1768	1856	4317	28.8
Urea-E	1	40	26	296	1116	1478	29.6
Coron-L	1	21	32	419	770	1242	24.8
Coron-E	1	40	26	205	344	615	12.3
Compost-L	1	45	34	368	1657	2104	42.1
Compost-E	1	114	23	659	786	1582	31.6
Control	0	110	23	198	357	688	-
Percolation inches		6.8	1.6	5.9	10.9	25.2	49.0

* L = Some fall application; E = Mostly spring applied nitrogen.

irrigation was estimated to have percolated through the soil during 1995. This carried with it nitrate-nitrogen ranging from 4.3 g/m^2 for the high rate of urea to 0.6 g/m^2 for the Coron treatment in which most was applied in the spring. This represented quantities equivalent to 29% and 12% of the nitrogen applied, respectively.

Because nitrate concentrations in the soil water were so low in the spring, relatively little nitrate leached during that season. Also, precipitation was low resulting in only 1.6 inches of percolation. The greatest percolation occurred in the fall when soil water nitrate levels were highest. This resulted in nitrate leaching in excess of 1.5 g N/m^2 from the Earthgro Lawn Food when half had been applied in early September. The least leachable nitrogen source was Coron which lost less than 25% of that applied.

The leaching levels observed in this study were greater than those noted in other experiments conducted as part of this investigation (Hull et al. 1993). In part, this was due to the low nitrogen rates applied. When expressed as a percent of that applied, even low leaching levels may appear large. In this study, those plots receiving 3-lbs of urea-N leached nitrate equivalent to 29% of the nitrogen applied but that represented only 37 lbs nitrogen per acre. The EarthGro Lawn Food treatment that received 1 lb N/1000 sq-ft and leached the equivalent of 42% of that nitrogen, actually lost only 18 lbs. nitrogen per acre.

Also, the high temperatures and dry conditions which characterized the 1995 growing season, probably contributed to rapid and extensive root decline while encouraging mineralization of soil organic nitrogen. This lack of roots reduced nitrate uptake by the turf leaving soil nitrogen vulnerable to leaching. Because these plots were sodded in 1994, root growth may not have been as extensive or deep as it would in seeded turf (Geron et al. 1993). The 1996 season having more normal precipitation and cooler than normal temperatures should promote greater root retention and activity with less nitrate leaching. This appears to be occurring.

CONCLUSIONS

During this first post-establishment year, treatment effects were evident and the turf began responding more like an established sod. This permits us to make the following tentative conclusions.

1. Nitrogen applied at 1 lb/1000 sq-ft can support good quality turf if one-half or three-fourths of it is applied during spring and early summer with the remainder applied in late summer.

2. A late fall application of nitrogen will provide earlier green-up in the spring but otherwise offers no advantage and can promote nitrate leaching.

3. Controlled release nitrogen sources support good turf quality and offer less potential for nitrate leaching.

4. Nitrate leaching occurs mostly during late summer and fall when living turf roots are least abundant. A total suppression of leaching will require managing turf so as to maintain active roots and maximize their growth.

5. Unfertilized turf leached about 6 lbs of nitrate-nitrogen per acre during 1995. This is equivalent to 0.14 lbs N/1000 sq-ft. One fertilizer treatment in this study leached less nitrate than the unfertilized turf.

ACKNOWLEDGMENTS

In addition to the support provided by the Rhode Island Water Resources Research Center, which is gratefully acknowledged, funding was also provided by Earthgro Inc., Coron Corp, and the Rhode Island Agricultural Experiment Station. Fertilizer materials were contributed by Coron Corp. and Earthgro Inc. The technical assistance of three undergraduate students, Paul Santer, Antoinette Snyman and Philip Thibaudeau for sample collection and analysis during the summer of 1995 is also gratefully appreciated. We thank Carl Sawyer for providing soil percolation data based on the CREAMS model. Greg Fales and his staff at the Turf Research Station is acknowledged for their efforts in maintaining the turf plot area.

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FISCAL YEAR 1996 PROGRAM REPORT
Grant No. 1434-HQ-96-GR02696

for

U.S. Department of the Interior
Geological Survey

WATER RESOURCES RESEARCH INSTITUTE
THE UNIVERSITY OF RHODE ISLAND

FISCAL YEAR 1996 PROGRAM REPORT
Grant No. 1434-HQ-96-GR02696

for

U.S. Department of the Interior
Geological Survey

by

Water Resources Center
University of Rhode Island
Kingston, RI 02881

Calvin P. C. Poon, Director

April, 1997

The activities on which this report is based were financed in part by the Department of the Interior, U.S. Geological Survey, through the Rhode Island Water Resources Center. The content of this publication do not necessarily reflect the views and policies of the Department of the Interior, nor does mention of trade names or commercial products constitute their endorsement by the United States Government.

ABSTRACT

The objective of the Rhode Island Water Resources Institute Program for the recent years has been (1)to identify critical policy and managment issues of water resources in the State and in the New England region, (2)to conduct research in order to generate information useful to address the issues and to solve the problems, (3) to transfer the information to potential users throughout the State and New England region, (4)to educate the public about water quality protection, and (5)to train students in water resources research. Since the beginning of the Base Grant for the Water Resources Research Institutes, the objective for the grant has been more narrowly focused due to budget constraints. The new objectoves are to identify important issues and carry out the research leading to information useful to address these issues and to solve the problesm. Training of students to do research in water resources is still an integral part of the program objective.

Turf management is becoming more important in Rhode Island and New England states because turfgrasses are used extensively in new land development projects. Minimizing the use of nitrogen in turf growth can reduce the nitrate contamination of groundwater. Urea applied at 3 lbs/1000 sq-ft often supports the best quality turf during spring and early summer but not later in the season. Higher nitrate levels though not exceeding 10 ppm are found in the leachate. Throughout most of the growing season, 1 lb N/1000 sq-ft rate of application supports turf of acceptable quality independent of the nitrogen source. Coron applications generally leach the least amount of nitrate, sometimes less than the unfertilized plots. At the 1 lb. N rate, no difference in nitrate leaching can be observed among the three different N sources, urea, Coron, and compost.

Wetland riparian forest area accumulates the sediment-bound P from upland runoff. Within a riparian forest area, PD soil has the highest P retention capacity, followed by MWD soil, with SPD soil as a potential source of P depending on the time of the year. It appears that the relationship between Fe in the oxidized form and Al in the oxidized form, organic matter content, and EPC_0 can be used to predict the P retention capacity of the soil. The numbers of samples required to estimate the mean EPC_0 at the 95% condifence level for different soils at different seasons have been determined.

Improved technologies for cost effective silver recovery/removal from photo imaging wastewaters are needed because of resources conservation and the lowering of the silver concentration in effluent pretreatment standards. It is found that electrolytic silver recovery can be applied to both black-and-white and color processing solutions. After electrolytic recovery (a primary silver recovery technology), ion exchange columns are useful to capture the majority of the silver from the effluent. Either fix-elution or acid in-situ precipitation method can be used to recover the silver from ion exchange resins. For very low silver concentration in the effluent,e.g., less than 0.1 mg/l, a tailing method such as carbon adsorption or manganese dioxide adsorption can be used. Two new technologies are being developed, namely Electrolytic-Activated Carbon and Electrolytic-

Ion Exchange processes, which can be used after a primary silver recovery system or for diluted photo processing solutions. A guidance to the selection of different silver recovery technologies for various specific applications is being developed for the photo processing industry.

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RESEARCH PROJECT SYNOPSES

WATER PROBLEMS AND ISSUES OF RHODE ISLAND

Many shallow aquifers including those for sole-source water supplies in Rhode Island and throughout southern New England are threatened by nutrient pollution due to the intensive activities of land development projects. Many of the residential and commercial developments have turf as ground cover. The management of turf needs the understanding of best agricultural practice for minimizing nutrient release from the turf areas. Many development projects have come under criticism as environmentally risk land use whenever groundwater protection is important. A minimum nitrogen use strategy in turf management is needed to maximize the protective functions of turf and to permit policy makers as well as planners to ensure safeguards for groundwater protection.

In addition to nitrogen, phosphorus is another nutrient that threatens the groundwater and surface water quality. Increased P loading, leading to eutrophicatiion of freshwater bodies, is of concern in Rhode Island. Using the mean total P trophic status index value, almost one quarter of 62 lakes in Rhode Island is ranked as eutrophic. Riparian wetland areas, because of their fatter slope and slower runoff, tend to accumulate sediment-bound P that originates from upland areas. Quantitative data on the P mitigation capacity of wetlands is important in Rhode Island since wetlands constitute 20% of the land-use within a 100-meter buffer strip around freshwater bodies, with adjacent upland riparian forests making up another 40%. There is a great need to assess the effects of soil texture on the capacity of riparian forest soils to serve as source or sink of P and to quantify P removal/release capacity of riparian forest soils associated with different land uses.

Silver bearing wastewater is discharged from industries in Rhode Island. In particular, the photo processing industry is a major contributor of silver in industrial discharge. Many state sewer authorities adopt the 5.0 mg/l as the silver discharge limit designated by USEPA. However both Providence and Cranston have pretreatment standards for silver lower than 0.5 mg/l as maximum daily value and even lower for a 10-day average basis. There is a proposal to lower the standards to a uniform concentration of 0.029 mg/l to protect the Narragansett Bay water quality. Even the Best Demonstrated Applied Technology (BDAT) with a 99% silver recovery cannot produce an effluent with 0.029 mg/l of silver. There is a need to study the ion exchange, carbon adsorption, and other technologies for more efficient silver recovery and at the same time reducing the silver to the proposed level of 0.029 mg/l.

PROGRAM GOALS AND PRIORITIES

The Institute Base Grant provides $20,000 federal fund and $64,991 University of Rhode Island matching fund for the FY-1996 program. A small portion of the grant is to support the administration of the Water Resources Center with the remaining portion supporting research works relevant to the State needs. The State Advisory Committee and the University Water Resources Coordinating Committee set the following research priority areas:

Water Rights and Water Allocation
Water Conservation Practices
Evaluation of the Significance of Low Stream Flow
Reduction of Non-Point Sources of Pollution to Surface Water and Groundwater
Technology Transfer

Due to the very limited amount of budget, our effort was mainly to support research works to satisfy state needs, to support training of students, and to support the process of the regional competition portion of the Section 104 Grant.

Table 1. Sources and Levels of Funding, FY-1996

Project	Funding Level	Sources of Funding Ending Jan. 31, 1997
02 Preventing Nitrate Contamination of Groundwater under Turf through Minimum Nitrogen Use -----Hull	$ 7,500 25,416	USGS Univ. of Rhode Island
03 Riparian Wetland Forest Soils as Sinks and Sources of Phosphorus --- Amador	7,500 25,473	USGS Univ. of Rhode Island
04 Silver Recovery/Removal from Photo Imaging Industries --- Poon	40,000 7,938 5,433	RI Dept. Environ. Manag. Univ. of Rhode Island Narraganset Bay Comm.
01 Center Administration	5,000 14,102	USGS Univ. of Rhode Island
FY-1996 Total Funding	20,000 72,929 5,433 40,000	USGS Univ. of Rhode Island Narraganset Bay Comm. RI Dept. Environ. Manag.

SYNOPSIS

Project Number: 02

Start: 2-1-96
End: 1-31-97

Title: Preventing Nitrate Contamination of Ground Water under Turf through Minimum Nitrogen Use.

Investigator:
Richard J. Hull
Plant Sciences Department
University of Rhode Island
Kingston, RI 02881

Focus categories: GW; NC; NPP; NU; WQL

Congressional District: 2nd RI

Descriptors: Ground water pollution; Nitrates; Land application; Organic Wastes; Aquifer; Fertilizers; Turfgrasses

Problem and research objectives:

Land development in southern New England is of such intensity that most areas are or soon will be subjected to some level of use. Shallow aquifers, especially those representing sole-source water supplies, need special protection but the land overlying them is often highly valued for residential or commercial development. It is important to identify those land uses which constitute the least threat to these sensitive water resources. Turf culture (residential, commercial, institutional and recreational) has come under much media criticism as an environmentally risky land use wherever ground water protection is important. This has influenced land use planning policy not withstanding an ever growing body of research which shows turf to be a relatively effective ground cover for minimizing both nitrate and pesticide leaching to ground water.

While turf may constitute an environmentally sound ground cover over high value aquifer systems, it is important that managers of turf and those responsible for protecting ground water resources understand the best cultural practices for minimizing nutrient release from the turf-soil ecosystem. Such knowledge will maximize the protective functions of turf and permit policy makers to assure the public that effective safeguards for ground water protection are being implemented. Most research has concentrated on quantifying the discharge of pollutants into ground water. This study will define fertilizer management strategies for turf culture which are most protective of ground water quality.

Research supported by the RIWRRC over the past eight years has generated a substantial data base of monthly nitrate concentrations in soil water under intensively managed lawn turf. This information, along with annual nitrogen budgets generated for turf-soil ecosystems in Rhode Island and elsewhere, provide the basis for modifying turf fertility management so as to minimize nitrogen use. The objectives of this research are:

1. To minimize nitrogen fertilizer use on turf by applying it only when soil nitrogen supplies are not adequate to maintain turf quality. Emphasis is placed on spring and early summer applications with less use in the fall.
2. To compare fertilizer sources for their ability to deliver nitrogen in the amount and over the time required by turfgrasses. Readily available and slow release organic nitrogen sources are being compared.
3. To determine if good quality Kentucky bluegrass turf can be maintained with annual nitrogen applications of not more than 1 lb N/1000 sq-ft (less than 50 lbs. N per acre).

Methodology:

Experimental design, plot area and treatments: The plot area utilized for this research is located on the Turfgrass Research Farm of the Rhode Island Agricultural Experiment Station at Kingston, RI. The soil type is an Enfield silt loam (Coarse loamy over sandy skeletal, mixed, mesic, Typic Dystrochrept). The site had been in turf for the past 25 years but not utilized for experimentation since 1989. In early April, 1994, existing sod was killed by a topical application of glyphosate [*N*-(phosphonomethyl)glycine] and the dead turf removed with a sod cutter. The site was limed and prepared for sodding. Commercially grown Kentucky bluegrass (*Poa pratensis* L.) sod was installed on April 26, 1994.

Seven nitrogen fertility treatments were initiated on June 20, 1994 and maintained to the present. These consisted of three nitrogen sources applied at 1 lb N/1000 sq-ft/year and appropriate control treatments: see table below. The 3 lb urea-N control treatment simulated conventional fertility management for a home lawn. CORON is a liquid methylene diurea product, 28% N by weight of which about 30% is urea and 70% is a controlled release polymerized material. The compost used was Earthgro Lawn Food with an analysis of 8-2-4. It consists mostly of composted leaves and poultry manure fortified with $NaNO_3$. Its 8% nitrogen is about 50% water soluble and 50% insoluble. These nitrogen sources represent the spectrum of materials currently used in lawn fertilizers and were intended to provide a realistic assessment of minimum fertility turf management. In this study, most fertilizer was applied in the spring when soil nitrate concentrations are lowest and absorption by grass roots is greatest. Low applications in September are intended to enable grass to recover more quickly from summer injury to the root system caused by drought, high temperatures, insect predation and human activity. An unfertilized control plot was included in each of the four replications to monitor natural seasonal changes in soil mineralization of organic nitrogen and normal fluctuations in soil water nitrate levels. Fertilizers were applied on 1 April, 14 June, 30 September and 21 November 1996.

N source	Rate	Time & amount applied (lbs.)
	lbs N/1000 ft^2/yr	
Urea	3	June - 1.0; Nov. - 2.0
Urea	1	April - 0.5; June - 0.25; Sept. - 0.25
CORON	1	April - 0.5; Sept. - 0.5
CORON	1	April - 0.5; June - 0.25; Sept. - 0.25
Compost	1	April - 0.5; June - 0.5
Compost	1	April - 0.5; June - 0.25; Sept. - 0.25
Control	0	

Data collected during 1996 included the following five measurements. Soil water samples were collected twice each month throughout the year and analyzed for nitrate content. Nitrate leaching was estimated based on the nitrate concentration of suction lysimeter derived soil water samples and the hydraulic flux through the soil estimated from climatological data using the CREAMS model. Nitrogen recovery in clippings was obtained from clipping harvests taken at least once each month from May through November. Turf quality scores for each plot were taken monthly throughout the growing season. On 9 July, core samples were taken from each plot to a six-inch depth. These were separated into shoots, roots, thatch and soil and each subsample analyzed for total nitrogen. These were used to estimate the total nitrogen partitioning within the turf-soil ecosystem.

Principal findings and significance:

This project is a continuing effort initiated in 1994 and the following summarizes the findings obtained since the 1996 synopsis. Turf of acceptable quality was present throughout most of 1996 due in part to the wetter and cooler than average conditions. Urea applied at 3 lbs/1000 sq-ft often supported the best quality turf during spring and early summer but not later in the season. Urea applied at the higher rate during late fall provided earlier spring recovery which persisted to early May. Throughout most of the growing season, the 1 lb. N/1000 sq-ft rate supported turf of acceptable quality independent of the nitrogen source. Soil water nitrate levels rarely exceeded 5 ppm nitrate-N in plots receiving the 1 lb. N/1000 sq-ft rate. The 3 lb. rate of urea-N produced higher nitrate levels in soil water but they never exceeded 10 ppm NO_3-N throughout 1996. Lowest soil nitrate levels occurred during the spring. The 3 lb. N plots lost the equivalent of 25% of applied nitrogen to nitrate leaching during 1995. Coron generally leached the least nitrate sometimes less than the unfertilized plots. At the 1 lb. N rate, no differences in nitrate leaching were observed among the three nitrogen sources. Nitrate leaching, nitrogen recovery in clippings and nitrogen partitioning for 1996 have not yet been completely analyzed.

Although these results are preliminary, it appears that good quality turf can be maintained with 1 lb. N/1000 sq-ft, if that nitrogen is applied when the soil cannot meet the grass needs. Some late summer decline in turf quality occurred independent of fertility level due to high temperature stimulated dollar spot and brown patch diseases. Quality recovered quickly when cooler weather returned in September. The summer-fall increase in soil water nitrate, noted in most earlier studies, was less evident in this study during 1995 and 1996 except in those plots receiving the higher rate of urea. It appears that nitrogen applied at 1 lb./1000 sq-ft offers little potential for nitrate leaching regardless of the nitrogen source. Increases in available nitrogen from mineralization of soil organic matter as the season progressed was evident in the unfertilized plots. So far, this study supports the theory that fertilizer nitrogen applied so as to supplement that mineralized from soil organic matter can be utilized with greater efficiency and maintain turf of acceptable quality. We will attempt to continue this study for two more years.

Utilization of Results:

Since this research has involved only two post-establishment years, recommendations for industry or commercial practice is premature. However, the stage has been set for the concept being tested in this research to be applied to commercial turf management. Articles published in regional and national newsletters have alerted turf managers to the prospect of greatly reduced nitrogen use in turfgrass culture (see publication list). As our results more firmly support the concept of minimum nitrogen fertilization it will be promoted among the commercial sector along with the theoretical bases on which it is predicated. The channels have been developed to expedite this information transfer.

Additional Funding:

While the RIWRRC is the primary source of funding for this research, other funding sources have been sought with modest success:

1. Earthgro Corp. - $3,000 requested for 1996 along with fertilizer materials to support nitrogen efficiency research. Only $500 was received along with a supply of their Lawn Food formulation.

2. RI Agricultural Experiment Station - $1,500 in operating funds for research on nitrogen use efficiency in turf management. In addition, the RIAES supports the field staff that maintains the plot area including herbicide application in the spring, irrigation when requested and regular mowing during the growing season.

3. A student assistance for the 1996 season was funded by the URI Turfgrass Research Fund of the URI Foundation.

4. Research grants to support other aspects of nitrogen use efficiency by turf have been submitted to the U.S. Department of Agriculture - Competitive Grants Program, the New England Golf Course Superintendents Association and the Regional Water Resources Research Program. All were not funded. Future funding of this and related research has been sought from the Regional Water Resources Research Program for 1997-98 and the Department of Energy. These are pending. A second proposal submitted to the New England Golf Course Superintendents Association was also denied.

SYNOPSIS

Project Number: 03

Start: February 1, 1996
End: January 31, 1997

Title: Phosphorus Removal and Release in Riparian Forest Soils: Effects of Land Use

Investigators: José A. Amador and Josef H. Gorres, University of Rhode Island

Focus Categories: NPP WQL NU

Congressional District: 2

Descriptors: Spatial variability Temporal variability Phosphorus removal Riparian areas

Problem and research objectives:

Riparian forest soils were investigated for their capacity to retain and/or release PO_4^{3-}-P using P-adsorption isotherms. Riparian zones have been found to remove P from surface runoff, thus can potentially act as filters of non-point source P pollution for surface waters. Soil properties important to P retention may vary along a soil drainage catena, as well as with a particular drainage class.

Methodology:

Spatially-referenced samples (300 on each date) were taken from a soil drainage catena in May and November to examine the spatial and temporal variability of P retention/release. Three drainage classes were examined, including moderately well, somewhat poorly, and poorly drained. The P retention/release capacity of the soil was related to soil properties measured at the same points, including soil organic matter, mass water content, pH, bulk density, and oxalate-extractable Fe and Al content. Isotherms were prepared by allowing 0.5 g air-dried soil and 15 ml of 0, 1, 3, 5, or 7 mg P/L solution to equilibrate for 24 h. The equilibrium phosphorus concentration at zero sorption (EPC_0) was determined from the isotherm for each sampling point. The lower the EPC_0, the higher P retention capacity.

Principal findings and significance:

Moderately well drained soil (MWD) had significantly different mean (CV) EPC_0 values of 1.0 (1.34) and 1.5 (1.03) mg P/L in May and November, respectively. Somewhat poorly drained soil (SPD) had the lowest retention capacity, with a mean EPC_0 value of 3.8 (0.49) mg P/L in May and no P sorption was apparent in November. Poorly drained (PD) soil had the highest P retention capacity for both sampling dates, with significantly different mean EPC_0 values of 0.5 (1.87) and 1.3 (1.13) mg P/L, respectively.

Mass water content, pH, and bulk density did not exhibit an apparent relationship with EPC_0 and therefore were not useful indicators of P retention capacity.

Phosphorus retention appeared to be controlled by organic matter content and adsorption to Fe- and Al-oxides. EPC_0 was positively correlated to soil organic matter for all three drainage classes on both dates. Low mean EPC_0 values -- high P retention capacity-- in MWD and PD soil corresponded with higher Fe_{ox} and Al_{ox} values. For SPD soil, a high mean EPC_0 corresponded with lower Fe_{ox} and Al_{ox} values. The relationship between EPC_0 and Fe_{ox} and Al_{ox} was described by a hyperbolic function for MWD and PD soil, but not for SPD soil.

The spatial structure and co-occurrence of the capacity of the soil to release and retain P and soil properties were analyzed using semivariograms and block kriging. EPC_0 did not exhibit spatial structure at the sampling scale used for any of the drainage classes. Spatial maps indicated co-occurrence of high EPC_0 values with low Fe_{ox} and Al_{ox} and high values of organic matter. The spatial structure of Fe_{ox} was similar for all three drainage classes with range values of 2.97, 3.45, and 4.33 m for PD, MWD, and SPD soil, respectively. The spatial structure of Al_{ox} varied among drainage classes with the highest range (8.78 m) for SPD soil, followed by PD (3.55 m), and MWD soil (0.54 m). The spatial structure of organic matter content varied among drainage classes with range values decreasing in the order MWD (8.65 m), SPD (2.99 m), and PD (0.51 m) soil.

The results of our study indicate that within a riparian forest area, PD soil has the highest P retention capacity, followed by MWD soil, with SPD soil as a potential source of P depending on the time of year. It appears that the relationship between Fe_{ox} and Al_{ox}, organic matter content and EPC_0 can be used to predict the P retention capacity of this soil. The similarity in means determined by classical statistics and kriging for EPC_0, organic matter content, Fe_{ox}, and Al_{ox} suggests that spatial structure does not need to be considered if a large number of samples is obtained. Eighty, 61, and 74 samples were required to estimate the mean EPC_0 at the 95% confidence level for MWD, SPD, and PD, respectively in May. For November, 66 and 82 samples were required for MWD and PD, respectively.

This information can help identify areas within riparian forest zones with the greatest removal and allow for more efficient use of these landscape features for water quality improvement. It can also be incorporated into P loading models, thus improving their accuracy.

1. The results of our study may be of use to the Rhode Island Department of Environmental Management.

2. We intend to submitt a proposal to the regional USGS/Water Resources Grant Program this year based on the data gathered in this study.

SYNOPSIS

Project Number: 04

Starting: 2-1-96
Ending: 1-31-97

Title: Silver Recovery/Removal from Photo Imaging Industries

Investigators: Calvin P. C. Poon and Rui-guang Guo
University of Rhode Island
Kingston, RI 02881

Focus Categories: TRT

Congressional District: 2nd district

Descriptors: Silver, adsorption, ion exchange, activated carbon, electrolytic, electrodeposition, industrial wastes

Problems and Research Objectives:

Silver bearing wastewater are generated from photo processing, X-ray processing, metal plating, and printing industries in Rhode Island and elsewhere in United States. The USEPA has designated 5 mg/l of silver as hazardous. However by taking into consideration of the silver toxicity in sewage treatment plant, silver content in sludge, silver toxicity in receiving waters, many sewer authorities have set silver pretreatment standards much lower than 5 mg/l. Currently the Narragansett Bay Commission has set pretreatment standards for silver at 0.43 mg/l maximum daily and 0.24 mg/l on 10-day average. There is a proposal to lower the standards to a uniform concentration limit of 0.29 mg/l.

The major form of silver in the photo and X-ray processing wastewater is silver thiosulfate complexes. Most industries use metal exchange or electrolytic recovery to recover silver. Electrolytic recovery technology can remove silver down to less than 100 mg/l and the latest metal exchange technology can remove silver down to 1.0 mg/l. Ion exchange technology is generally used to lower the silver concentration down to the pretreatment standards. However the ion exchange technology is expensive because of the its limited exchange capacity for silver. Methods to increase the silver exchange capacity or using ion exchange technology in combination with other technologies for a more cost effective means of silver recovery is needed.

Methodology:

This is the second year of a 2-year project. In the first year, most work was conducted in the investigation of silver adsorption by activated carbon and by manganese dioxides as a tailing method of silver removal. Adsorption isotherms were conducted. Different ion exchange resins were investigated. IRA-68, a weak base anionic exchanger was found to be the most cost effective. A fix-elution procedure using ammonium thiosulfate as the eluent at 30% concentration was able to elute up to 89% of the silver absorbed on the resins. Acid precipitation (in situ precipitation) using 4% sulfuric acid was found able to fix the silver on the resins and reactivate the resin for more silver absorption. In the laboratory condition using batch process, it was demonstrated the in situ precipitation could increase the silver exchange capacity of IRA-68 from 0.034 to as much as 1.44 grams of silver per gram of resin.

In this second year of study, electrolytic silver recovery was conducted with both a laboratory built electrolytic cell and a commercially available electrolytic cell. It was found cost effective to recover silver with high quality on the cathode of the electrolytic cell. The technology can be applied to spent photo processing solutions from both black-and-white or color fix or bleach-fix. It will be cost effective if the technology is used as a primary silver recovery method. The effluent, with a silver concentration of about 200 mg/l should be diluted with washwater (to reduce the thiosulfate concentration) and applied to a tailing method of silver removal such as ion exchange or carbon adsorption so that a very low silver concentration at 0.1 mg/l or lower can be obtained.

A new technology was investigated in this study by combining electrodeposition and activated carbon in one single reactor, called E-AC process. A E-AC reactor consists of a rectangular tank filled with 1.1 kg of 6x12 mesh granulated activated carbon with stainless steel plates imbedded in the carbon particles. The plates served as anodes and cathodes. The reactor held approximately 1.8 liters of solution. The unit was operated as a flow through reactor with porous cathodes composed of carbon particles. It is considered equivalent to a reactor with graphite-felt cathode. Because of its large cathode surface area per unit volume, high void ratio, and a good conductivity, this E-AC reactor with a 3-dimensional cathode is a high performance silver recovery unit compared to a conventional two-dimensional cathode reactor. The study showed that a diluted silver bearing solution or an effluent from a primary silver recover unit diluted with washwater could be applied to the E-AC reactor with very good result. With the initial silver concentration at or lower than 45 mg/l and with a hydraulic retention time of 1.2-hour, an effluent with 0.15 to 0.05 mg/l of silver was obtained.

The E-AC process works much faster than the conventional activate carbon adsorption. However the effluent quality appears to be affected by the pH of the solution. To obtain a low silver concentration at 0.05 mg/l, the pH has to be at 8.0 or above. More work needs to be done with more testing at different flow rates and different current density. The reactor design with different geometry and different arrangement of electrodes in relation to the carbon particles needs further investigation.

Another part of the study was to develop a technology combining the electrodeposition and ion exchange technologies. In a reactor containing a weak base anionic resin, the resin can be activated by the proton generated by an anode imbedded in the resin. The activated resins can then absorb the silver thiosulfate complexes. A continuous supply of proton will fix or decompose the silver thiosulfate complexes into silver sulfide precipitates. This will release the site where the continuous supply of proton activates them again for more silver absorption. The pH of the solution has to be kept at pH 7 or below because the hydroxides generated from the cathode will be oxidized to O_2 and produce more electron which converts the silver thiosulfate to elemental silver and thiosulfate ions.

The result of this technology called electrolytic-ion exchange or E-IX process shows that it is much more efficient than the conventional ion exchange process. However the technology was only tested with high to medium silver concentration solution at 736 mg/l and 340 mg/l. The tests with the 340 mg/l initial silver concentration produced an effluent of less than 1 mg/l. More tests need to be done to investigate if much lower silver concentration can be obtained when a diluted spent photo processing solution is used.

The study shows that all facilities should segregate their process wastewaters. All spent black-and-white processing solution (fixer) can use an electrolytic cell for silver recovery, with the solution internally recycled to the fixing tank. For spent color fix or bleach-fix solutions, electrolytic silver recovery also should be carried out. However internal recycle of the process solution is difficult because of the decomposition of Fe-EDTA and other chemicals. After the primary silver recovery using electrolytic cells, ion exchange columns and or metallic replacement can reduce the silver to less than 1 mg/l in the effluent. Silver from the ion exchange columns or metallic replacement canisters can be recovered by refining. Other options include fix-elution using strong ammonium thiosulfate to elute silver from ion exchange columns followed by electrolytic recovery of silver, or acid in-situ precipitation of silver in the ion exchange columns to increase the exchange capacity. Eventually the resins have to be shipped out for refining.

The exploratory study of the two new processes, namely E-AC and E-IX, show great potential of these technology to replace the conventional ion exchange technology as a tailing method for silver recovery/removal. In order to obtain the very low silver concentration in the effluent meeting the newly proposed pretreatment standards at 0.029 mg/l, an activated carbon adsorption or manganese dioxide adsorption could be used. Between these two technologies, activated carbon is easier to use and should be more cost effective.

Utilization of Results:

A detailed completion report is being prepared together with a brochure to outline the various silver recovery/removal technologies. The brochure will serve as a guidance to the photo imaging industries in the selection of these technologies for various specific applications.

COOPERATIVE ARRANGEMENTS

The Water Resources Center at the University of Rhode Island has two advisory committees, namely the State Advisory Committee and the University Water Resources Coordinating Committee. The membership listed below reflects the recent interest and availability of many water resources experts in Rhode Island:

State Advisory Committee

Comb, Walter	RI Dept. of Health
Falcone, William	RI Water Resources Board
Campbell, James	US Geological Survey
Mark, Eugene	RI Audubon Society
Meyer, Henry	Kingston Fire District
Millar, Scott	Office of System Planning, RI Dept of Adm.
Rose, Vincent	Save the Bay
Solomon, Eric W.	Ambrust Chain Co.
Scott, Elizabeth	Div. of Water Supply Management, RI DEM
Stuart, Everett	US Dept. of Agriculture
Szymanski, Edward.	RI Dept. of Environmental Management
Weygand, Robert A.	Lieutenant Governor

The state advisory committee consists of leading water resources officials of the state and federal agencies as well as representatives from prominent citizen groups and manufacturers.

The other committee is the University Coordinating Committee, consisting of faculty members of the University of Rhode Island from various colleges and the director of the Sea Grant program. Each member has a significant contribution to academic and research programs related to water resources area.

University Coordinating Committee

Cain, J. Allen	Professor and Head of the State Geologist Office
Frohlich, Reinhard K.	Professor of Geology
Gold, Arthur	Professor of Natural Resources Science
Miller, Robert, H.	Dean, College of Resources Development
Nixon, Scott	Professor and Coordinator of Sea Grant Program
Calvin P. C. Poon	Professor of Environmental Engineering

The two committees discussed water resources issues and research priorities for the FY-1996 State Water Research Institute Program. As a result of the discussion and suggestions from the members, the research priority list was prepared and announced to the public.

Both committees also reviewed and ranked research proposals, made comments and suggestions for proposal revision. They also serve as points of contact to collect and to disseminate information to various audience.

PUBLICATIONS

1. Articles in Referee Scientific Journals

	Supporting Section 104 Project Number
Liu,H., R. J. Hull and D.T. Duff, 1997 Comparing Cultivars of Three Cool-Season Turfgrass for Soil Water Nitrate Concentration and Leaching Potential. Corp Science (in press)	02 (FY-96)
Duff, D.T., H. Liu, R.J. Hull and C.D. Sawyer, 1997 Nitrate Leaching from Long Established Kentucky Bluegrass Turf. Jour. Inter. Turfgrass Soc. (in press)	02 (FY-96)
Amador. J.A., A. Glucksman, J. Lyons, and J. Gorres, 97 Distribution of Soil P Activity within a Riparian Forest Buffer Zone. Soil Science(in revision)	03 (FY-96)
Lyons, J.B., J.H. Gorres, and J.A. Amador, 97 Spatial and Temporal Patterns of P Retention and Release in Riparian Forest Soils. To be submitted to Soil Science.	03 (FY-96)

2. Book Chapters

Hull R. J., 1996 Chapter 33: Turfgrasses, in E. Zamski and A.A. Schaffer (eds.) Photosynthate Distribution in Plants and Crops- Source-sink Relationships, Marcel Dekker, Inc., New York, pp. 781-796	02(FY-96)

3. Dissertations

Lyons, J. B., 1996 Spatial and Temporal Distribution Patterns of Phosphorus Retention and Release in Riparian Forest Soils, M.S. Thesis, Dept. Natural Resources Science, Univ. of RI, Kingston, RI	03(FY-96)

4. Water Resources Research Institute Reports

Hull, R.J. Completion Report, Preventing Nitrate Contamination of Groundwater under Turf through Minimum Nitrogen Use (in preparation)	02(FY-96)

Amador, J.A., J. Gorres, 1997 03(FY-96)
Completion Report, Phosphorus Removal and
Release in Riparian Forest Soils: Effects of Land
Use (in preparation)

Poon, C.P.C., R.G., Guang, 1997 04(FY-96)
Completion Report, Silver Recovery/Removal from
Photo Imaging Industries (in preparation)

5. Conference Proceedings

Hull, R.J., Z. Jiang 1996 02(FY-96)
Minimum Nitrogen Use for Turf Management,
URI Turfgrass Field Day Field Book, 65:9-17

Hull, R.J., 1996 02(FY-1996)
Managing Turf for Minimum Water Use, Turfgrass
Trends 5(10):1-9. M. Haber(ed), Washington, D.C.

Hull, R.J., 1996 02(FY-96)
Nitrogen Usage by Turfgrass, Turfgrass Trends
5(11):6-15. M Haber (ed) Washington, D.C.

Hull, R.J., 1996 02(FY-96)
Physiology Affecting Turfgrass Water Use, Golf
Course Management, 64(12):63-66

Hull, R.J., 1996 02(FY-96)
Managing Turf for Minimum Water Use, Irrigation:
Business and Technology, 4(6):36-44.

Glucksman, A.M., J.A. Amador, J.B. Lyons and J.H. Gorres 03(FY-96)
Distribution of P Activity within a Riparian Forest Buffer
Zone, Agronomy Abstracts 88:232

Lyons, J.B., J.A. Amador, and J.H. Gorres, 1996 03(FY-96)
Temoral and Spatial Patterns of P Retention and
Release in Riparian Forest Soils, Agronomy Abstracts
88:306

TRAINING ACCOMPLISHMENT

Field of study	Under-graduate	Master's degree	Ph.D. degree	Research fellow	Total
Environmental				1	1
Natural Resource Science		1			1
Plant Science			1		1
Total		**1**	**1**	**1**	**3**

Completion Report

Preventing Nitrate Contamination of Groundwater under Turf Through Minimum Nitrogen Use

by

Richard J. Hull, Zhongchun Jiang
and Carl D. Sawyer

WATER RESOURCES RESEARCH INSTITUTE
THE UNIVERSITY OF RHODE ISLAND

FY-96

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for

U.S. Department of the Interior
Geological Survey

and
Water Resources Center
University of Rhode Island

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ABSTRACT

In an effort to protect ground water resources in shallow aquifers, research was conducted to investigate the potential for minimum fertilizer use in turf maintenance. Since the soils in much of southern New England overlaying shallow aquifers are highly suited for turfgrass culture, either as recreational facilities or commercial sod production, it is critical that the use of fertilizers and pesticides that might leach beneath the root zone be used at minimum rates. Based on research conducted over the past 15 years, it seems reasonable that fertilizer-N rates used on turf could be reduced to 1 lb/1000 sq-ft (<50 lbs/acre). This is possible if fertilizers are used so as to supplement nitrogen released in the soil through natural mineralization of organic matter.

Three nitrogen sources were applied to sodded Kentucky bluegrass plots established during the spring of 1994. Fertilizers were applied at two or three times in early spring and early or late summer such that the total amount used was 1 lb N/1000 sq-ft. A 3 lb N/1000 sq-ft and an unfertilized control were included among the seven fertility treatments. Suction lysimeters were installed in each plot at a two-foot depth extending below the root zone and used to monitor the nitrate content of soil water throughout the year. Soil water nitrate concentrations together with net water percolation rates were used to estimate nitrate leaching from turf. Grass clippings were sampled and analyzed for total nitrogen. These analyses provided an indication that the turf generally was obtaining sufficient nitrogen to maintain growth and good quality. Turf quality was maintained at acceptable levels in all treatments except during August when high temperature and disease caused quality to decline in most plots. The high fertility turf receiving 2 lbs. N in the late fall, exhibited better quality throughout the spring. By fall, all plots contained turf of good quality. Nitrate leaching was markedly reduced by the lower nitrogen rate and slow-release materials leached less than urea. Leaching from 1.0 lb. N plots and unfertilized plots was comparable. Nitrogen recovery in clippings reflected the soil nitrate levels and the prevailing growing conditions. Total nitrogen partitioning within the turf-soil ecosystems indicated that more than 90% of the approximately 1000 lbs of total nitrogen was present in soil organic fractions. This research confirms the idea that nitrogen use efficiency in turf can be improved by applying fertilizer nitrogen so as to supplement that made available from the soil.

Preventing Nitrate Contamination of Ground Water Under Turf Through Minimum Nitrogen Use

INTRODUCTION

Land use in southern New England is of such intensity that most areas are or soon will be subjected to some level of development. Shallow aquifers, especially those representing sole-source water supplies, need special protection but the land overlying them is often highly valued for residential or commercial development. Much of this land is flat and contains good soil making it ideal for agriculture. Presently, as traditional agriculture becomes less profitable, this land is being converted to high value specialty crops (turfgrass sod, nursery stock) or being developed for entirely different purposes (golf courses, residential communities, industrial parks, commercial complexes). It is important to identify those land uses which constitute the least threat to these water-sensitive areas. Turf culture (residential, commercial, institutional and recreational) has come under much media criticism as an environmentally risky land use wherever ground water protection is important (Jenkins 1994). This has influenced land use planning policy in spite of an ever growing body of research which shows turf to be a relatively effective ground cover for minimizing both nitrate and pesticide leaching to ground water (Cohen et al. 1990; Petrovic 1990; Kenna 1995).

While turf may constitute an environmentally sound ground cover over high value aquifer systems, it is important that managers of turf and those responsible for protecting ground water resources understand the best cultural practices for minimizing nutrient release from turf areas. Such knowledge will maximize the protective functions of turf and permit policy makers to assure the public that effective safeguards for the preservation of water quality are being implemented. Most research has concentrated on quantifying the discharge of pollutants into ground water. This study helps define fertilizer management strategies for turf culture which are most protective of ground water quality.

For the past 15 years, we have been conducting research on nitrate recovery and discharge by turf. While our studies have emphasized worse case situations in order to determine the potential for nitrate leaching, we have learned much about the seasonal patterns of soil water nitrate fluctuations and the annual cycle of nitrogen demand by turfgrasses. Based on such information, we believe that a turf fertilization program can be devised which will require only 25% of the nitrogen commonly applied to turf with no decline in turf quality. This research is an evaluation of several approaches to achieving this marked reduction in nitrogen use and hopefully one or more strategies will emerge as successful and can be recommended to turf managers.

RESEARCH OBJECTIVES

The research reported here is from the first three years of a study which has the following three objectives.

1. To minimize nitrogen fertilizer use on turf by applying it only when soil nitrogen supplies are not adequate to maintain turf quality. Emphasis is being placed on spring and early summer applications with less use in the fall.

2. To compare fertilizer sources for their ability to deliver nitrogen in the amount and at a rate required by turfgrasses. Readily available and slow release organic nitrogen sources are being compared.

3. To determine if good quality Kentucky bluegrass turf can be maintained with annual nitrogen applications of not more than 1 lb N/1000 sq-ft (less than 50 lbs. N per acre).

METHODOLOGY

Experimental Design:

The plot area utilized for this research is located on the Turfgrass Research Farm of the Rhode Island Agricultural Experiment Station at Kingston, RI. The soil type is an Enfield silt loam (Coarse loamy over sandy skeletal, mixed, mesic, Typic Dystrochrept). The site had been in turf for the past 25 years but not utilized for experimentation between 1989 and 1994. In early April, 1994, the existing sod was killed by a topical application of the systemic herbicide glyphosate [*N*-(phosphonomethyl)glycine] and the dead turf removed with a sod cutter. The site was limed and prepared for sodding. Commercially grown Kentucky bluegrass (*Poa pratensis* L.) sod was installed on April 26, 1994. The sod was grown within 500 yards of the plot site using a commercial blend

(Lofts Seed Inc.) consisting of 25% by weight 'Suffolk', 25% 'Sydsport', 25% 'Baron', 15% 'P-104' Kentucky bluegrasses and 10% 'Jamestown II' Chewings fescue. Past experimentation has shown Kentucky bluegrass to be least efficient in recovering nitrate from solution (Liu et al. 1993) and soil (Liu et al. 1997) and, therefore, most demanding of fertilizer nitrogen. If Kentucky bluegrass turf can be maintained at 1 lb N/1000 sq-ft/year, the same should be possible with any cool-season turfgrass.

Seven nitrogen fertility treatments were initiated on June 20, 1994 and maintained to the present. These are summarized below:

N source	Rate	Time & amount applied (lbs.)
	lbs N/1000 ft^2/yr	
Urea (U-L)	3	June - 1.0; Nov. - 2.0
Urea (U-E)*	1	April - 0.5; June - 0.25; Sept. - 0.25
CORON (C-L)	1	April - 0.5; Sept. - 0.5
CORON (C-E)	1	April - 0.5; June - 0.25; Sept. - 0.25
Compost (E-E)	1	April - 0.5; June - 0.5
Compost (E-L)	1	April - 0.5; June - 0.25; Sept. - 0.25
Control (CTL)	0	

* E = N applied primarily in the spring; L = Fall N application significant

The 3 lb urea-N treatment simulated conventional fertility management for a home lawn. Urea is a water soluble, readily available, and inexpensive nitrogen source commonly included in commercial turf fertilizers. CORON is a liquid methylene diurea product, 28% N by weight of which about 30% is urea and 70% is controlled release polymerized material. In our earlier research, it has supported good quality turf, provided little leachable nitrate, and is the sort of nitrogen formulation popular with lawn maintenance companies. The compost used was Earthgro Lawn Food (Earthgro Inc., Lebanon, CT) with an analysis of 8-2-4. It consists mostly of composted leaves and poultry manure fortified with $NaNO_3$. Its 8% nitrogen is about 50% water soluble and 50% insoluble. It is typical of commercially available 'organic' lawn fertilizers and in our research, has supported good quality turf but tends to leach some nitrate when used at more than 3 lb N/1000 sq-ft/year. These nitrogen sources represent the spectrum of materials currently used in lawn fertilizers and were utilized to provide a realistic assessment of minimum fertility turf management.

In this study, most fertilizer was applied in the spring when soil nitrate concentrations are lowest and absorption by grass roots is greatest (Hull et al. 1993; Liu et al. 1997). Low applications in September are intended to facilitate more rapid grass recovery from summer injury to the root system caused by drought, high temperatures, insect predation and human activity. An unfertilized control plot was included in each of the four replications to monitor natural seasonal changes in soil mineralization of organic nitrogen and normal fluctuations in soil water nitrate levels.

The early spring applications of 0.5 lbs. N/1000 sq-ft were made on April 13, 1995 and April 1, 1996. Mid-June nitrogen applications were made on June 20, 1994, June 15, 1995 and June 14, 1996 which included all treatments except Coron early spring/late summer and the unfertilized controls. The late summer nitrogen applications were made on September 1, 1994 and 1995 and August 30, 1996. This involved all plots except the 3 lbs. urea-N/1000 sq-ft and the unfertilized control. The late fall application of 2 lbs. urea-N/1000 sq-ft to the high nitrogen plots were made on November 17, 1994, November 24, 1995 and November 21, 1996. All late spring and summer applications were followed by 0.5 inches of irrigation within one hour of applying fertilizers.

The experimental design is a randomized complete block with seven treatments and four replications. Data were subjected to an analysis of variance using the general linear model of the SAS program (SAS Inst., Inc. 1990) and means were separated using the Waller-Duncan K-ratio T test.

Nitrate Leaching, Nitrogen Recovery in Clippings and Turf Quality:

Suction cup lysimeters were installed in each plot at a depth of two feet on June 1, 1994. Lysimeters consisted of a ceramic cup 0.88 inch OD by 2.75 inches long mounted on a 21 inch long PVC pipe 0.8 inch OD. The ceramic cups were obtained from Soilmoisture Equipment Corp., Santa Barbara, CA and rated for standard flow rate. During installation, cups were set in a slurry of silica flour to insure good contact with the soil matrix. When the lysimeters were evacuated to -0.8 bars, 10 to 50 mL of soil water were drawn into the cup over a two hour period.

During 1994, soil water samples were collected on nine dates; in 1995 on 15 dates and in 1996 on 27 dates. These were analyzed for nitrate-N by passing a water sample through a cadmium/copper

MINIMUM MAINTENANCE TURF MANAGEMENT FOR AQUIFER PROTECTION

F 15	C 16	E 17	G 18	A 19	B 20	D 21	A 22	C 23	F 24	D 25	G 26	B 27	E 28
A 1	B 2	C 3	D 4	E 5	F 6	G 7	B 8	D 9	E 10	G 11	F 12	A 13	C 14

↑ N

TREATMENTS

A	UREA 15 gN/sq-m	5 g 15 June, 10 g 1 Nov
B	UREA 5 gN/sq-m	2.5g 15 April, 1.25g 15 June, 1.25g 1 Sept.
C	CORON 5 gN/sq-m	2.5g 1 April, 2.5g 1 Sept.
D	CORON 5 gN/sq-m	2.5g 1 April, 1.25g 15 June, 1.25g 1 Sept.
E	EARTHGRO 5 gN/sq-m	2.5g 1 April, 2.5g 15 June
F	EARTHGRO 5 gN/sq-m	2.5g 1 April, 1.25g 15 June, 1.25g 1 Sept.
G	CONTROL 0 gN/sq-m	

TURFGRASSES

Kentucky Bluegrass sod blend

ESTABLISHED

26 April 1994

PLOT SIZE

Total area: 84 X 28 ft.
Individual plot area: 6 X 14 ft.

PRINCIPAL INVESTIGATOR

Richard J. Hull

reduction column and analyzing the resulting nitrite spectrophotometrically (Keeney and Nelson 1982). The results were used to estimate nitrate leaching by multiplying the soil water nitrate concentration by leachate volumes calculated for each precipitation event based on soil and meteorological data using the hydrologic component of the CREAMS model (Smith and Williams 1980).

Clippings were harvested on four dates during the 1994 growing season, 11 dates in 1995 and 10 dates in 1996. A 10.3 sq-ft area of each plot was mowed and the clippings captured in a catcher attached to the mower. Clippings were oven dried, ground to pass a 30-mesh screen and analyzed for total Kjeldahl nitrogen according to Easton (1978). Nitrogen recovered in clippings is a non-destructive means of estimating nitrogen absorption by roots and transport to shoots and for monitoring the nutritional status of turf.

All plots were scored for visual quality on four dates during the 1994 growing season and 8 times each in 1995 and 1996. Quality scores constituted a subjective integration of turf color, texture, uniformity and freedom from weeds, disease and other injury. Perfect turf was assigned a score of 9 while dead turf would be scored at 1. A score of 6 or higher indicates acceptable turf quality.

On July 9, 1996, three 0.87 inch (2.2 cm) diameter core samples were taken from each plot to a six-inch depth. These were separated into shoots, roots, thatch and soil with each subsample analyzed for total nitrogen. Data from these analyses were used to estimate the total nitrogen partitioning within the turf-soil ecosystems represented in this experiment.

RESULTS AND DISCUSSION

This report concentrates on results obtained in the two post-establishment years, 1995 and 1996. The year of establishment, 1994, provided little useful information since the sod was not yet fully rooted and the fertility treatments imposed had little opportunity to influence turf performance or nitrogen leaching. The results for 1994 are summarized in an earlier completion report (Hull 1995).

Turf quality:

Turf quality scores were taken on eight dates each during the 1995 and 1996 growing seasons (Figs. 1 & 2). Marked climatic differences were recorded between the two seasons: 1995 was drier and warmer than the 30-year average while 1996 was wetter and cooler (Table 1). The May through September growing season of 1995 received 3.67 inches less rain than normal while 1996 received 4.52 inches more than normal. In other words, the 1996 season was 8.19 inches wetter than 1995. Both growing seasons were milder than normal but 1995 averaged 2.1°F warmer than 1996. These seasonal differences contributed to a higher quality Kentucky bluegrass turf generally being observed in 1996 than 1995. All plots lost turf quality during August of both years probably because that month was consistently hotter and drier than normal. Cool-season grasses (C-3 photosynthesis) are less tolerant of elevated temperatures and often lose quality during the warmest months of summer. However, the return to cooler and, in 1996, wetter conditions during early fall resulted in a marked improvement in turf quality.

Table 1. Temperature and precipitation data for 1995 and 1996 from the Rhode Island Agricultural Experiment Station Weather Monitoring Center, Kingston, RI.

	Precipitation		Temperature	
Month	1995	1996	1995	1996
	inches (+/- 30-yr. mean		°F (+/- 30-yr. mean)	
January	4.04 (-0.23)	5.51 (+1.24)	35.0 (+7.3)	29.1 (+1.4)
February	3.85 (+0.15)	3.59 (-0.11)	29.5 (+0.2)	29.3 (0.0)
March	2.55 (-1.91)	3.24 (-1.22)	39.6 (+2.2)	34.4 (-3.0)
April	3.04 (-1.52)	6.63 (+2.07)	46.2 (-0.2)	47.5 (+1.1)
May	4.23 (-0.11)	4.39 (+0.05)	55.4 (-0.7)	56.0 (-0.1)
June	3.55 (-0.19)	2.58 (-1.16)	66.1 (+1.1)	66.9 (+1.9)
July	1.25 (-2.02)	7.35 (+4.08)	73.3 (+2.8)	69.2 (-1.3)
August	2.28 (-1.44)	2.82 (-0.90)	70.7 (+1.3)	70.1 (+0.7)
September	4.05 (+0.09)	6.41 (+2.45)	62.1 (-0.2)	63.3 (+1.0)
October	5.97 (+2.00)	6.75 (+2.78)	55.9 (+3.7)	51.1 (-0.1)
November	5.14 (-0.17)	2.17 (-3.14)	41.5 (-1.5)	38.7 (-4.3)
December	3.75 (-0.89)	8.67 (+4.03)	29.1 (-3.4)	38.9 (+6.4)
TOTAL	43.70 (-6.24)	60.11 (+10.17)		
AVERAGE			50.4 (+1.2)	49.5 (+0.3)

The fall application of urea to the higher nitrogen plots (3 lbs. N/1000 sq-ft/year) caused them to green-up earlier and generally maintain superior quality through April and much of May. Later in the growing season, the higher fertility plots were not significantly better than those receiving only 1.0 lb. N/1000 sq-ft/year although in 1996 the superior quality of the high N plots began to be evident during the fall as well. As the experiment continued through its second and third years, the unfertilized plots began to lose quality compared to those receiving N and this was especially evident during 1996. All nitrogen sources applied at the one-pound rate supported turf of comparable quality with significant differences among them rarely detected. However, the Earthgro Lawn Food (compost) generally supported somewhat better quality turf during late June through mid-August when it was all applied in the spring. This might be due to the greater readily available nitrogen content of this material. In general, with the exception of April and May, the one-pound nitrogen treatments produced turf of comparable quality to the more conventional three-pound rate.

Soil water nitrate and nitrate leaching:

Soil water samples collected at a two foot depth were below the turf root zone and constitute water that had escaped the turf-soil ecosystem are was on its way to the underlying aquifer. Monthly averages of soil water nitrate concentrations collected during 1994 and 1995 are summarized in Figure 3 while results for all 28 sampling dates in 1996 are presented in Figure 4. During the establishment year, 1994, soil nitrate levels were generally elevated reflecting the poorly established root system. By the spring of 1995, soil water nitrate levels had declined to barely detectable levels and increased gradually as the summer progressed. However, the conventional nitrogen plots, that received only 1.0 lb. urea-N/1000 sq-ft in mid-June, promoted a marked nitrate increase in soil water during the summer which persisted into the fall (Fig. 3). All slow-release nitrogen sources applied at the one-pound annual rate maintained soil water nitrate levels less than 8 mg NO_3-N/L (ppm) during 1995 and these levels never exceeded 4 ppm throughout 1996. This is somewhat surprising considering the excess precipitation occurring in July, September and October of that year. Apparently, increased root activity maintained through the summer because of the more favorable climatic conditions in 1996 immobilized both fertilizer and naturally mineralized soil nitrogen as rapidly as it was released to the soil solution. Also, as observed by Geron et al. (1993), the full establishment of a root system from transplanted sod may require two or more years and in 1995, our plots had been sodded for only one year.

Only the conventional rate of urea-N, with 2/3 applied in mid-November, resulted in elevated soil water NO_3-N, exceeding 10 ppm during July and August of 1995 and more than doubling that caused by the other two nitrogen sources during winter and fall of 1996. The 0.25 lb. application of urea-N in early September, 1996 promoted a sharp increase in soil water nitrate-N (7 ppm) illustrating how even a modest application of a readily available nitrogen source can increase soil water nitrate escape from the root zone if it is applied at a time when roots are unable to absorb it rapidly and excess rainfall is occurring. Even the 1.0 lb urea-N application in mid-June of 1996 caused only a minor short-lived increase in soil water nitrate reflecting the greater root activity early in the summer. The marked increase in solution nitrate during late May of 1996 in the conventional fertility plots is difficult to explain. Rainfall was near normal during May and June and temperatures were only slightly below normal (Table 1). Rapid remineralization of nitrogen immobilized earlier in the spring or nitrogen release from heavy clipping production (Fig. 11) might account for this.

Both Coron and EarthGro Lawn Food resulted in little nitrate release to ground water. Modest increases in soil water nitrate following early September applications of the Earthgro product were noted but they failed to persist beyond a single precipitation event. The $NaNO_3$ used to fortify that product probably contributed to this nitrate increase but its significance to nitrate leaching can well be questioned.

It is evident that a conventional 3 lb N/1000 sq-ft rate applied mostly in late fall contributes to an elevated soil water nitrate content over that produced by a lower rate applied mostly in the spring. The impact of this on nitrate leaching is evident from the data presented in Figures 5, 6 and 7. In 1996, the conventionally fertilized plots lost four-times more nitrogen to nitrate leaching than did those receiving nitrogen sources applied at 1.0 lb N/1000 sq-ft. In 1995, the differences were not as great but generally significant. The 4 g N/m-sq loss to leaching calculated for the conventionally fertilized turf is equivalent to 0.8 lbs N/1000 sq-ft or 35 lbs. N per acre.

It is clear from this study and others (Geron 1993) that as turf became better established, its capacity for trapping nitrogen increased. By 1996, in spite of excess precipitation, the slow-release nitrogen sources lost less than 1.0 g N/sq-m (0.2 lbs N.1000 sq-ft) to leaching compared to the 4.0 g loss from the conventionally fertilized plots. While the EarthGro product promoted somewhat greater nitrate leaching in 1994 and 1995, it failed to differ from Coron or the unfertilized plots in 1996. This is somewhat surprising because the quantity of water percolating through the soil column has been identified as a major contributor to nitrate leaching (Morton et al. 1988). A soluble nitrogen source ($NaNO_3$) applied at times of heavy precipitation should increase not decrease nitrate leaching. It is likely that the more favorable conditions experienced by cool-season grasses in 1996 may have preserved root function to such an extent that nitrogen absorption was increased enough to offset the potential for greater nitrate leaching.

Most nitrate leaching occurred after June in 1995 and 1996. Late winter and early spring offer little opportunity for nitrate movement due to frozen ground and low temperature inhibition of mineralization and nitrification. The greater capacity for turf roots to absorb nitrate during the spring also minimizes leaching until stressful conditions of summer reduce root activity and soil nitrate accumulates. This greater vulnerability to nitrate leaching in late summer and fall casts into question the environmental soundness of emphasizing late season nitrogen fertilization of turf.

The nitrate leaching rate estimated for the slow-release nitrogen sources applied at 1.0 lb N/1000 sq-ft was 8.2 lbs. N/acre, which is equivalent to 1.4-times that of our unfertilized turf and 7-times that reported for an unfertilized native forest in southern Rhode Island (Gold et al. 1990). These results indicate that reducing nitrogen applications to 1.0 lb./1000 sq-ft/year and using slow release materials can significantly reduce nitrate leaching to levels comparable to an unfertilized lawn.

Clipping recovery of nitrogen:

Clipping samples were collected on ten dates during 1995 and 1996 and their nitrogen content determined (Fig. 9 & 10). In general, the nitrogen content of clippings fell within the 27.5 to 35.0 mg/g range recognized as nitrogen sufficiency for cool-season turfgrasses (Turner and Hummel 1992). Only during early July, 1995 did turf begin to approach the nitrogen deficiency range.

Nitrogen content of clippings generally declined as growth rates increased during May (Figs 10 & 11). A low nitrogen content was reached during June or July, (depending of growing conditions, soil moisture levels, etc.) followed by a gradual increase through July, August and September as growth rates declined but soil mineralization increased the nitrogen supply. During the fall when shoot growth increased, soil nitrate concentrations were sufficiently high that clippings approached the 5% nitrogen level generally regarded as supraoptimal.

Significant differences in the nitrogen content of clippings from plots receiving 1.0 lb. N/1000 sq-ft/year were rarely observed (Figs. 8 & 9). Only the 3-lb. nitrogen rate produced clippings of significantly greater nitrogen content and then only in the late spring and early summer when nitrate levels in the soil were low. By 1996, the second post-establishment year, unfertilized plots began to exhibit significant decreases in nitrogen content and reduced nitrogen recovery in clippings (Figs. 9 & 11).

The slow-release nitrogen sources showed no consistent differences in the nitrogen content of clippings or the total nitrogen recovered in clippings. The application of fertilizer mostly in the spring (E treatments) tended to result in greater nitrogen recovery when urea or EarthGro Lawn Food were the nitrogen sources (Fig. 10). During the early summer growth increase of 1996 (Fig. 11) the EarthGro product made somewhat more nitrogen available to the grass followed by urea and Coron. This pretty much agrees with the relative rate of nitrogen release by these three materials recognizing the $NaNO_3$ present in the EarthGro Lawn Food. These differences were small and rarely significant.

The higher nitrogen rate clearly stimulated clipping production and increased their nitrogen content but, except for the spring season, this did not consistently translate into better turf quality. While it is too early to reach a conclusion on the matter, it appears that the elevated nitrogen rate stimulates greater clipping production but this does not necessarily result in better turf. A confounding factor, which expressed itself more in 1995 than 1996, was a greater incidence of dollar spot in the 1-lb nitrogen plots during early summer. Since dollar spot is regarded as a disease more serious on low fertility turf (Tani and Beard 1997), its presence may have reflected the low nitrogen status of the early summer turf in 1995. Disease incidence may be a problem that could confound efforts toward low nitrogen turf management. If, however, fertilizer nitrogen is used to supplement soil supplies of available nitrogen, the problem of low fertility diseases may be avoided.

Nitrogen partitioning in the turf-soil ecosystem:

The total nitrogen partitioning in the turf-soil systems compared in this study is summarized in Figure 12. Soil organic fractions averaged 92.7% of the total nitrogen present. Living tissues contained 4.5% of the total nitrogen and thatch accounted for the remaining 2.8%. Grass shoots from conventionally fertilized plots contained significantly more nitrogen than those from all plots fertilized at the 1.0 lb. N rate. No other differences among nitrogen fractions were significant. Total nitrogen detected within the upper six inches of the turf-soil systems averaged 119 g/m-sq. This is equivalent to 1040 lbs. nitrogen per acre of which 964 lbs. is in the soil fractions.

During the course of a growing season, perhaps 10% of the soil organic nitrogen is mineralized releasing 96 lbs. of nitrogen as ammonium into the soil solution. The 76 lbs. of nitrogen present in shoots and roots of living grass and 29 lbs. present in thatch also are partially released but those fractions probably remain relatively constant as nitrogen is acquired from the soil. It is reasonable that approximately 100 lbs. of nitrogen are made available to turf each year through the mineralization of organic nitrogen present within the turf soil system. This is more than enough to replenish all nitrogen present within grass plants at any given time. Consequently, an annual nitrogen application of 43.6 lbs./acre (1 lb./1000 sq-ft) combined with that mineralized from the soil should be sufficient to meet turfgrass needs.

Turf normally exhibits nitrogen deficiency if not fertilized annually because the time of greatest nitrogen release from soil organic matter and thatch does not correspond to the time of greatest turf need. Cool-season turfgrasses grow most in the spring when soils have not warmed sufficiently for microbial mineralization to release enough nitrogen to meet plant demands and deficiency symptoms result. Later during the heat of summer, grass growth is inhibited by heat stress, periodic drought and insect predation of the roots preventing the turf from utilizing the nitrogen then made available through mineralization. Nitrate leaching potential is greatest during the late summer to early fall season. If this analysis of turf nitrogen dynamics is correct, it would seem unwise to apply fertilizer nitrogen during late summer or fall since at that time the soil is already providing more nitrogen than the grass roots can absorb.

If little nitrogen is lost from turf through nitrate leaching as appears to be the case (Starr and DeRoo 1981; Hull et al. 1993; Miltner et al. 1996), then repeated nitrogen applications should result in nitrogen accumulation within the turf-soil ecosystem. This may very well be happening unless denitrification losses become more significant than has yet been observed (Petrovic 1990). Such long term accumulation may eventually result in an unstable nitrogen overload that could precipitate a disastrous nitrate release to ground water should the turf be killed or a massive mineralization event occurs. Therefore, it is reasonable to revise turf fertility management so as to utilize maximally nitrogen cycling within the turf-soil system and rely less on adding fertilizer nitrogen.

Thus far, this experiment has confirmed our hypothesis that turf of good quality can be maintained with annual nitrogen applications totaling no more than 1.0 lb./1000 sq-ft if it is applied in the spring and early summer when the grass needs are greatest and the soil is unable to meet these demands. The two years of valid data presently available are not sufficient to make the case. The turf may yet be coming to equilibrium with its soil environment and only two rather different growing seasons have been observed. We hope to be able to continue this research for another two to three years.

CONCLUSIONS

With two post-establishment years of observation available, we can draw some tentative conclusions concerning the feasibility of maintaining quality turf using 1/3 the nitrogen normally employed.

1. Nitrogen applied at 1.0 lb./1000 sq-ft can support good quality turf if one-half or three-fourths of it is applied during spring and early summer with the remainder applied in late summer.

2. Late fall nitrogen application will provide earlier green-up in the spring but otherwise offers little advantage and it can promote nitrate leaching. A very early spring application of nitrogen may offer the same spring green-up with less nitrate leaching potential.

3. Controlled release nitrogen sources support good turf quality and offer less potential for nitrate leaching. These materials appear to be best adapted to a minimum nitrogen use strategy.

4. Nitrate leaching occurs mostly during late summer and fall when living turf roots are least abundant or able to absorb nitrate efficiently. A total suppression of leaching will require managing turf so as to maintain active roots and maximize their growth.

5. Unfertilized turf leached about 6 lbs. nitrate-N per acre. Some of the slow-release fertilizer treatments in this study leached about as much nitrate as unfertilized turf. We appear to be on the right track for maximizing fertilizer use efficiency by manipulating application rates, timing and nitrogen source.

ACKNOWLEDGMENTS

In addition to the support provided by the Rhode Island Water Resources Research Center, which is gratefully acknowledged, funding was also provided by Earthgro Inc., Coron Corp, and the Rhode Island Agricultural Experiment Station. Fertilizer materials were contributed by Coron Corp. and Earthgro Inc. The technical assistance of three undergraduate students, Keith Cote, Mark Simster and Michael Stimpson during 1994, is also acknowledged with appreciation. The assistance of Paul Santer, Antoinette Snyman and Philip Thibaudeau for their service during the summer of 1995 is also gratefully appreciated. The invaluable assistance of Christina Carroll during the summer and Jeff Rozansky during the fall semester of 1996 are also gratefully acknowledged. Greg Fales and his staff at the Turf Research Station is acknowledged for their efforts in installing and maintaining the turf plot area.

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FIGURE 1. TURF QUALITY SCORES FOR KENTUCKY BLUEGRASS TURF RECEIVING THREE N SOURCES - 1995

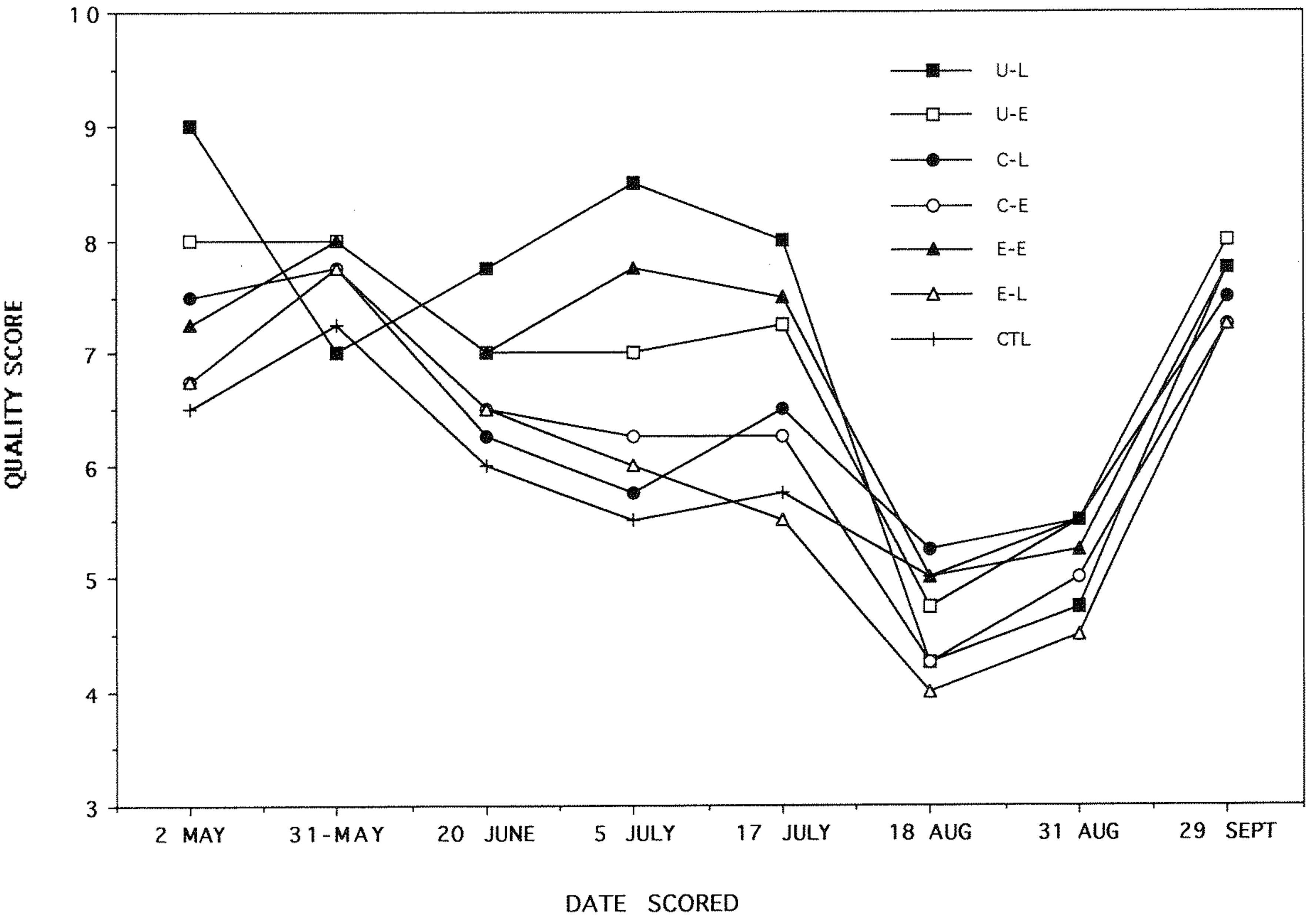


FIGURE 2. TURF QUALITY SCORES FOR KENTUCKY BLUEGRASS TURF
REVEIVING THREE N SOURCES - 1996

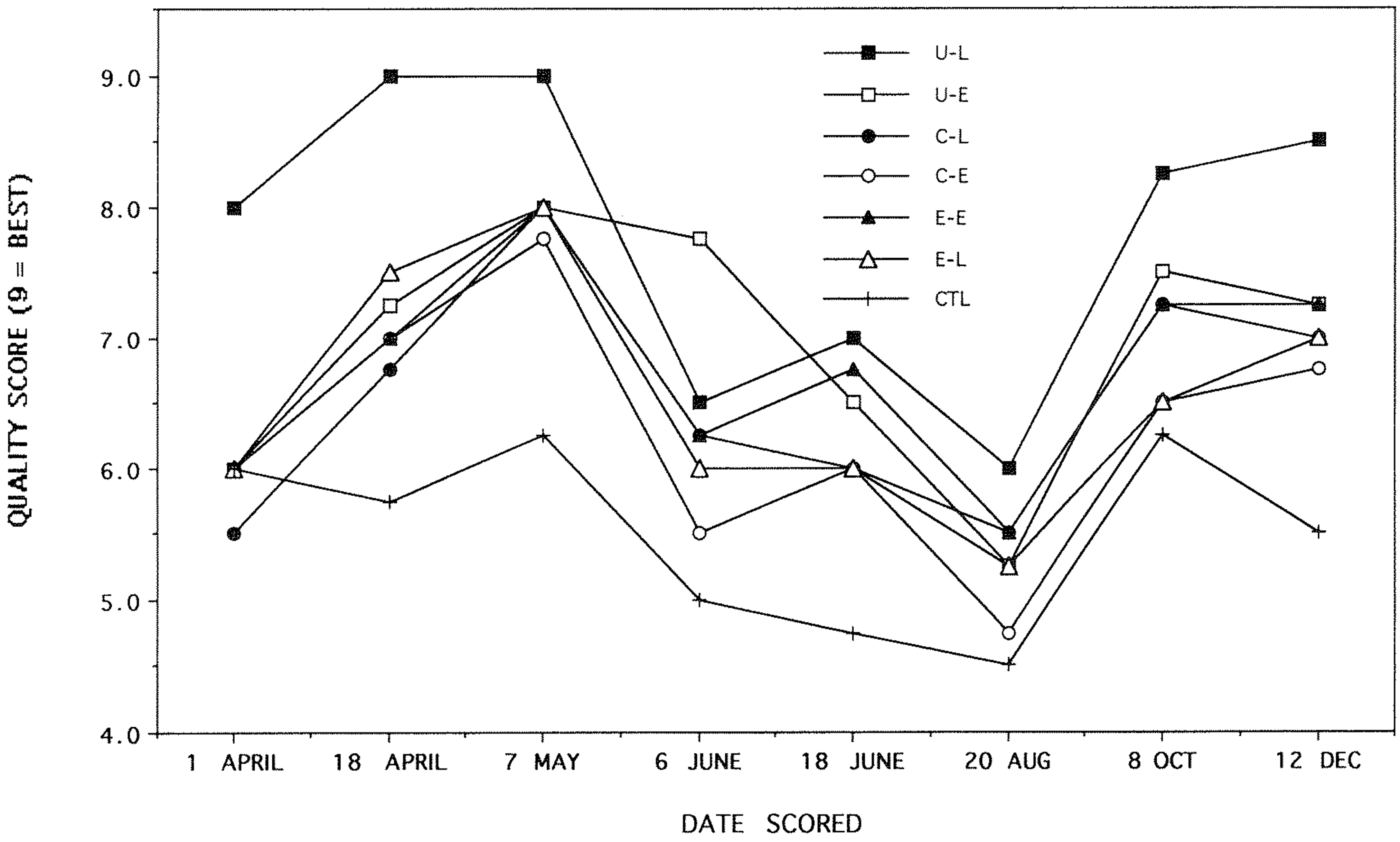


FIGURE 3. SOIL WATER NITRATE-N CONCENTRATIONS UNDER KENTUCKY BLUEGRASS TURF FERTILIZED WITH THREE N SOURCES - 1994-95

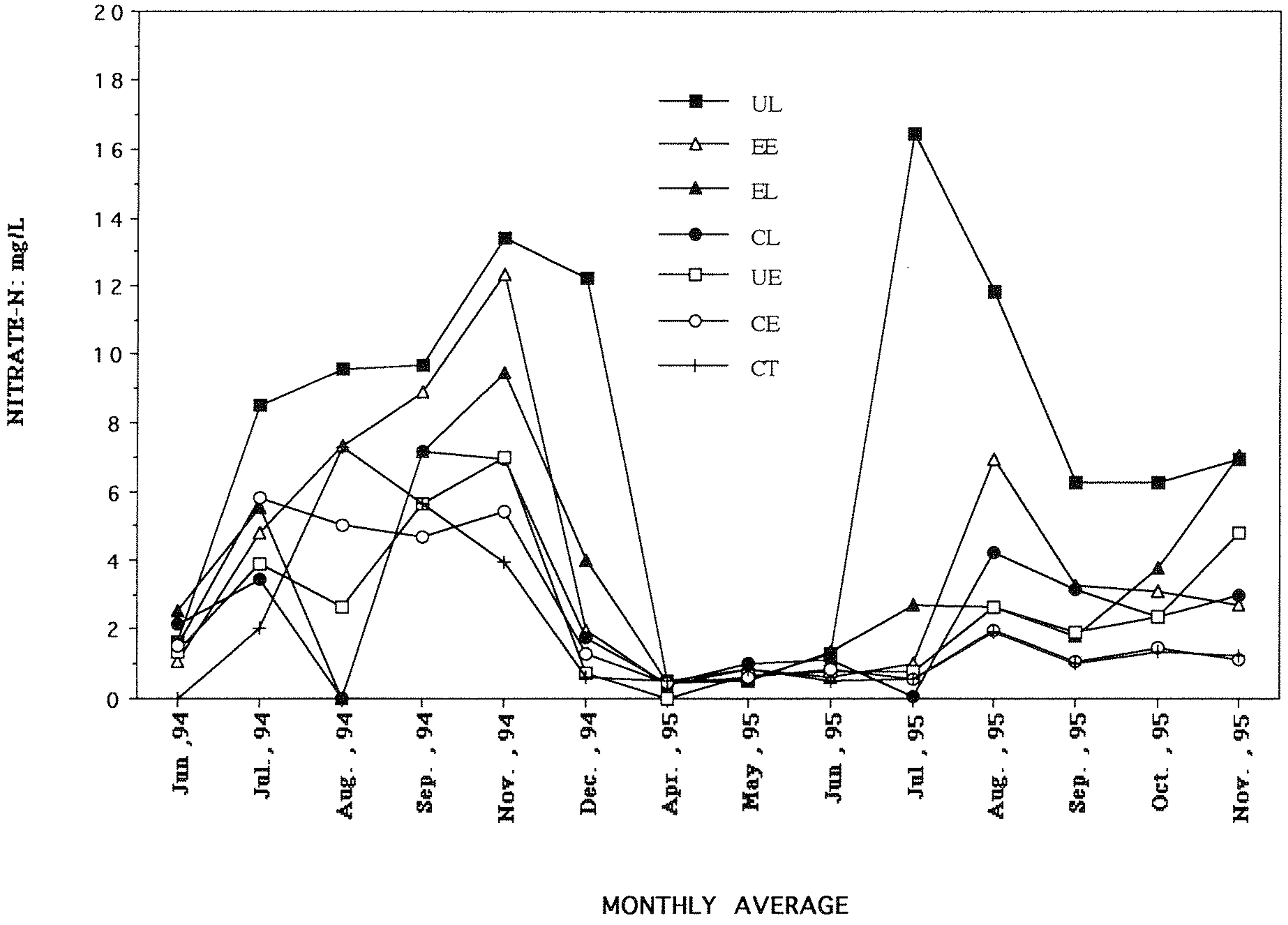


FIGURE 4. SOIL WATER NITRATE-N CONCENTRATION UNDER KENTUCKY BLUEGRASS TURF FERTILIZED WITH THREE N SOURCES - 1996

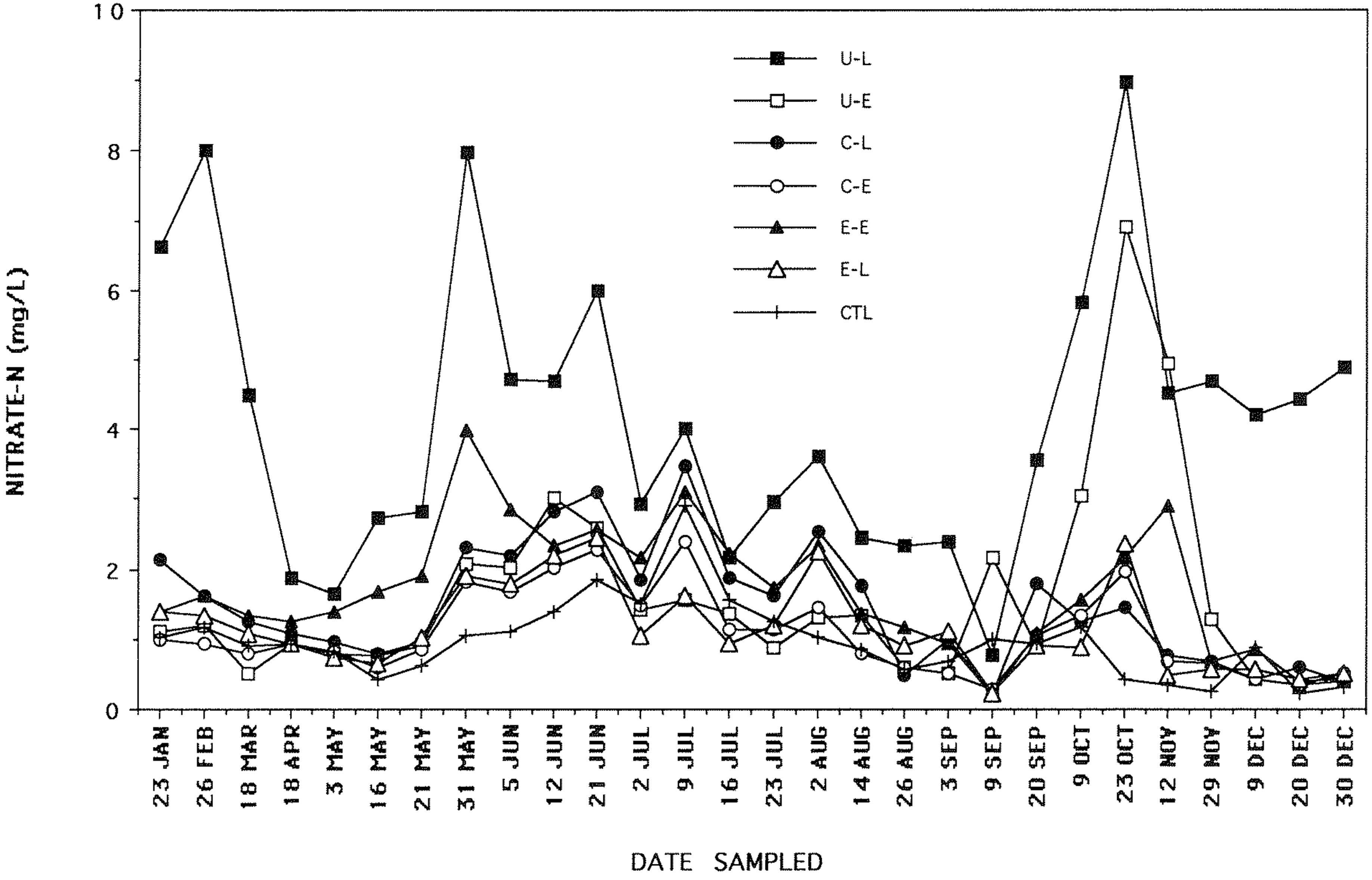


FIGURE 5. NITRATE-N LEACHED FROM KENTUCKY BLUEGRASS SOD FERTILIZED WITH THREE N SOURCES - 1994

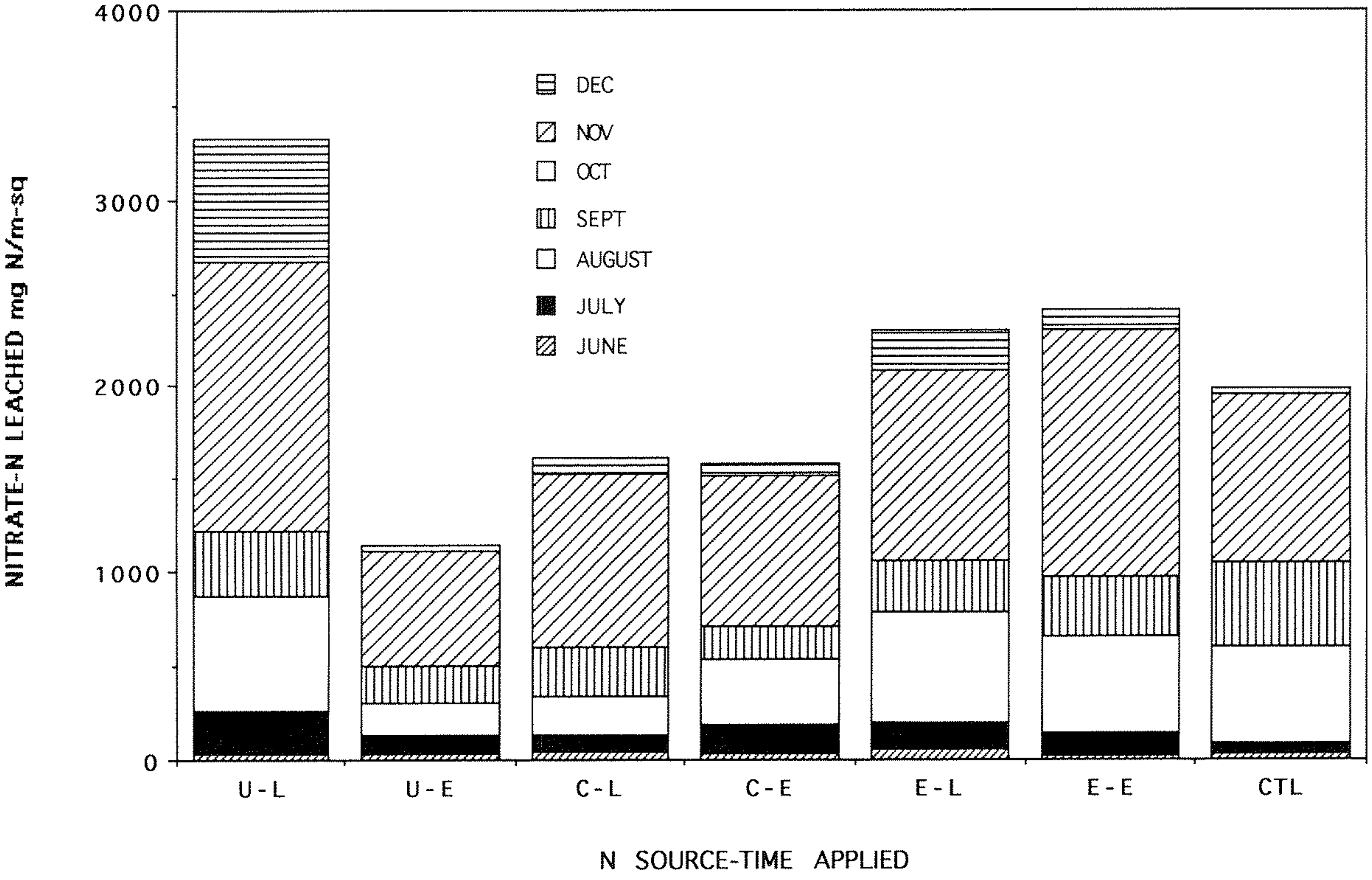


FIGURE 6. NITRATE-N LEACHED FROM KENTUCKY BLUEGRASS TURF FERTILIZED WITH THREE N SOURCES - 1995

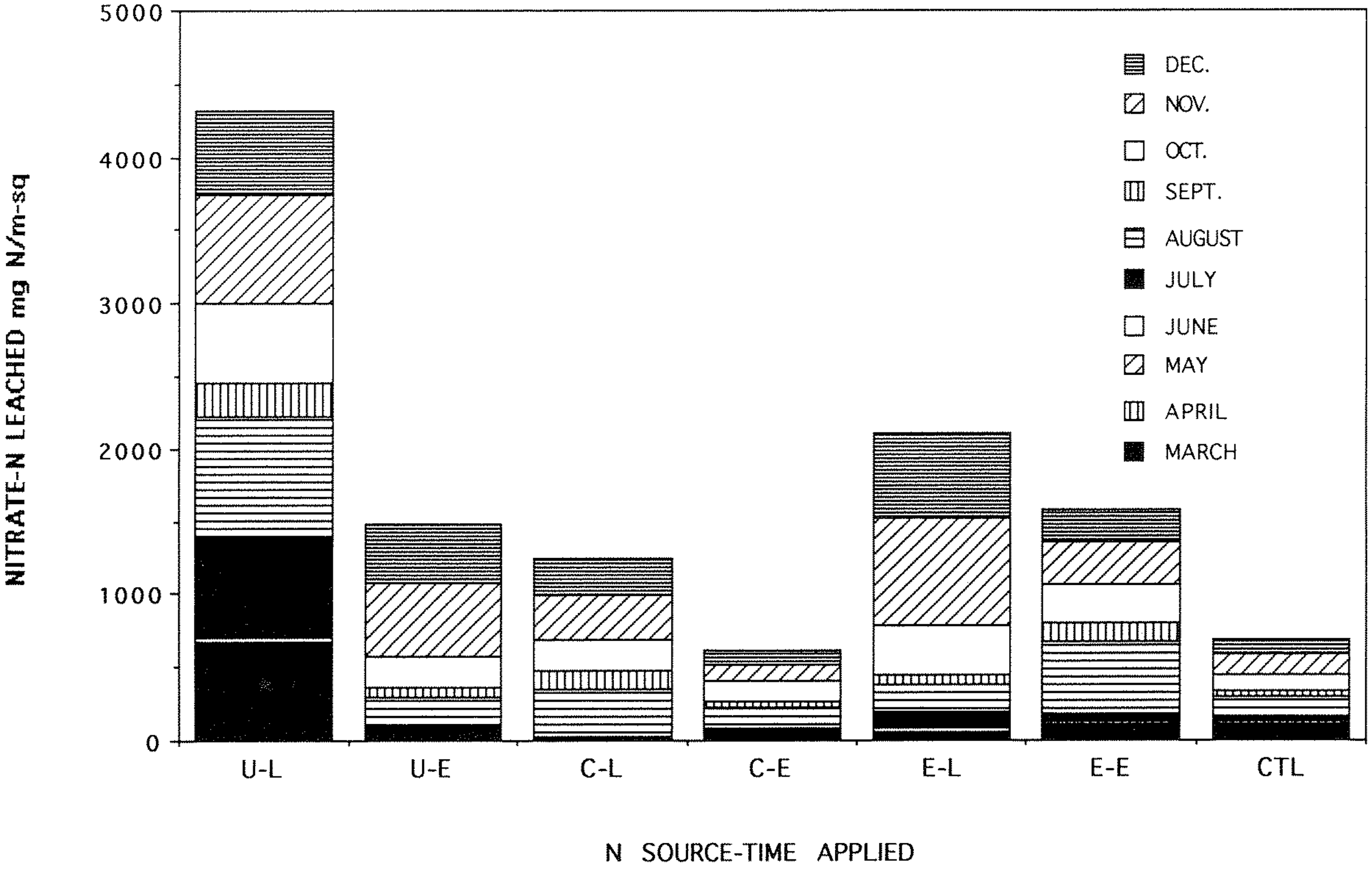


FIGURE 7. NITRATE-N LEACHED FROM KENTUCKY BLUEGRASS TURF FERTILIZED WITH THREE N SOURCES - 1996

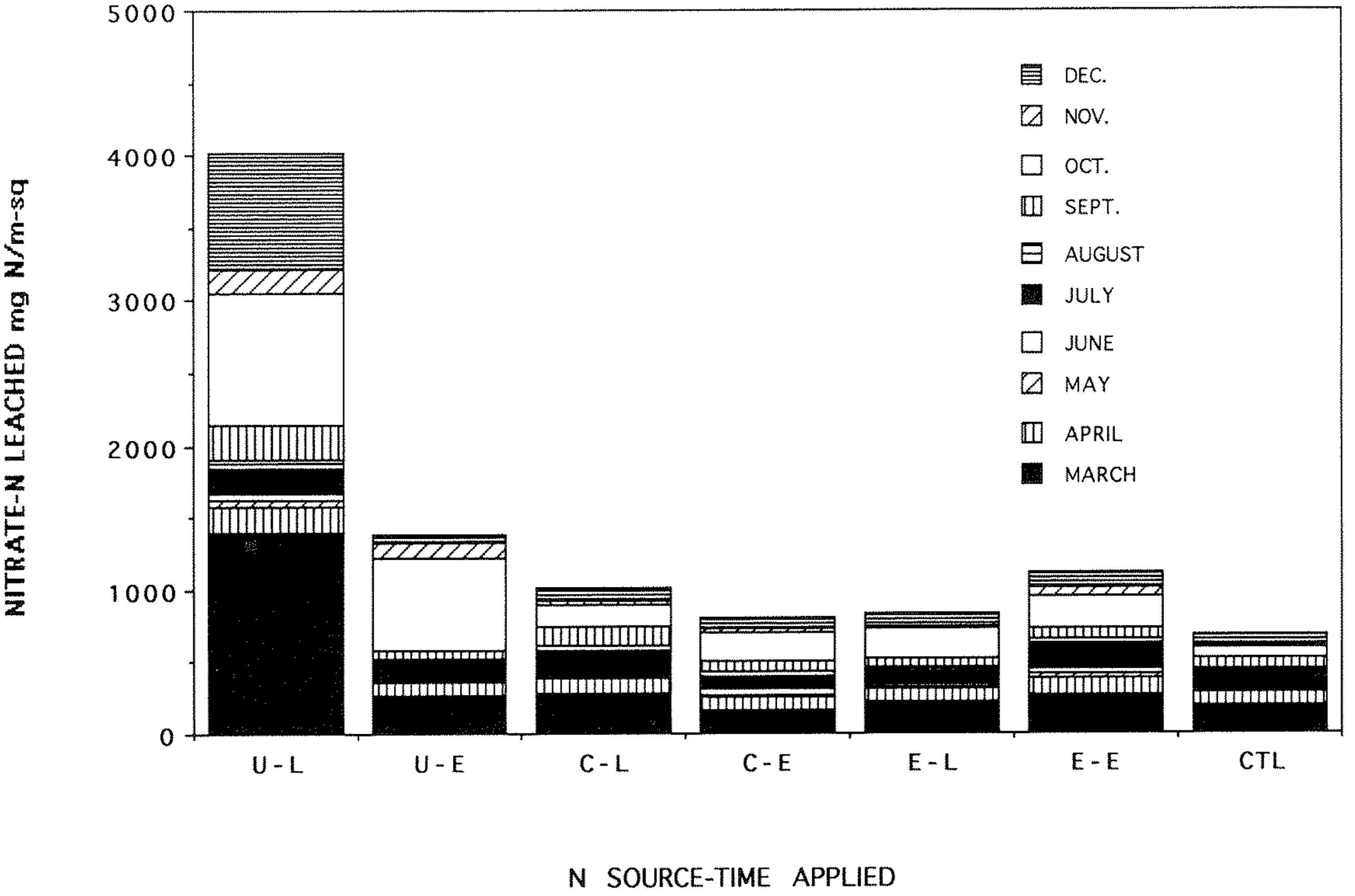


FIGURE 8. NITROGEN CONTENT OF GRASS CLIPPINGS - 1995

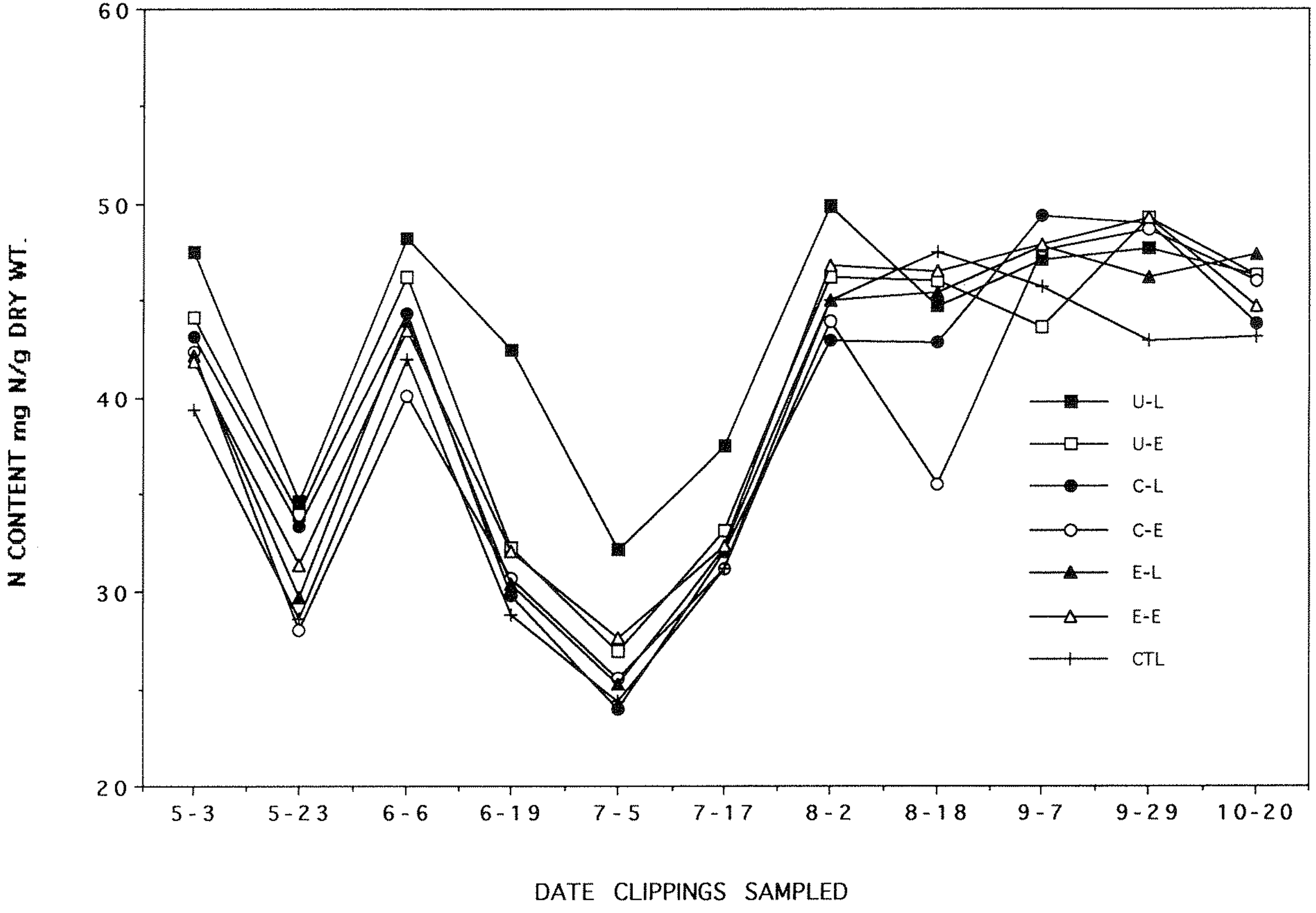


FIGURE 9. NITROGEN CONTENT OF GRASS CLIPPINGS - 1996

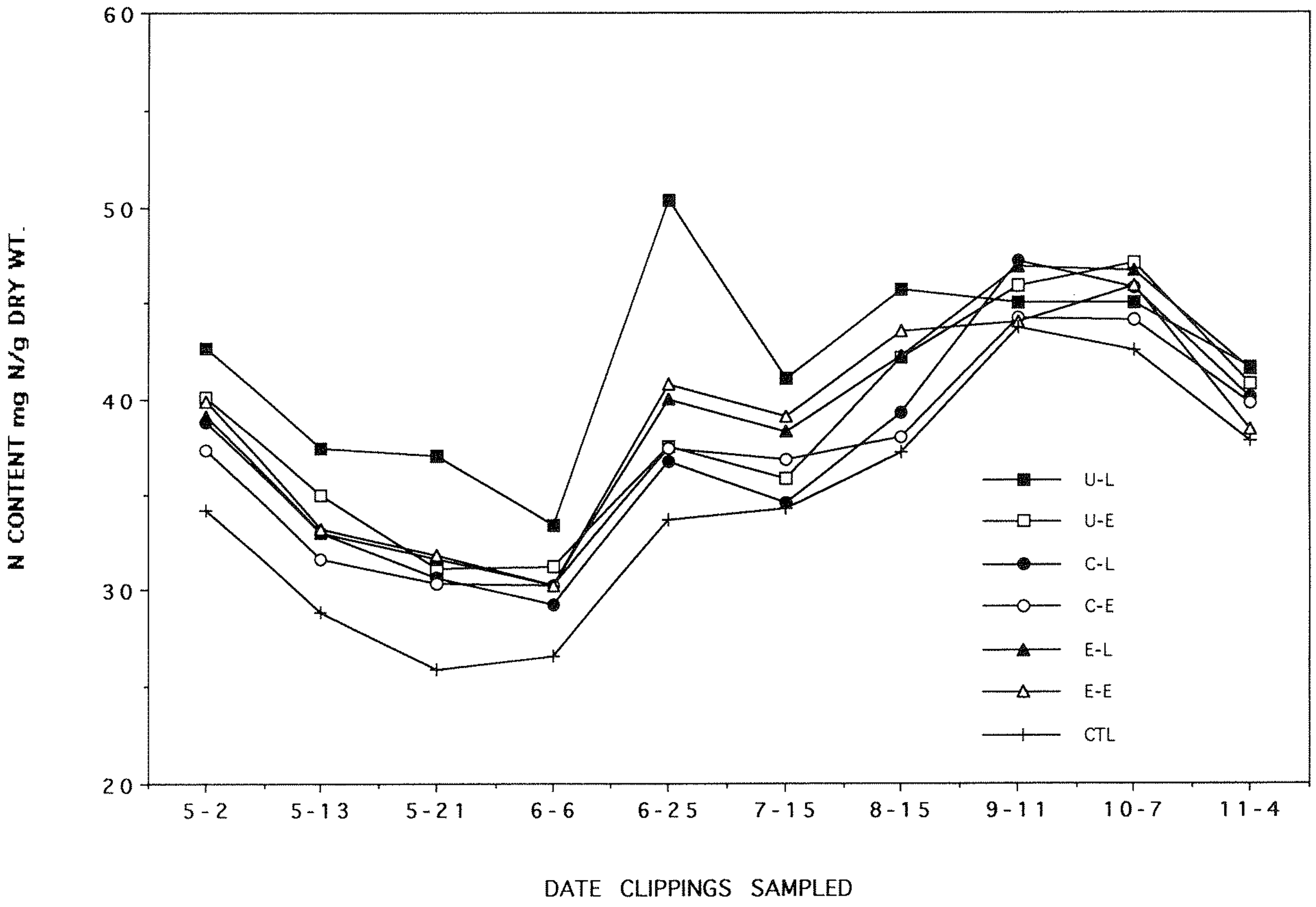


FIGURE 10. SEASONAL NITROGEN RECOVERY RATE IN CLIPPINGS - 1995

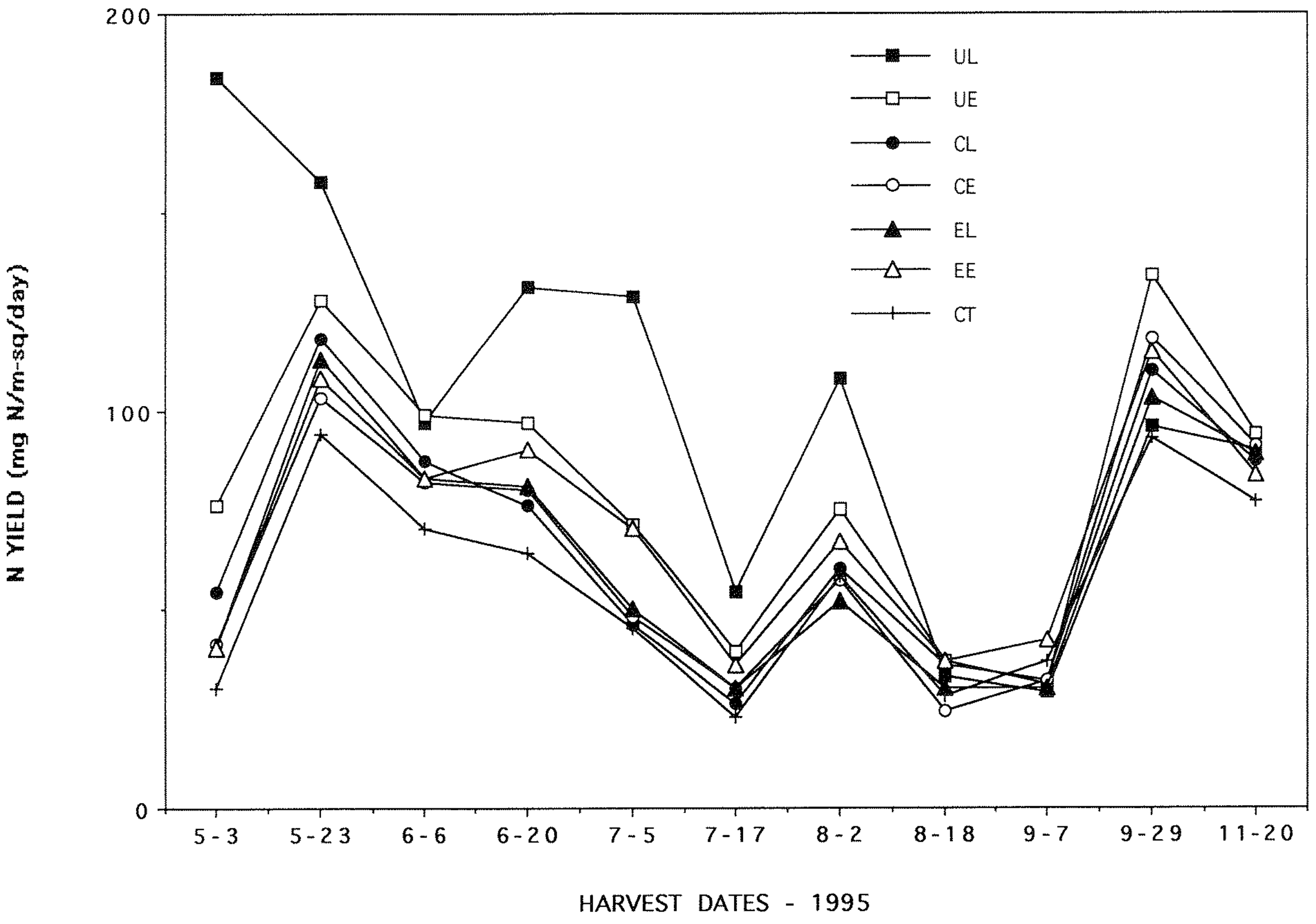


FIGURE 11. SEASONAL NITROGEN RECOVERY RATE IN CLIPPINGS - 1996

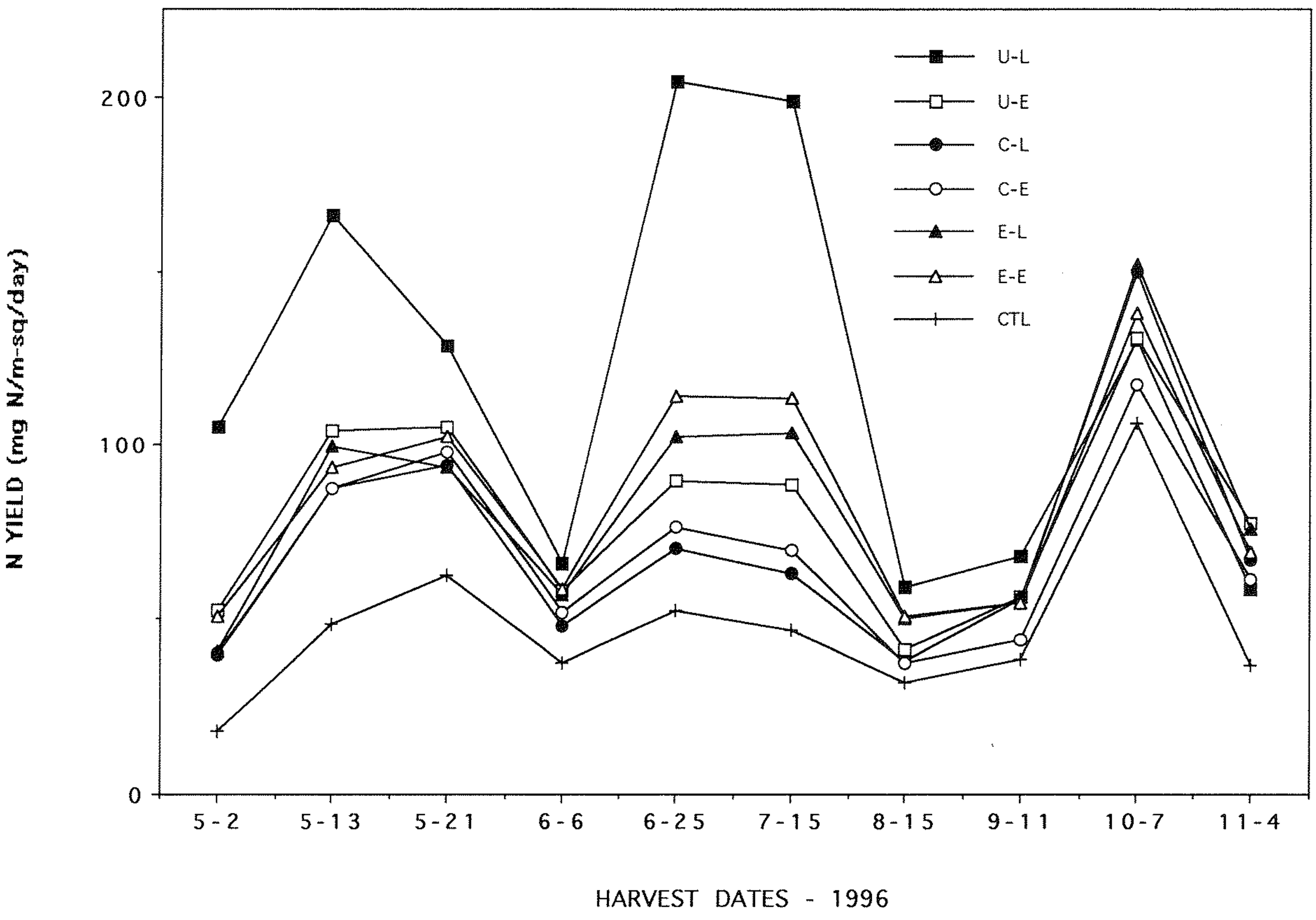
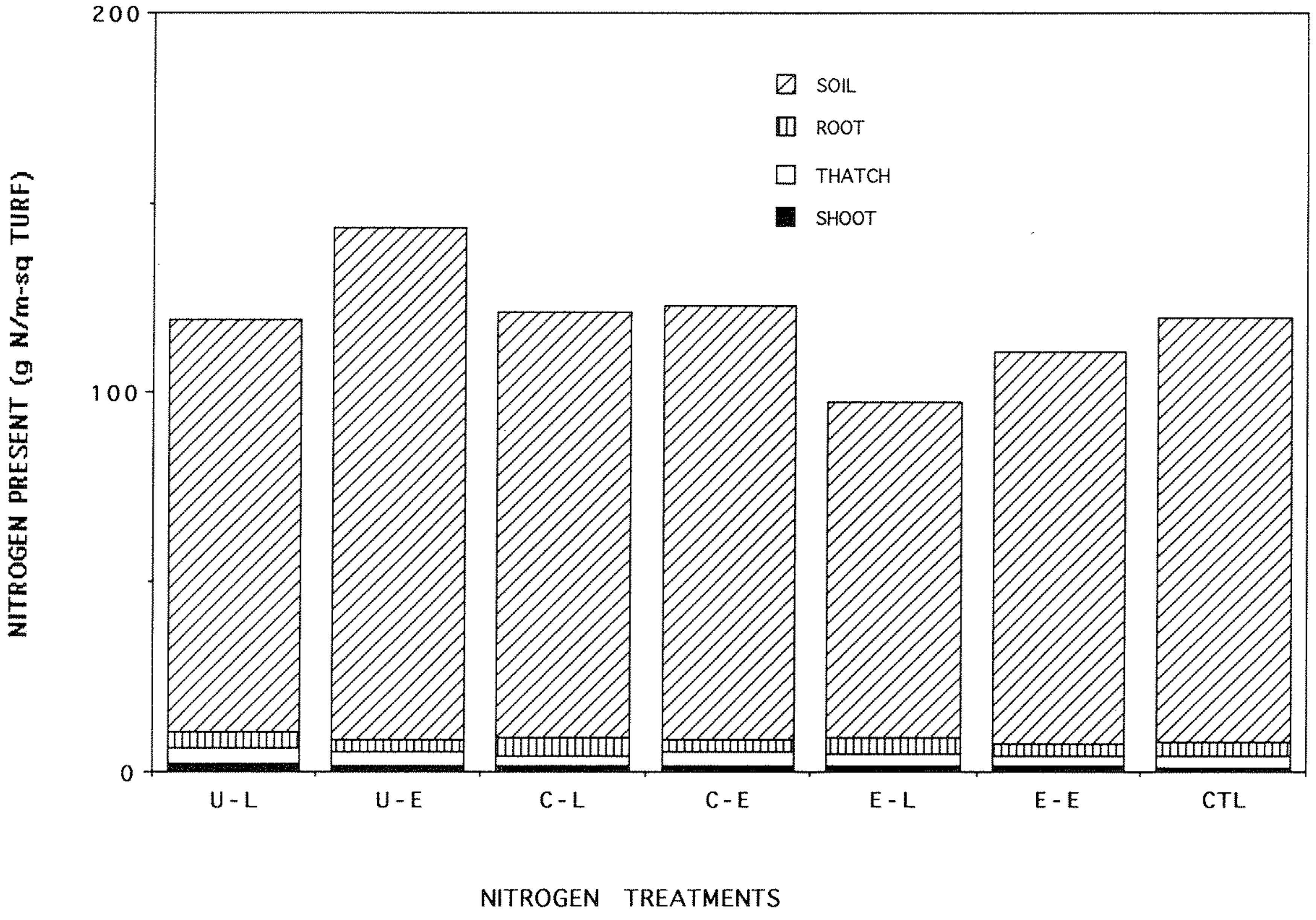
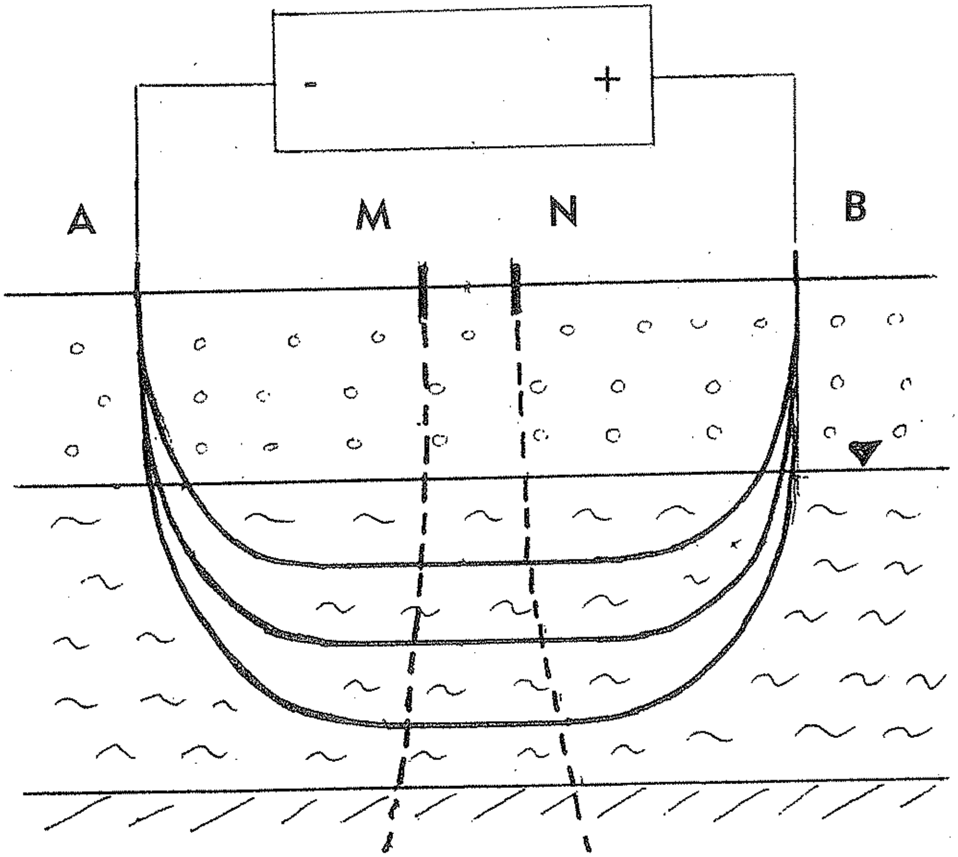


FIGURE 12. NITROGEN PARTITIONING IN TURF-SOIL ECOSYSTEMS RECEIVING SEVEN NITROGEN TREATMENTS - 1996



GEOPHYSICAL METHODS
for
Hydrogeologic and Contaminant Hydrology Applications

Reinhard K. Frohlich



URI Water Resources Research Center

GEOPHYSICAL METHODS

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June, 1996

Table of Contents

Appendix

Introduction

This is not a text book. The book shall inform leaders and decision maker at the municipal, state and federal level of government and people in the industry on the usefulness of surface geophysics. A problem with modern research is that results are not made available to those who may benefit from using them or who need them. Groundwater pollution, for instance, involves scientific disciplines, like hydrogeology, hydrology, fluid flow systems, soil science, biology, microbiology, bacteriology, geophysics, immunology, groundwater chemistry, water well engineering and sampling. We can be certain that this list is not complete.

Groundwater exploration and the assessment, remediation, and control of pollution is associated with skyrocketing costs that call for reforms similar to those that have been suggested in health care. Much of the work in hydrology is accomplished with test wells and chemical analyses. Geophysical surface methods provide cost-saving potential, and may eliminate the need for some of the more expensive borings and analyses. More effort is needed to bring the results of reseach in near surface geophysics to those people who would most benefit from them.

Geophysics has been applied for commercial purposes since the early 1930's for the search of buried ores and coal, and later for the search for hydrocarbons, i.e. gas and oil, with the sesimic reflection method. Unprecedented scientific discoveries were made in order to obtain reliable information about oil reservoirs at depths of 10,000 feet before boreholes were drilled. This booklet will inform on the usefulness of geophysical surface methods for groundwater and contaminant hydrology. The motivation is the same, namely that borings are prohibitively expensive unless they are guided and supplemented with geophysics. The precision requirements and the nature of groundwater and pollution plumes present new problems. Equipment needs to be retooled, interpretation methods have to be readapted and often new phenomena are observed that can basically change fundamental geophysical concepts. It is not simply an application of old methods to new problems. In some cases new methods need to be developed.

There are four main chapters on Geoelectrics, Seismic Refraction, Gravity, and the Magnetic Method followed by an extensive list of references. Also included, and this is rather new, is a comparison of expenses for drilling only and for a combination of geophysics and drilling. Each of the four chapters consists of an introductory part which describes the measuring unit and how it is related to the hydrogeological parameters. This will be followed by a description of the field work, the time requirements and some information on the geophysical equipment. A short chapter on interpretation, which normally is the main part of textbooks, will be included so that the reader understands the effort and necessary qualification of the interpreter. This will be followed by an extended chapter on various applications of the method. An appendix on the basics of groundwater shows hydraulic parameters in conjunction with water wells, which can be related to geophysics.

method. Sometimes it is possible to formulate a hydrological problem in terms of S or T.

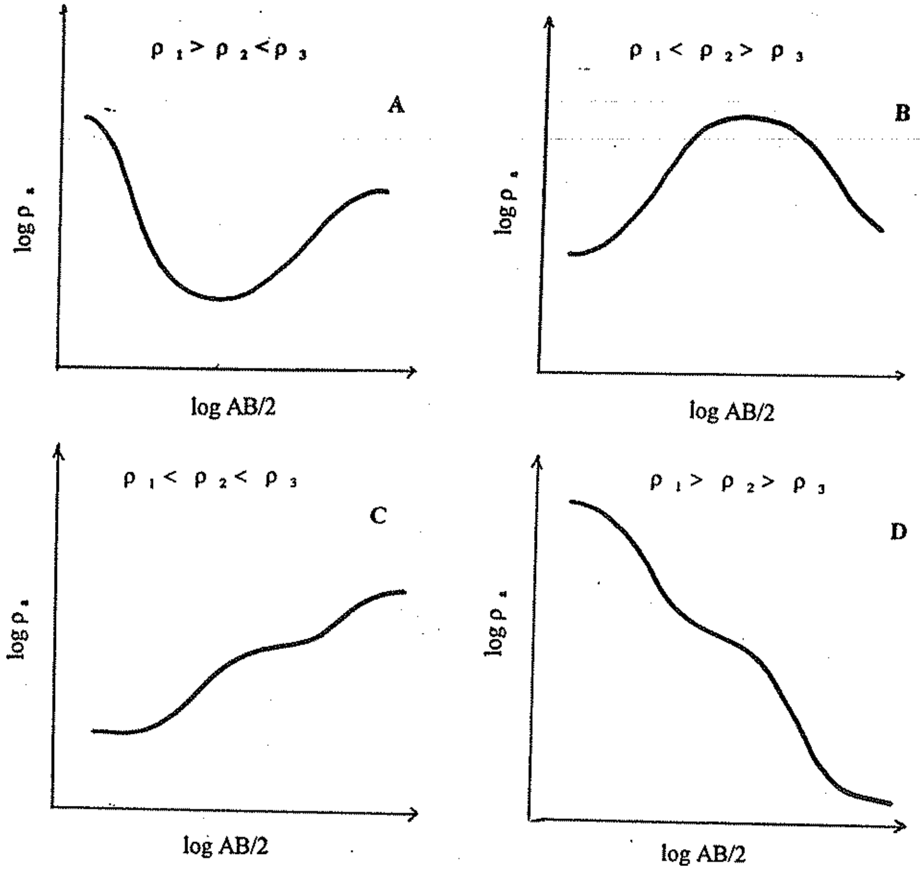


Fig. 1.3: The four different 3-layer depth sounding curve types.

Three-layer curves are classified into four types (Fig.1.3) as follows:

The H-type curve (Fig.3.4A): ρ_1 : unsaturated sand ρ_2 : saturated sand ρ_3 : bedrock
The K-type curve (Fig.3.4B): ρ_1 : loam and silt ρ_2 : saturated gravel ρ_3 : clay
The A-type curve (Fig.3.4C): ρ_1 : saturated sand ρ_2 : fractured bedrock ρ_3 : bedrock.
The Q-type curve (Fig.3.4D): ρ_1 : unsaturated sand ρ_2 : saturated sand ρ_3 : saltw. sat. sand.

There are serious scientists who do not like computer modeling, as they fear that it is something artificial. This is a philosophical question of epistemology: how do we understand nature? Without models and thought-concepts we would understand nothing, and the person who needs to see everything is not a scientist but a collector. The question is how good are these models and how applicable are they? Interpretation models in geoelectrics are based on potential theory and have been extensively tested. This, of course, does not automatically eliminate errors.

1.5 Applications of the resistivity method

Example 1: (Class Project GEL/ CVE 485, Environmental Engineering Geophysics) Geoelectrical depth sounding after Schlumberger over a glacial stream channel, Chipuxet river, southern Rhode Island (s. Fig. 1.4).

The field curve is a four-layer K-type curve with the following resistivity sequence: $\rho_1 < \rho_2 > \rho_3 < \rho_4$. Model 2, shown at the bottom, generates the best-fitting model curve (drawn curve) with the observed data (crosses). Model curves generated by models 1 and 3 are still possible models that show the range of resistivities and thicknesses of the third layer for which the interpretation is nonunique. All three models have a constant conductance of $S = h/\rho = 0.13$. We can further analyse the model resistivities of the saturated aquifer by estimating the porosities with Archie's equation (eq. 1.2).

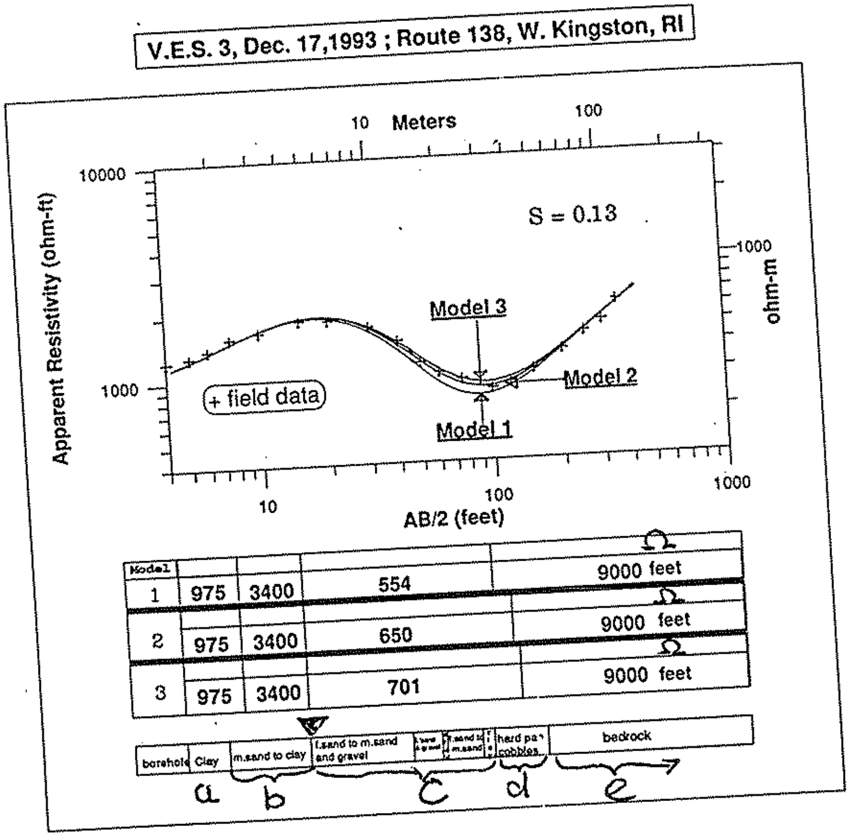


Fig. 1.4: Geoelectrical depth sounding with models and drilling result, West Kingston, RI.

Minimum ρ	Best Fit ρ	Maximum ρ	
554	650	701	(ohm-feet)
49%	44%	41%	Porosity

The water conductivity was measured in the borehole as $\sigma_\omega = 150\ \mu$ S/cm.

The result of the boring is identified with letters:

a: Near-surface silt; b: unsaturated sand; c: saturated fine sand to gravel (aquifer)
d: hard pan, cobbles; e: bedrock.

From the well log it is not possible to decide which of the three models is applicable, probably because the models are relatively close. The boundary to the poor conductor of 9000 ohm-feet is in the layer identified as hard pan. The relatively low bedrock resistivity suggests that the bedrock is fractured.

<u>Example 2:</u> (Parke, 1984) Change of the unsaturated zone from late spring to summer, Chipuxet Valley, Rhode Island(s. Fig. 1.5).

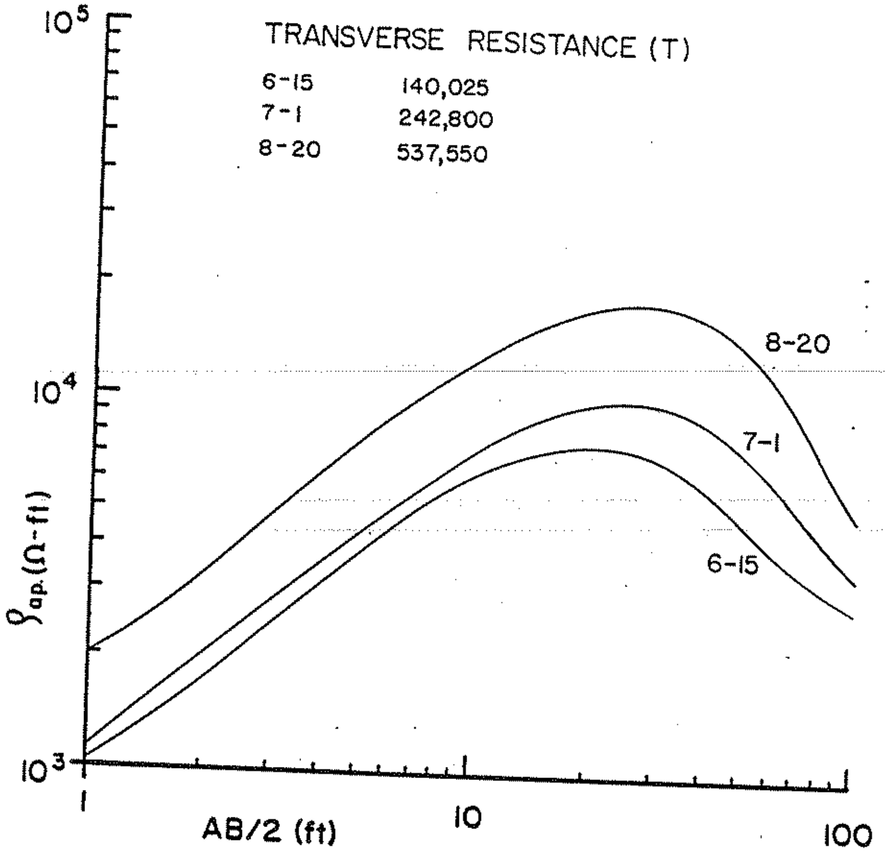


Fig. 1.5: Repeated depth soundings to monitor changes in the unsaturated zone.

Three geoelectrical depth soundings after Schlumberger were conducted over the same location on 6/15/1983; 7/1/1983 and 8/20/1983. The upward shift of the curve upon repetition indicates an overall increase in the electrical resistivity due to a decrease in moisture. At the same time the thickness of the unsaturated layer increases due to a decrease of the water level. Both effects, a decrease in moisture and an increase of the unsaturated layer thickness, are expressed in the transverse resistance $T = h \ \rho$. The values are shown at the top of the figure 1.5.

Example 3: (Boland, 1989) Location of groundwater resources with resistivity in potatoe country Aroostook County, Maine.

Several geoelectrical depth soundings were conducted after Schlumberger to locate sites for potential water extraction from bedrock sources (Frohlich, 1989). Bedrock resistivities were interpreted from the depth soundings. The bedrock is a uniform calcareous shale and low resistivities show the potential of water in fractures. A test well driven next to the lowest bedrock resistivity of 2000 ohm-feet produced water at a yield of 100 gal/min.

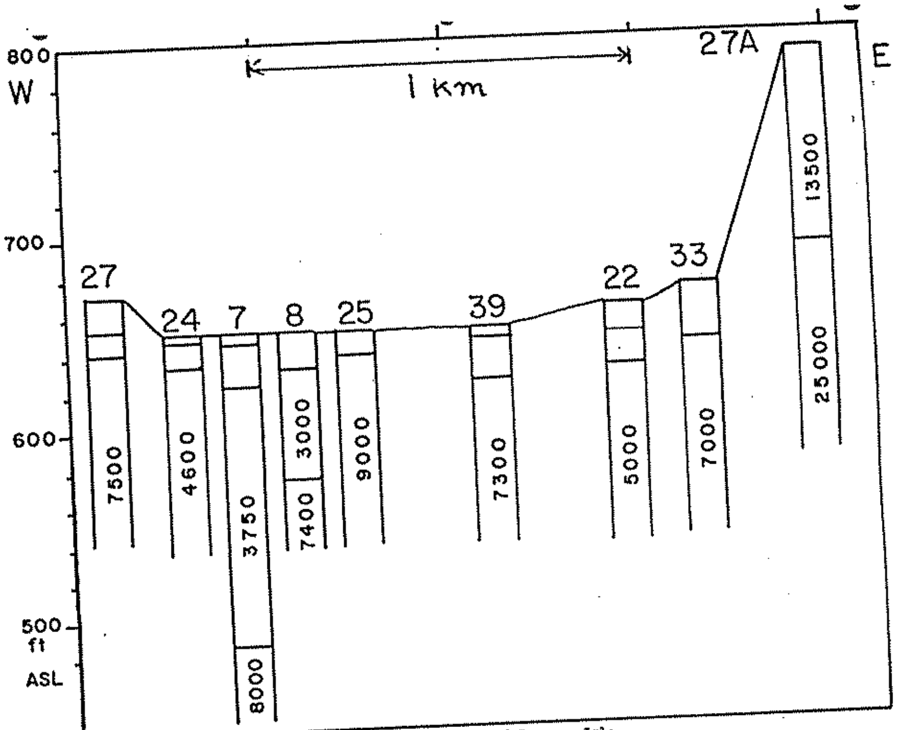


Fig. 7: Profile of bedrock resistivities southeast of Presque Isle.

Fig. 1.6: Bedrock resistivities observed along a profile with depth soundings. Location at soundings 7 and 8 were optimal and recommended for a well.

Two geoelectrical depth soundings are shown: Fig.1.7 shows a low resistivity bedrock of 3750 Ohm-ft resistivity to a depth of 180 feet. Fig. 1.8 shows high bedrock resistivities of 13500 ohm-ft to a depth of 100 ft.

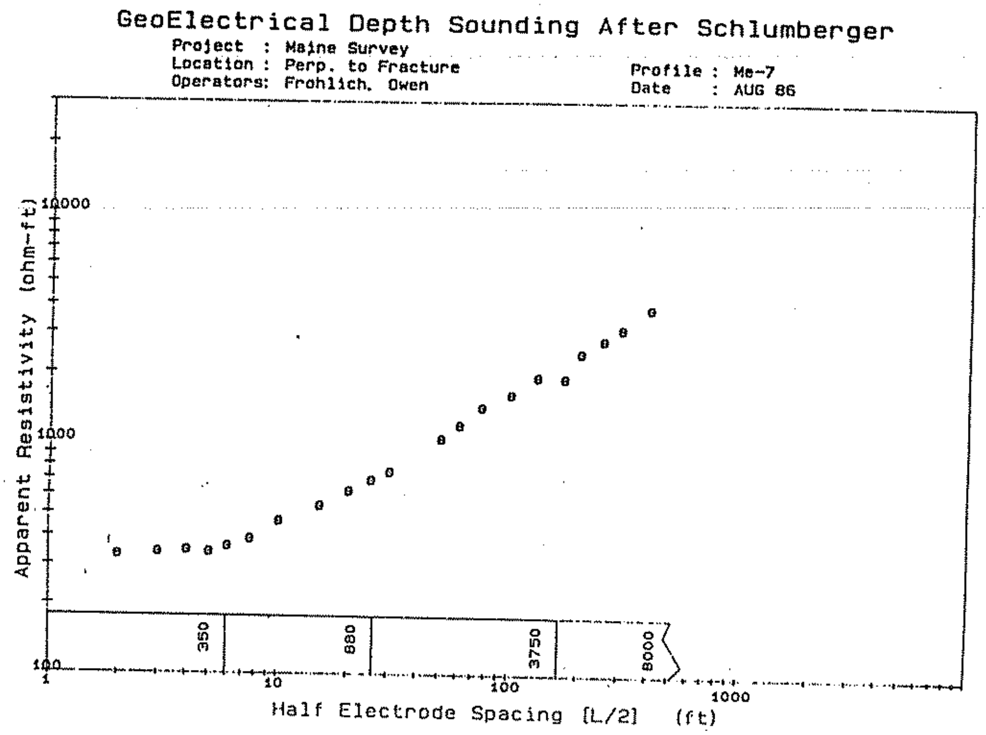


Fig. 1.7: Geoelectrical depth sounding over a low resistivity bedrock

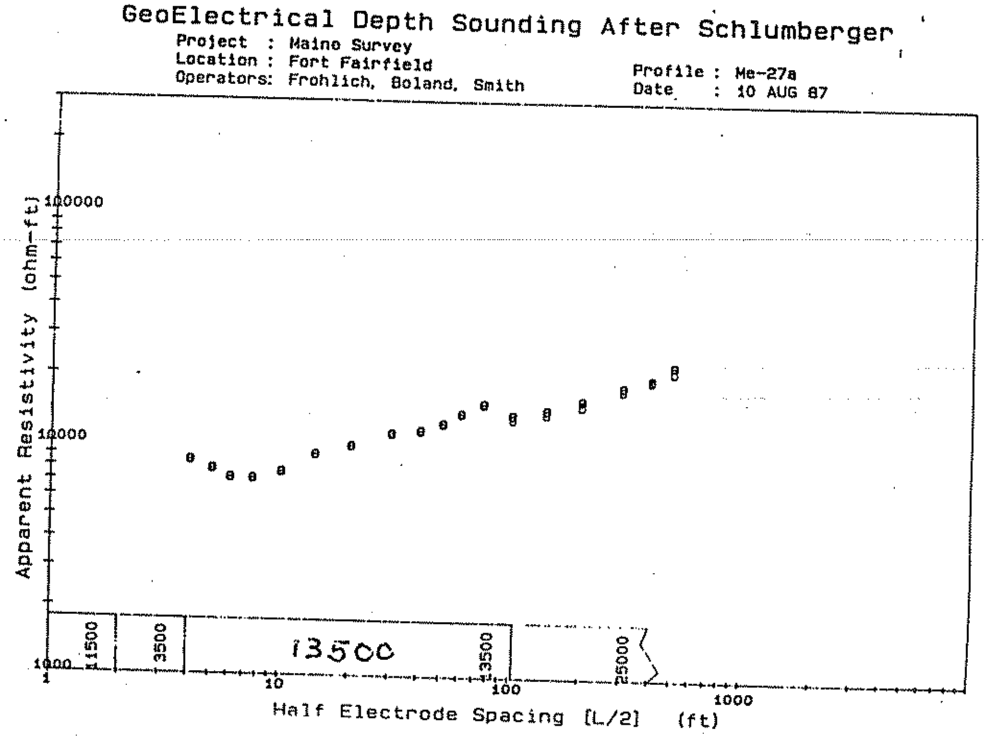


Fig. 1.8: Geoelectrical depth sounding over a high resistivity bedrock.

Example 4: (Frohlich, Urish, and Argudo, 1995) This is a complicated case of polluted fresh water in the saturated zone.

1.) There was a 12 m wide strip between a ware house and the steel sheets of a bulkhead separating the land from the Narragansett Bay. The effect of the steel sheets and the saltwater was corrected by using the image method, a model calculation for estimating the effect of a vertical boundary.

2.) The unconsolidated material is a till with a clay component. We therefore cannot apply Archie's law to estimate the pore water conductivity to see whether it is polluted.

3.) The fresh water saturated layer is sandwiched between the unsaturated zone and the salt water saturated layer of very low resistivity. Polluted water may have a sufficiently high salinity so that it becomes difficult to distinguish it from the bottom layer.

Fig. 1.9 shows the location of the ware house and the bulkhead. Five geoelectrical depth soundings were completed as close to the ware house as possible. Circles, marked 1, 2, 3 are sites for test wells, numbered in the order of priorities. Borings 1and 2 were sited with the results of the geoelectrical survey, which extended further to the east (not shown here).

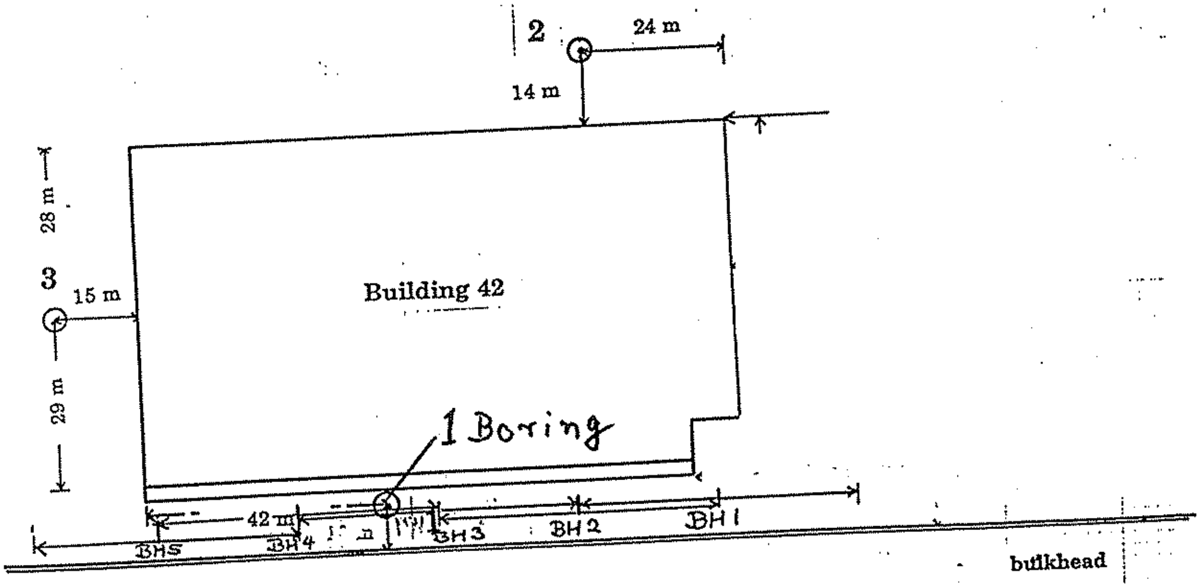


Fig. 1.9: Location of soundings and test wells on the Derecktor shipyard, Newport, R.I.

Fig. 1.10 shows an example of a depth sounding with an interpreted resistivity-depth profile. The fresh water saturated zone of 9 Ohm-m is followed by the salt water saturated zone of 2.6 Ohm-m. In figure 1.11 a lab sample from test well # 1 was saturated with water of different salinities

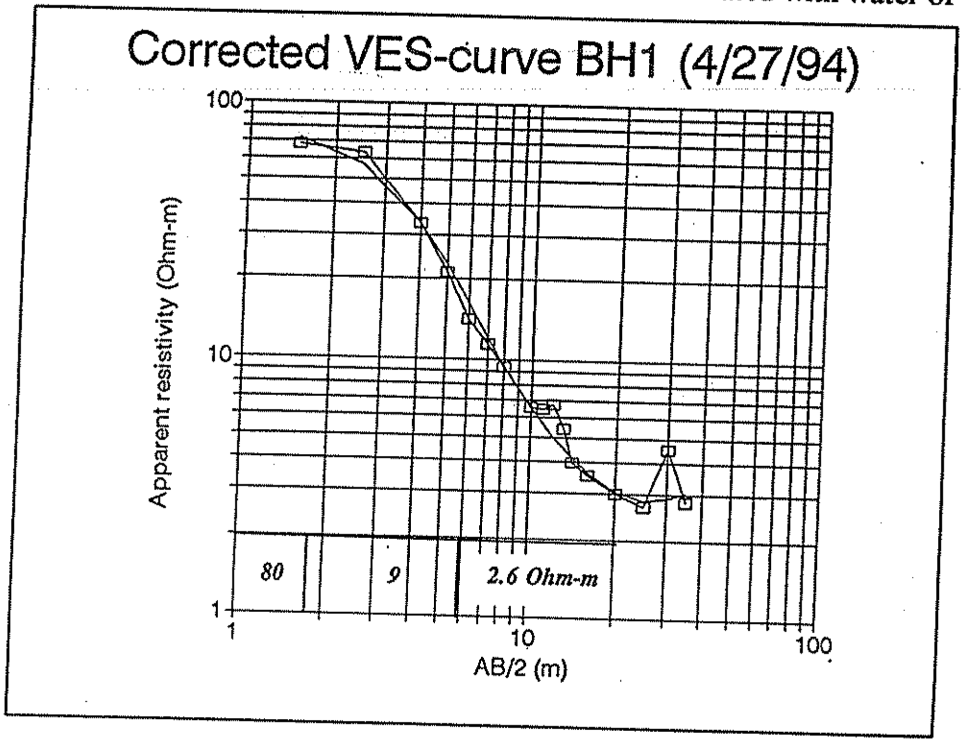


Fig. 1.10: Example of a depth sounding (BH1) with model and model curve.

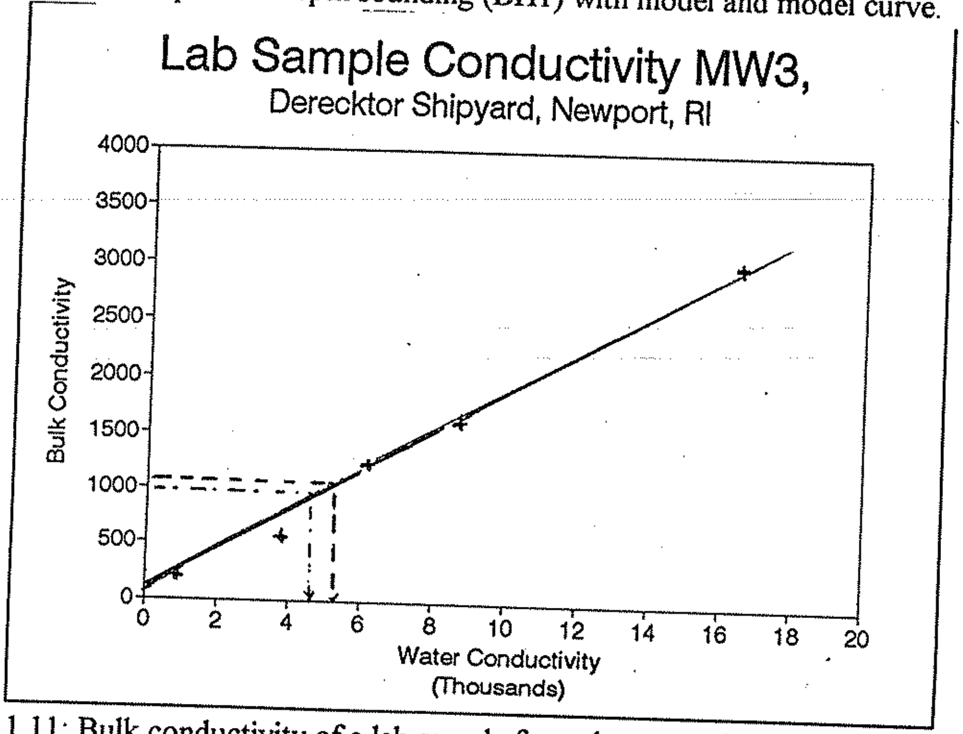


Fig. 1.11: Bulk conductivity of a lab sample from the test well as a function of σ

This curve (Fig.1.11) allows us to estimate the pore water conductivity if we know the bulk conductivity from the interpretation of the geoelectrical depth sounding, shown in Figure 1.10. The bulk conductivity is 1111 μ S /cm, which translates into a pore water resistivity of $\sigma = 5200\ \mu$ S/ cm. Obviously this is a highly polluted site, which was expected as pollutants flow downgradient towards the bay. Some of this salinity may have been caused by storm surges.

1.6 The EM and GPR method

Both the EM and GPR methods are very popular, as they are fast and the results are meaningful if the interpretation is qualitative. The EM (electromagnetic) method induces an alternate current in the ground with a coil that can be carried over the ground. The voltage is picked up with a second coil, known as the receiver coil. Altering the distance between both coils can alter the depth penetration. Another instrument, based on the same principle, has current- and receiver coil installed at opposite ends of a boom. The instrument measures apparent electrical conductivities that are composed of true resistivities and their boundaries.

The advantages of fast coverage and a usefulness of the data for qualitative reconnaissance surveys make this method very popular. The EM method cannot provide a vertical distinction of different layers with different resistivities as accurately as it is possible with the AMNB method. This method works best if the target is very shallow.

The GPR (ground-penetrating radar) method emits a vertical radar impulse. A GPR profile looks very similar to a seismic reflection record. Changes in the dielectric constant and electrical conductivity cause some of the radar energy to be reflected. High electrical conductivities attenuate the radar energy considerably. This can be applied to locate pollution from landfill leachates. High electrical conductivities in the groundwater is recognized by the disappearance of reflections. This is suitable to locate pollution plumes, particularly if other geophysical methods are used to characterize the aquifer. The same data processing methods as they are used in the seismic reflection method can be applied. This allows the use of various filter methods and includes deconvolution and autocorrelation. Uncertainties in the two-way reflection velocity can be overcome with occassional borings and other geophysical methods. High resistivity rocks transmits radar energy very well. GPR has been successfully used to locate fractures in rocks.

The major disadvantage is a limited depth penetration of less than 70 feet. Saturated clays at shallower depths can also terminate the depth penetration, as clay can fully reflect all electromagnetic energy.

For shallow depth engineering work the GPR is suitable for projects, such as laying pipe lines, sewer pipes, and foundation work. A high frequency radar emitter has a smaller depth penetration but a higher resolution. This is useful for quality checks of a road construction, for instance.

Example 1: GPR profile across a sediment filled bedrock depression (Davis and Annan, 1992).

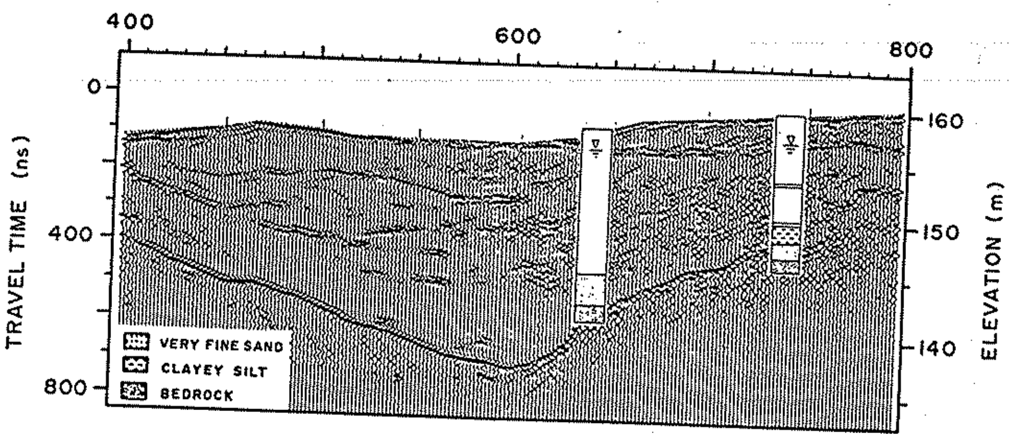


Fig. 1.12: GPR Profile

Example 2: Underground GPR profile for locating fractures (Holloway, 1992).

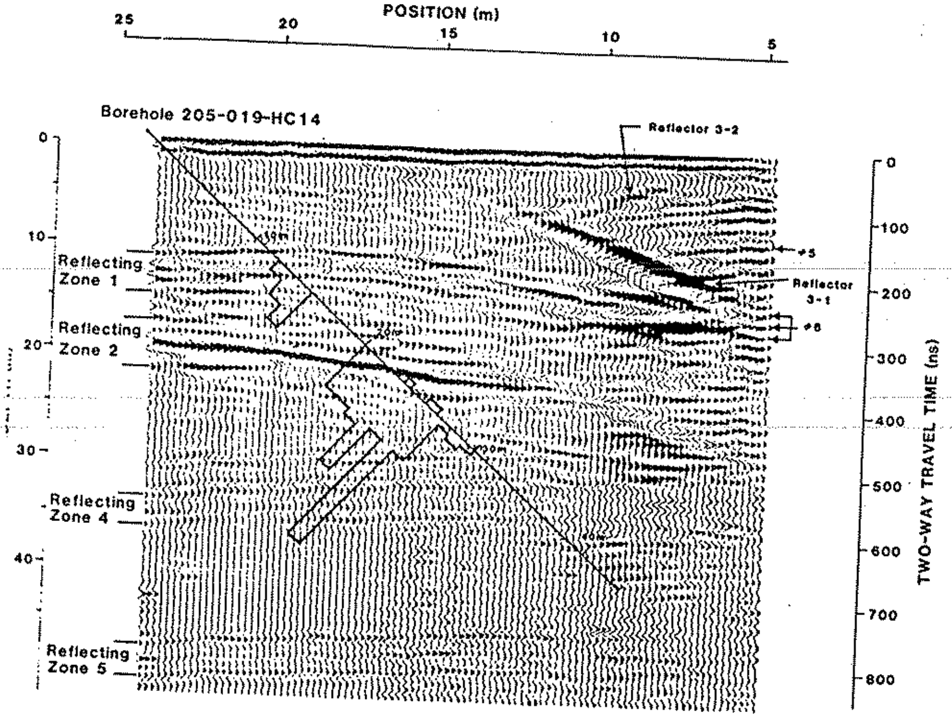


Fig. 1.13: GPR profile underground. Whiteshell Nuclear Research Area, Manitoba, Lac du Bonnet batholith.

2. The Seismic Refraction Method

2.1 Introduction

This well established and frequently used method is based on the travel time of a shock wave through different types of rock. The travel time that elapses beween the impact of a hammer, fall weight, or an explosion and the arrival at a vibration pick-up, a geophone, informs us about the subsurface structure. The seismic refraction method allows us to determine the wave propagation velocities of different layers, layer thichnesses and dips. In the seismic reflection method the travel times of near vertical reflections are observed. This method has been used exclusively for oil exploration, but there are some successful near-surface applications from depths as shallow as 10m. The measurements are being conducted with compressional or P-waves. Shear or S-wave applications in the weathered zone are indicative of rock weathering and fracturing. In this booklet we restrict ourselves to the seismic refraction method using P-waves.

2.2 Measurement units and hydraulic parameters

From the travel times we can obtain the seismic wave velocity of P-waves, which is a characteristic rock parameter. There are general rules for unconsolidated rocks that are more of a qualitative nature. The velocity of unsaturated sand, V_1 , is always smaller than that of saturated sand, V_2, and the bedrock velocity, V_4 , is largest. Between V_2 and V_4 is the intermediate velocity, V_3, of till or weathered bedrock. If this is basal till it is seldom observed because of its relatively small thickness. Typical velocity ranges are:

V_1 : 400-600 m/sec; V_2 : 1300-1500 m/sec; V_3 : 2300-2900 m/sec; V_4 :3000-6700 m/sec

There is also a considerable variability of the P-velocity in compact bedrock. In the crystalline igneous and metamorphic terrane of New England the bedrock velocity depends on the degree of fracturing. Relationships between V_p and the RQD factor have been observed. The latter represents the percentage of unfractured recovered core from a boring. For a fractured rock this factor is small because of frequent breakage.

2.3 Field measurements and instrumentation

Seismic refraction profiles are laid out in reverse lines. I is the impact of a hammer, a fall weight, or an explosion (s. Fig. 2.1). The arrival times from I to G1 .... G6 are measured with geophones. The same is done for I' to G6.....G along the reverse profile.

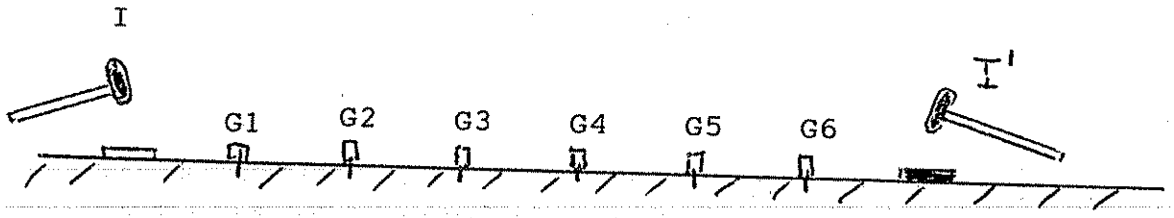


Fig. 2.1: Layout of geophones and hammer impact for reversed seismic refraction profiles.

The travel times are plotted in both directions. For horizontal layers travel times of both profiles would be the same, as it is shown in Fig. 2.2.

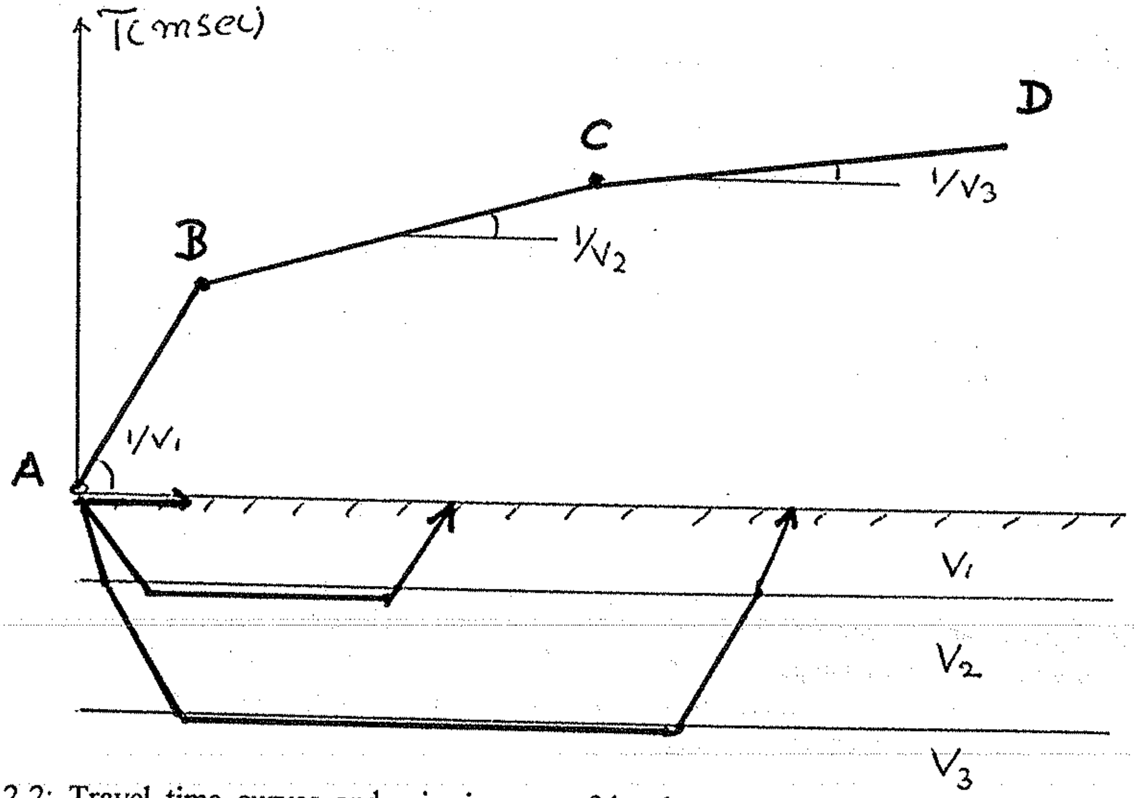


Fig. 2.2: Travel time curves and seismic rays of head waves (heavy lines) over a horizontal three-layered substratum.

The travel time curves in figure 2.2 show T in milliseconds versus the distance I-G. The first arrivals are on straight line segments.

The instruments are "High Tech" electronic digital recorders. The geophones are connected with an amplifier, digitizer and a data processing unit. A good unit , available for $ 20,000. , is a 12-channel recorder. It processes and filters the vibrations and prints all 12 channels for a comparison and visual correlation of first and sometimes later arrivals. Again, there are single channel seismic recorders for educational purposes, but a professional job should at least utilize a 12, if not a 24 channel recorder.

2.4 Interpretation

The principle of seismic wave refraction is the formation of a wave travelling with the speed of V_2 along the boundary between layer 1 and 2. This wave is known as the "head wave" and is shown in figure 2.2 as a heavy line. The head wave continuously returns energy to the surface, where it is the first arrival along the second segment from B to C. Another head wave develops along the second interface between layers 2 and 3. This wave will return energy to the surface, where it forms the third segment of a first arrival from C to D. For each segment the slope is the inverse of the true layer velocity. If the layers are inclined, one needs a reverse profile. One obtains from the slopes apparent velocities. A computer program, based on a rather complicated set of geometrical relationships, provides an estimate of the true layer velocities, the layer thicknesses and dips.

The seismic refraction method is not always successfull, when the layers are curved or offset by faults. In this case more refined interpretation methods, like the plus-minus method can be useful. A layer that is too thin does not show as a first arrival. This is known as the "blind layer" problem, which leads to significant errors of all depth estimates. Often the first arrival is very small and it needs considerable impact energy to recognize it. If two successive layers do not increase but decrease in velocity (velocity inversion) the head-wave cannot form and a refraction is obtained from the next deeper layer. Problems associated with the blind layer and the velocity inversion can only be recognized with a comparison with borings. Another obstacle is the noise in the form of unwanted ground vibrations. There is always some vibrational noise from wind, trees, traffic, and people. The larger the distance between I and the most distant geophone, the larger is the depth penetration. At large distances, however, the signal from the impact becomes very small which is compensated with a larger instrument amplification. Effective filtering sometimes helps, but in general one would need to use larger explosive charges.

2.5 Applications of the seismic refraction method

Example 1: (Hanson, 1988) Two reversed profiles are shown from the Central Landfill, Johnson, Rhode Island. The purpose was to investigate the integrity of the rock, whether it is compact, weathered, or fractured. The assumption was that a fractured and weathered rock shows a smaller seismic velocity than a compact rock. Figure 2.3 shows a reversed profile over a compact rock.

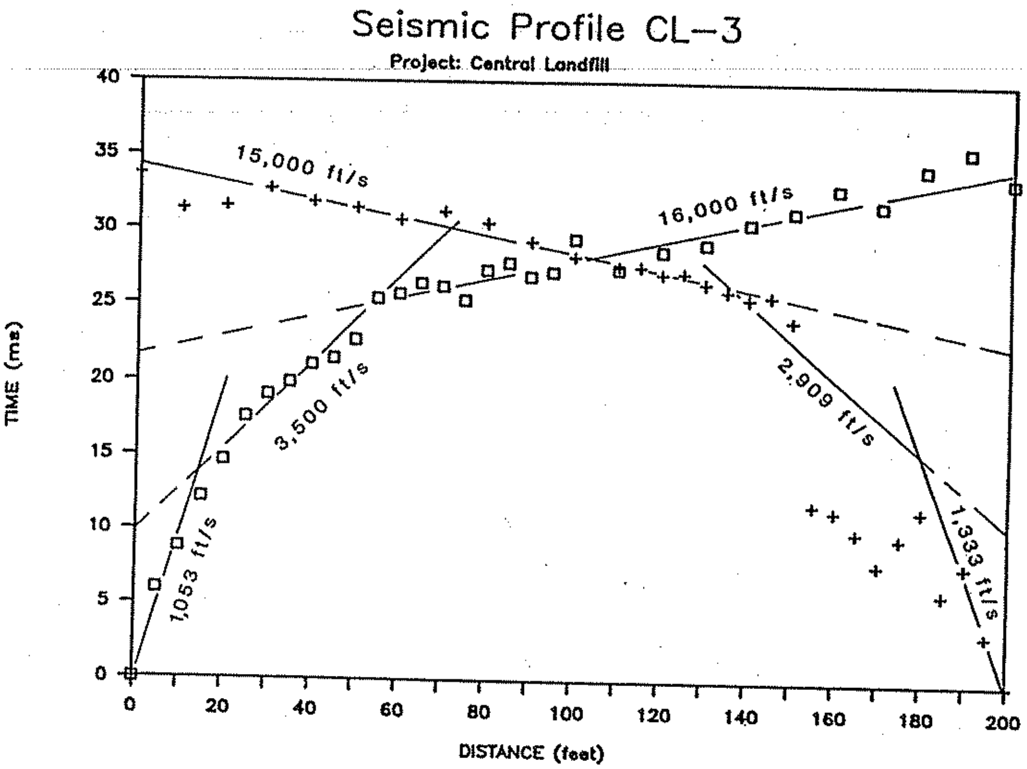


Fig. 2.3: Reversed seismic refraction profile over a compact rock

Interpretation

1195 ft/sec

------------------------ 6.5 ft

3175 ft/sec

------------------------ 18.5 ft

15,405 ft/sec

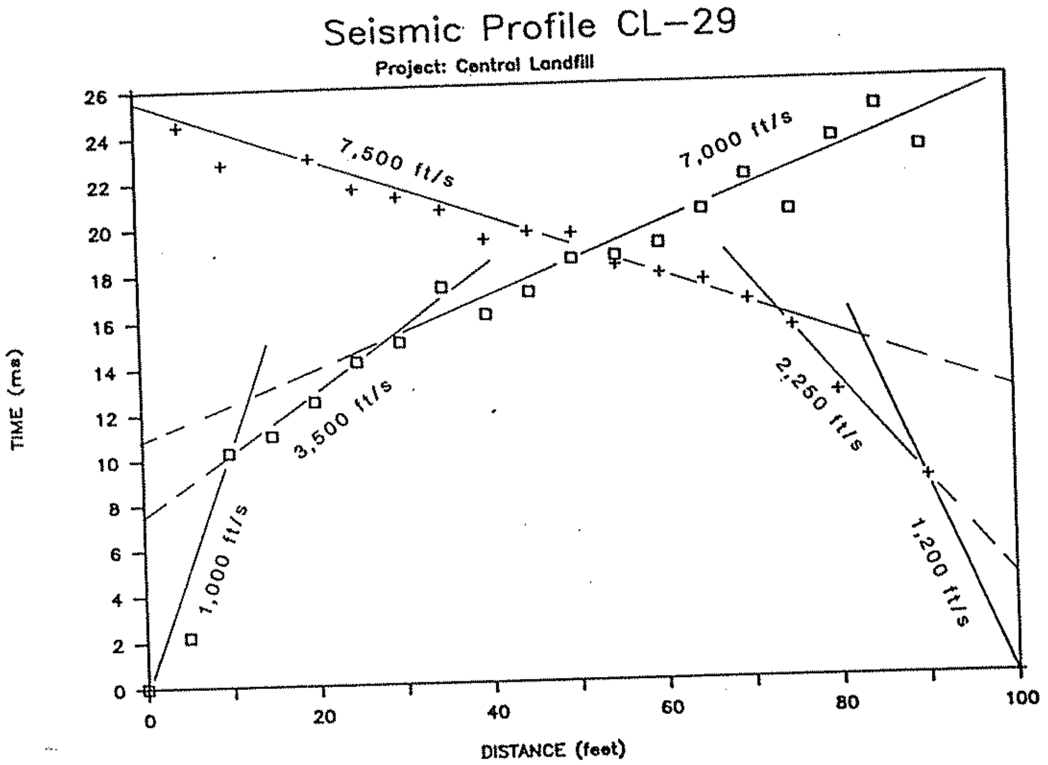


Fig. 2.4: Reversed seismic refraction profile over a fractured bedrock

---------------------- Interpretation

1050 ft/sec

---------------------- 6.3 ft

3230 ft/sec

---------------------- 16.5 ft

9175 ft/sec

On the Central landfill the second example is typical for a highly weathered and fractured rock. The bedrock velocities were compared with the RQD factor. The following relation was found:

$$V = 850 + 137 * (RQD) \quad \text{ft/sec} \qquad \text{(Hanson, 1988).}$$

<u>Example 2:</u> (Hanson, 1989) Another example of a compact bedrock is shown from Tiverton in Rhode Island.

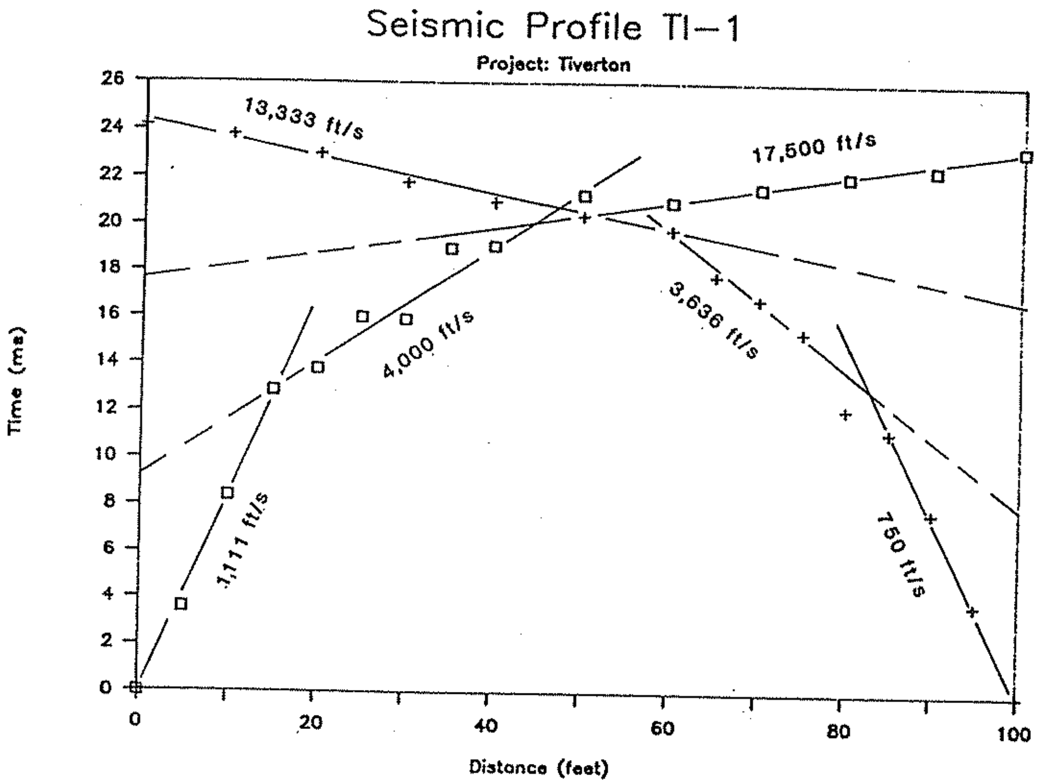


Fig. 2.6: Reversed seismic profile over granite in Tiverton

Interpretation

1150 ft/sec

5.5 ft

3770 ft/sec

11.7 ft

16150 ft/sec

3. Gravity

3.1 Introduction

In comparison to the geoelectric and seismic method we do not apply artificial energies in either the gravity or the magnetic method. Both methods are therefore not as powerful, but they respond to lateral material changes that can be useful to descibe the lateral limits of aquifers.

3.2 Measuring units and related rock parameters

The earth's gravity attracts masses towards its center due to a gravitational acceleration g. It is measured in gals or milligals. The approximate value of g at the earth's surface is 980 gals or 980,000 milligals (mgals). 1 mgal is the adopted unit of measurement for anomalies of the normal gravity of the earth. The anomalies are deviations from the normal gravity caused by lateral changes in the mass distribution of geological and hydrogeological structures. Changes in the mass distribution are caused, for instance, by the displacement of a dense rock, such as a granite, versus a less dense glacial sediment. But there are also density contrasts between massive rocks, as they exist, for instance, between granite and gabbro, which are both igneous rocks.

For unconsolidated rock the density is closely related to the porosity, which ranges in a sand of uniform particle size between 48 and 28% depending on the type of packing. With a density of the particles of 2.65 gr/cm^3 (grams per cubiccentimeter), a saturated sand ranges between 1.30 and 1.91 gr/cc. One can make, with some borehole control, quantitative estimates of the depth of sedimentary basins and the associated aquifers. One can further estimate bulk densities, some porosities and the horizontal extent of aquifers.

3.3 The field survey and instruments

The measurements are conducted with a gravimeter that is placed on the ground and needs leveling. A base station is needed for frequent reoccupation in order to observe the instrumental and tidal drift. The field work is considerably slowed down, as the elevation of each observation point needs to be known within + 5 cm accuracy.

The instrument shows the extension of a spring-supported mass, known as a scale reading. The difference in the scale reading observed between the base and an observation station is multiplied with a scale factor to give the difference in mgal. Repeated observations at the base station are necessary to construct the drift curve, that represents the change of gravity with time due to tidal forces and small changes of the instrumental response. Since the gravity is also dependent on the exact elevation, the observed gravity needs to be reduced to a uniform datum. Also the latitude needs to be known for each station, as the normal gravity increases with latitude due to the oblateness of the earth and its rotation around the polar axis.

Gravimeters are highly sensitive instruments that need a well-trained technician to operate.

A good instrument has an accuracy of + 0.01 mgal at a price around $20,000. Elevation surveys are conducted with a theodolite. A considerable reduction of the field work is possible with a GPS (ground positioning system) that can measure elevations as accurate as 5 to 7.5 cm, which is sufficient for most applications. This way, one can also measure gravity in poorly accessible areas, where one could not make a conventional line-of-sight elevation survey, such as in jungles and areas of karst collapses. The cost is approximately $30,000. The most accurate measurements are made with the Lacoste & Romberg gravimeter Type D, which has an accuracy of + 0.0025 mgal at a price of $60,000. Such accuracies are needed to find underground addits, tunnels, and archaeological remains. Also important is that the gravity method is the only geophysical method one can use in a city without having to worry about noise interference.

3.4 Data processing and interpretation

Before we can relate the gravity observations to subsurface structures it is necessary to apply some reductions. First, the temporal change of the gravity, observed at the base, is used to apply the drift reduction. The normal gravity is defined as the gravity one would measure at sea level if the earth were homogeneous. It is an ellipsoid with a short radius at the poles and a long radius at the equator. The resulting latitude dependence of the normal gravity is shown in the international gravity formula (Geodetic Reference System, GRS 1967):

$$g = 978.031846\,(1 + 0.005278895 \sin^2 \Phi - 0.000023462 \sin^4 \Phi) \qquad (3.1)$$

Next we need to apply the elevation reduction with a well known reduction formula. For this we need to know a good estimate of the surface density. If the terrain is characterized by steep mountains and valleys, one also needs the tedious topographic reduction. If all reductions are applied, we obtain the BOUGUER gravity, which is :

$$\Delta g_{\mathrm{Boug}} = \Delta g_{\mathrm{obs}} + \Delta g_{\mathrm{drift}} + \Delta g_{\mathrm{elev}} + \Delta g_{\mathrm{lat}} + \Delta g_{\mathrm{topog}} \qquad (3.2)$$

Contour lines of the Bouguer gravity show the distribution of subsurface masses. The gravity anomaly is positive if the Bouguer gravity is above the normal gravity due to eq. 3.1 , otherwise the anomaly is negative.

Similar as in geoelectrics one can generate model anomalies, based on assumed density contrasts and boundaries, and compare them with the observed Bouguer anomaly. Preliminary models are mathematically simple; they consist of spheres, prisms, sheets, and dikes. Most geological structures do not fit into such simple geometries. Complicated two-dimensional structures with a constant crossection can approximate any geological structure with the polygon method.

We are again confronted with the nonuniqueness problem. In the case of the buried sphere, for instance, the mass and its depth controls the anomaly curve. If the mass has the form of a sphere we do not know how big its radius and how big the density contrast is, as they are both interchangeable. But we do know the mass. Again, we need some borehole evidence to narrow down the estimate of the source of the anomaly.

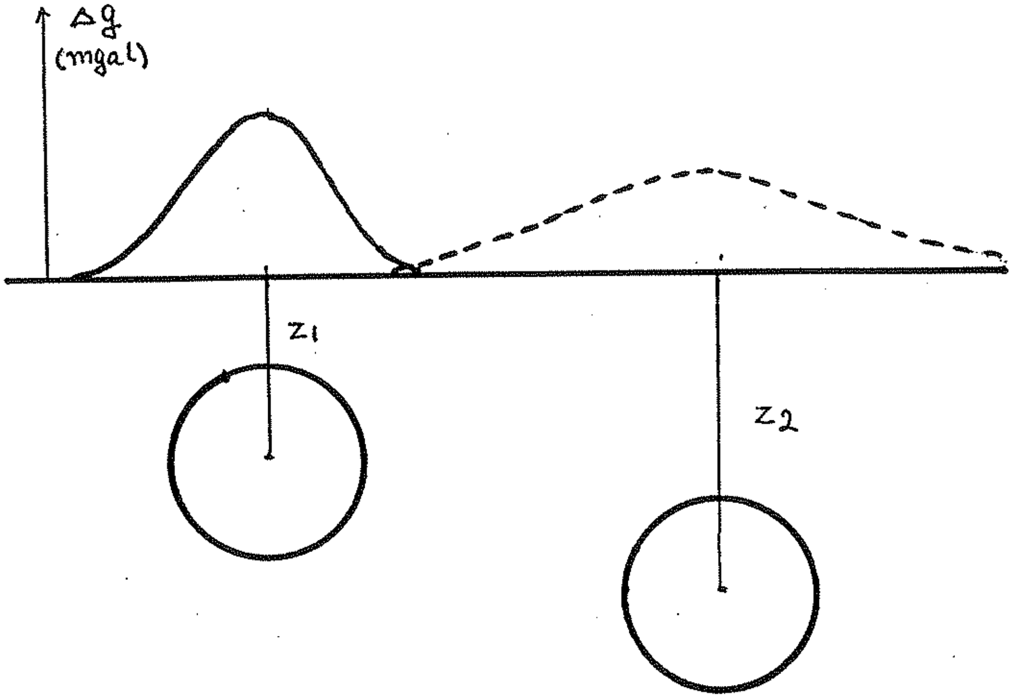


Fig. 3.1: Gravity anomaly curves of two identical spheres buried at different depths.

A further important theorem is the possibility to distinguish shallow from deep sources. Using again the sphere, the left anomaly in figure 3.1 shows a shallow sphere with a peaked anomaly and steep flanks. The anomaly to the right originates from the same mass that is buried at a greater depth. The anomaly shows gently rising slopes and a lower maximum anomaly than the anomaly to the left. Steep gradients are characteristic for shallow hydrogeological anomalies.

3.5 Application of the gravity method

Example 1: This example of the Big River Reservoir shows how an extensive boring program can be replaced by a few borings and a gravity survey. The purpose of this study was to test the subsurface conditions for its suitability as a barrier against seepage from a planned water reservoir. After the bedrock depths and the condition of the sediments became known from numerous borings a gravity survey was conducted as a class project of an advanced undergraduate course (GEL 465 Introduction to Geophysics) of the Department of Geology at the University of Rhode Island.

Figure 3.2 A(top) shows the gravity stations along Division street south of Highway 95 and Lake Mishnuck. Figure 3.2 B (center) shows the Bouguer gravity, displaying a broad gravity low of -1.6 mgal. One value at 1700 m distance from the west falls out of the regular gravity low, probably due to an erroneous reading. Fig. 3.2 C (bottom) shows the bedrock depths and the types of sediments as they were constructed from well logs. The sediments consist primarily of fine to medium sand and some silt.

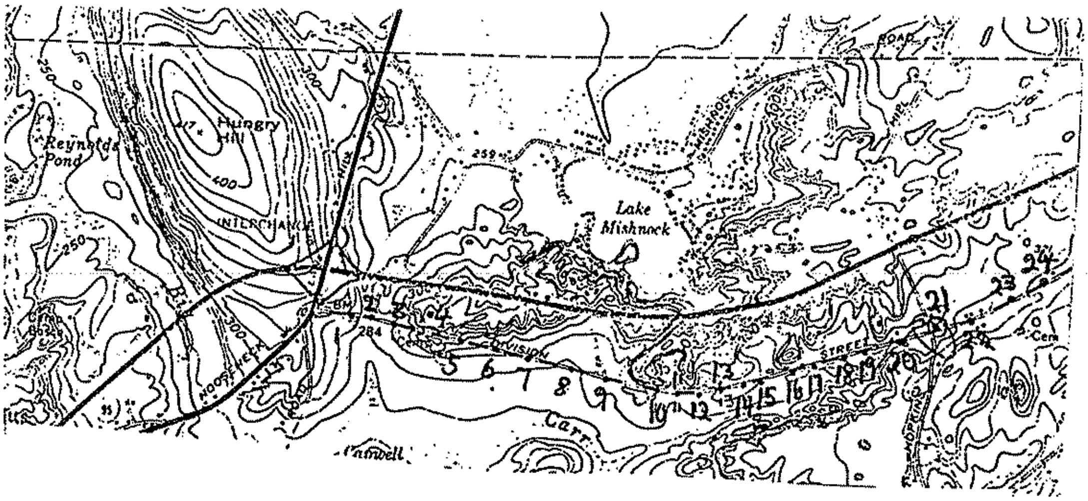


Fig. 3.2 A: Big River Reservoir - location of gravity stations

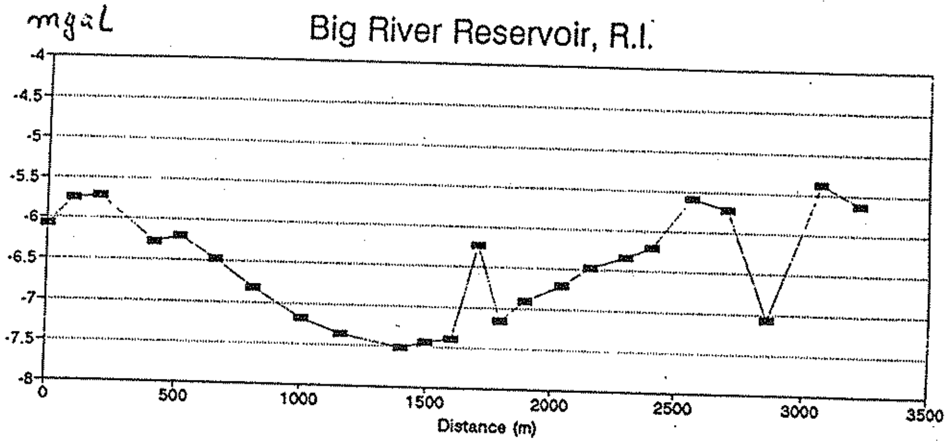


Fig. 3.2 B: Big River Reservoir - Bouguer gravity across a bedrock valley

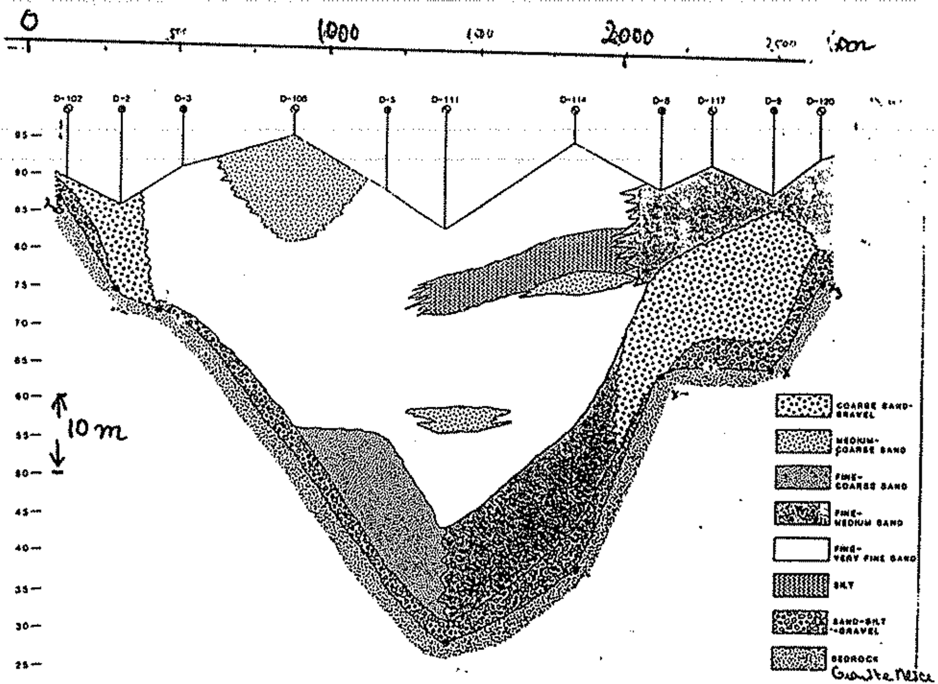


Fig. 3.2 C: Big River Reservoir - bedrock depth and glacial sediments

Fig.3.3 presents an interpretation of the gravity anomaly with the polygon method. Figure 3.2 C shows the depths and X-coordinates that were used for the polygon model. Since the size and location of the sediments are known from the borings, one can obtain from the gravity interpretation, i.e. the model, the overall density contrast and the average porosity. The best-fitting model curve shows a density contrast of $\Delta \sigma = -0{,}6$ gr/cc . If we assume a density for the Scituate granite of $\sigma = 2.67$ gr/cc. This can be converted to an average porosity of 37 %, a material that is unlikely suitable as a barrier for a reservoir.

Fig.[illegible]: Bouguer anomaly (dashed) and model anomalies (drawn) of the gravity across the Big River Reservoir. Crompton Quad. Rhode Island, USA. Density contrast of sediment fill versus bedrock.

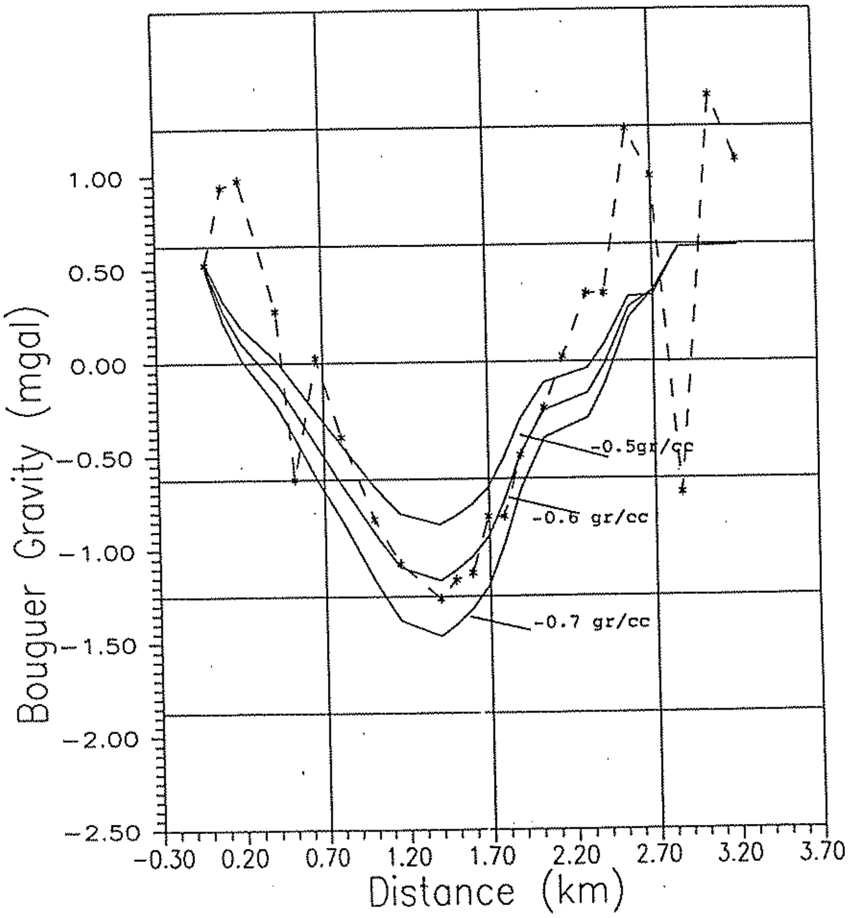


Fig.3.3: Model curves calculated for different density contrasts compared with the observed gravity, Big River Reservoir, R.I.

Example 2: This is a small section of the contoured gravity map of Rhode Island (Frohlich, 1978). The Narrow River in Narragansett flows from north to south in a straight line. It can also be seen on the lineament map of Rhode Island as a straight lineament (Ross and Frohlich, 1991). The southern cuspate lobes of the contour lines are characteristic for the superposition of a local anomaly, an elongate gravity low, over a more regional larger gravity field caused by deeper bedrock structures. This example strongly suggests that the Narrow River flows on top of an extensive fracture zone.

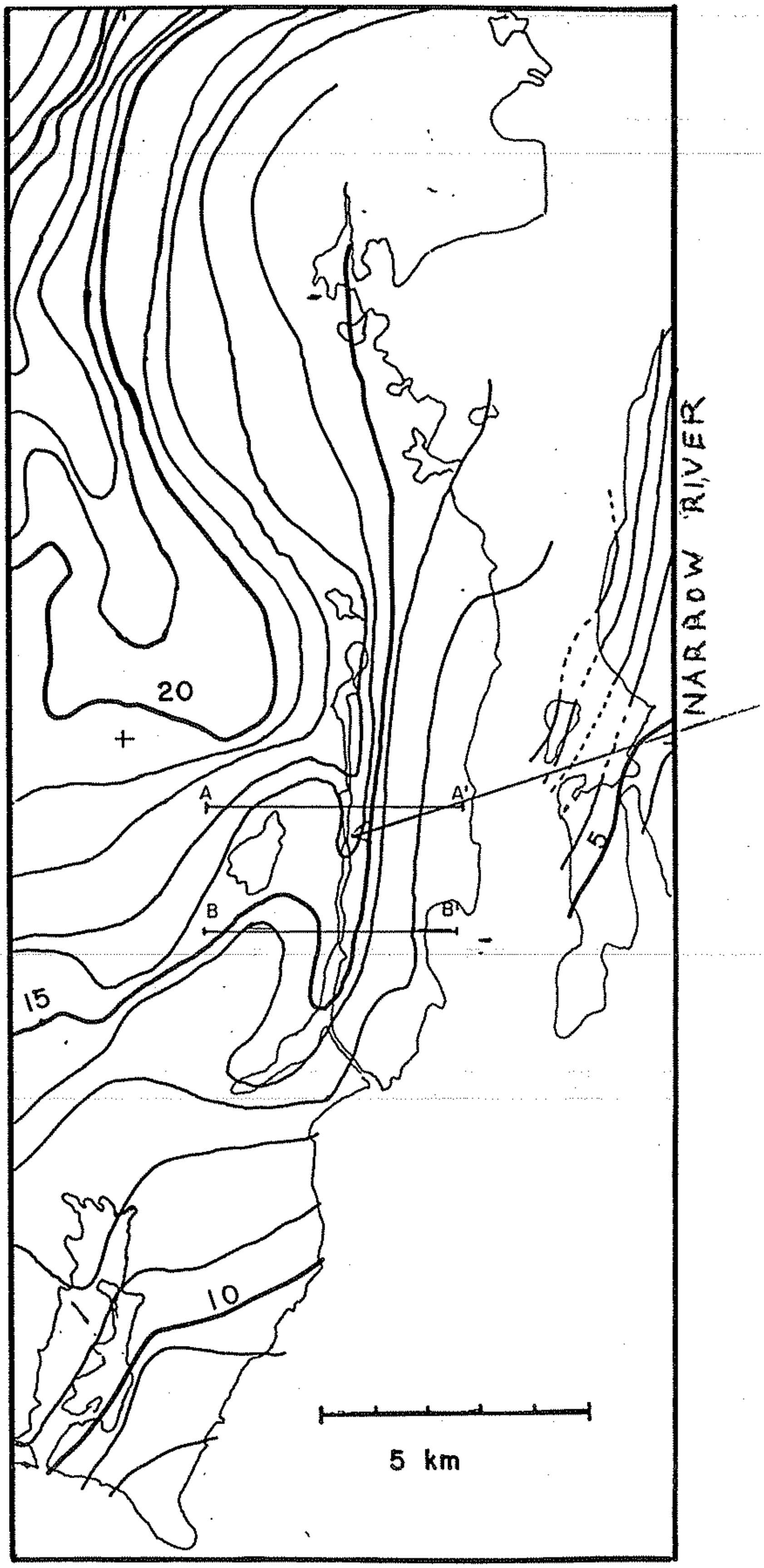


Fig. 3.4: Narrow River gravity anomaly. Narragansett Quadrangle, RI.

4. The Magnetic Method

4.1 Introduction

Magnetic anomalies are deviations of the normal magnetic field of the earth. The anomalies are caused by geologic structures that cause an irregular distribution of magnetized rocks. Measuring the magnetic anomalies has contributed to the understanding of large geological structures, as they occur, for instance, near major plate boundaries. The method is of limited use in environmental and hydrological work. Under special conditions, however, magnetic anomalies are related to water bearing fracture zones. Fracture-related anomalies are frequently observed in crystalline rocks.

4.2 Measuring units and rock parameters

The earth has a static magnetic field that is measured in Oerstedt. Some rocks are magnetized so that their magnetic field is superimposed over the earth's magnetic field. This superposition generates a magnetic anomaly which is measured with a magnetometer in units of nanoTesla (nT), which convert to Oerstedt as follows: $1\ \text{nT} = 10^{-4}$ Oerstedt.

A rock becomes magnetized in two different ways. One is the induced magnetization , J_{ind}, which is proportional to the ambient magnetic field F and the magnetic susceptibility χ , a rock constant. The arrow over F indicates that it is a vector, which means that it has besides an intensity also an orientation. The second kind is the remnant magnetization., J_{rem}. This type of magnetization was acquired during the formation of the rock and it does not depend on the ambient magnetic field. The total magnetization of a rock is then:

$$M = \chi\ F\ +\ J_{rem} \qquad (4.1)$$

While J_{rem} is constant with respect to latitude, the induced magnetization changes with F and thus with the location. The ambient field changes in direction from the equator to the poles from horizontal to vertical respectively. Its intensity increases from the equator to the poles by a factor of two. The ratio of remnant to induced magnetization is Q:

$$\mathbf{Q} = \frac{|\mathbf{J}_{\mathbf{rem}}|}{|\chi\ \mathbf{F}|} \qquad (4.2)$$

Young ocean basalts, the tholeitic basalts, can have Q's as high as 100. Most crystalline rocks of southern New England have Q<1, they have a predominantly induced magnetization (Stolzman, 1978).

4.3 Field measurements and instrumentation

Field measurements are simpler than observing gravity, as it is not necessary to know the elevation. It is, of course, important to locate the observation point on the map. Sometimes rock outcrops are also magnetic. In this case it is advisable to measure the magnetic field three times at the corners of a small equal-sided triangle. Large differences observed on the corners of this triangle suggest near surface disturbances from rock outcrops or from buried iron scraps.

There are many different magnetometers, all of the proton precession type. The measurement is accomplished by pushing a button which yields the magnetic field intensity. It is advisable to return at equal time intevals to a base point as the earth's magnetic field is, like the gravity field, subject to temporal changes. For $5500 one can obtain a good instrument with an accuracy of 1nT. Better instruments for $8000 have a memory so that one can load the data into a computer. The accuracy of this instrument is 0.1 nT, which, however, is seldom needed.

4.4 Interpretation

The magnetic anomalies are interpreted by trial and error with magnetic models by changing model parameters until field and model curve fit. This is similar to the interpretation of gravity anomalies. The number and nature of assumptions is more numerous and complicated in comparison to gravity observations. Magnetic susceptibility meters can measure susceptibility on outcropping rocks and rock samples. The laboratory Spinner magnetometer measures the remnant magnetization of a rock sample. Such additional data can reduce the uncertainty due to the nonuniqueness.

The fundamental source of a magnetic anomaly is the magnetic dipole, which has a positive, + P, and negative magnetic pole, -P, separated by a distance l. This dipole is characterized by a dipole moment: $m = 2 P l$. The most simple body is the uniformly magnetized sphere that can also be represented by a magnetic dipole. Simple magnetized bodies are the sphere, dike, and a semi-infinite horizontal layer. More complicated geologic bodies can be approximated with the polygon method, similar as with gravity models. Important is that the model anomalies change shape and amplitude depending on the latitude, or more specifically, on the inclination of the earth's magnetic field. Figure 4.1 shows the anomaly of a magnetized sphere due to induced magnetization at different latitudes. The anomaly has at low latitudes (A) a large magnetic high followed to the north by a small but broad low. At higher latitudes (B) the sphere has a sharp and larger high and a subdued broad low to the north. At the northpole (C) the anomaly is symmetric and very large and positive in amplitude with minute lows at both flanks. The arrows in the spheres indicate the orientation of the induced magnetization, which is equal to the inclination of the ambient magnetic field. Important is that the anomalies look completely different at different geographic latitudes for the same body with constant magnetic susceptibility.

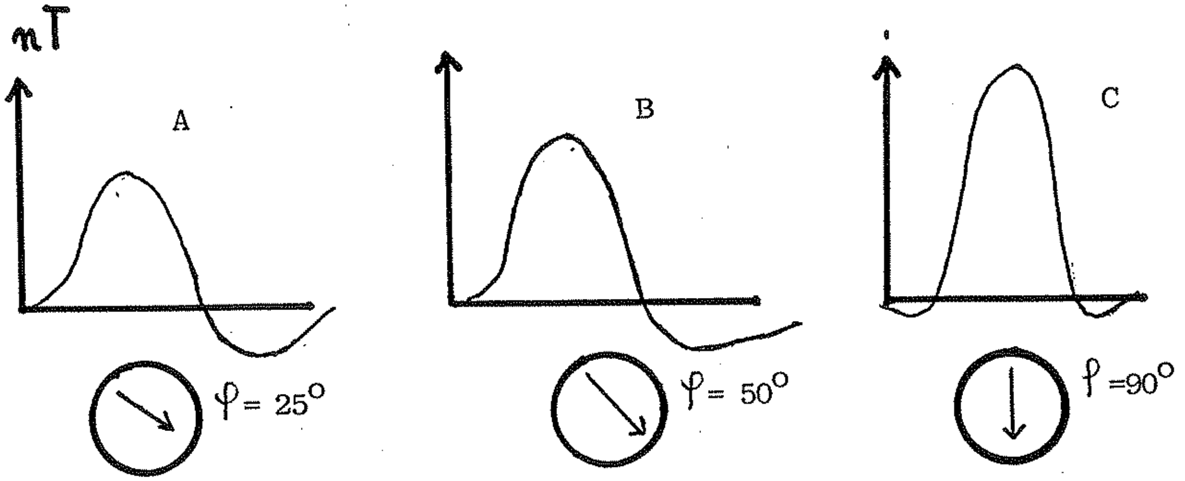


Fig. 4.1 Magnetic anomalies over a buried sphere at different latitudes

4.5 Application of the magnetic method

Example 1: This anomaly was observed over a mapped fracture zone. Predominantly magnetic lows with no positive peaks are difficult to understand in the northern hemisphere, unless one uses a remnant magnetization that is inverse to the induced magnetization.

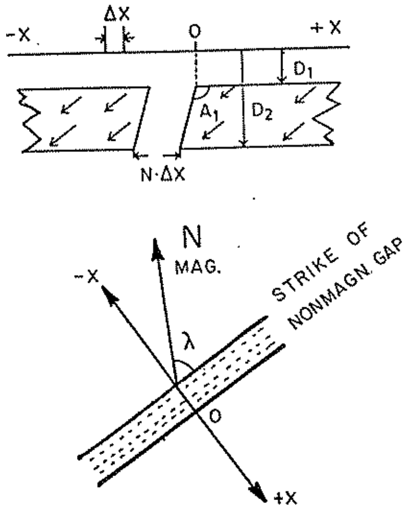


Fig. 4.2: Model of a nonmagnetic fracture zone between magnetized slabs.

As this is very unlikely for granites, other frequent structures need to be found. A possible way of producing a magnetic low without inverse remnant magnetization is a nonmagnetic fractured zone, while the unfractured bedrock remains magnetized. Figure 4.2 shows the model parameters necessary for calculating a model anomaly.

Figure 4.3 shows an interpretation of a magnetic anomaly with a model after figure 4.2. The drawn curve is the model anomaly and the dashed curve the observed magnetic anomaly.

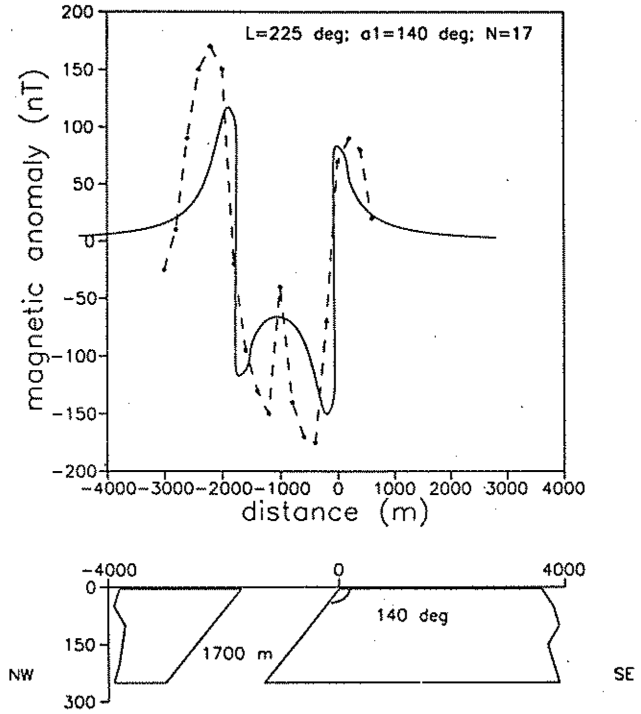


Fig. 4.3: Magnetic model (bottom) and model anomaly compared with observed anomaly dashed curve.

<u>Example 2:</u> The example on the next page is the result of a class project to study a buried fracture zone that has an elongate depression at the surface(s.Fig.4.4A). Underneath, Figure 4.4B shows six profiles along which the magnetic field was observed at 10m station intervals. Fig. 4.4C shows the magnetic profiles. The peaks signify the center of the ravine. The profiles have not yet been interpreted with a model.

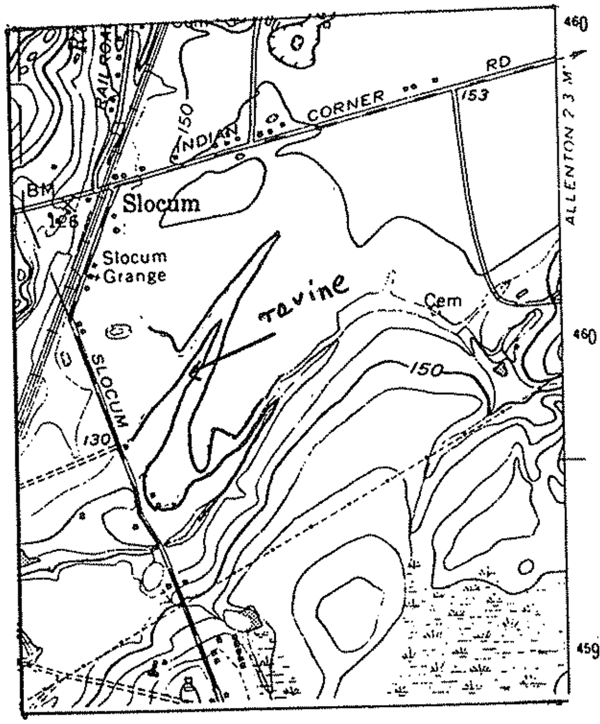


Fig. 4.4A: Location of an elongate depression (ravine). Slocum Quad. R.I.

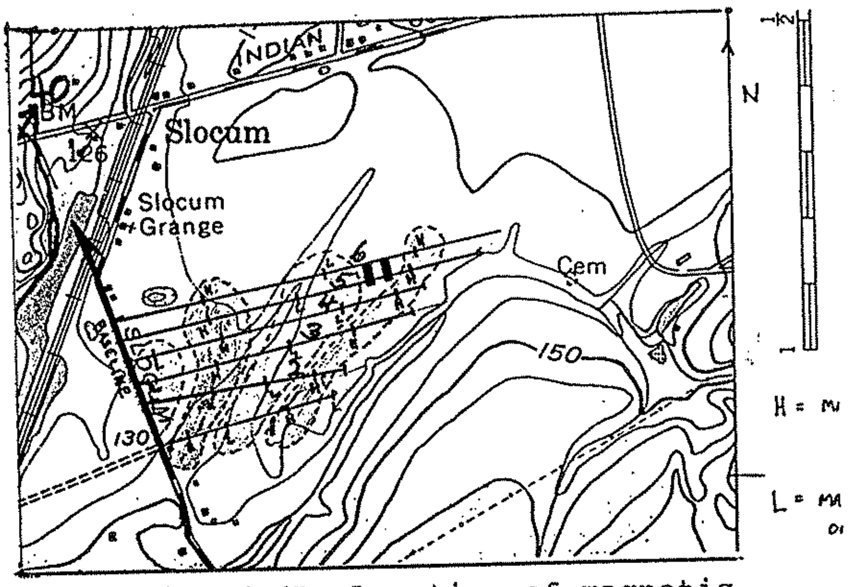
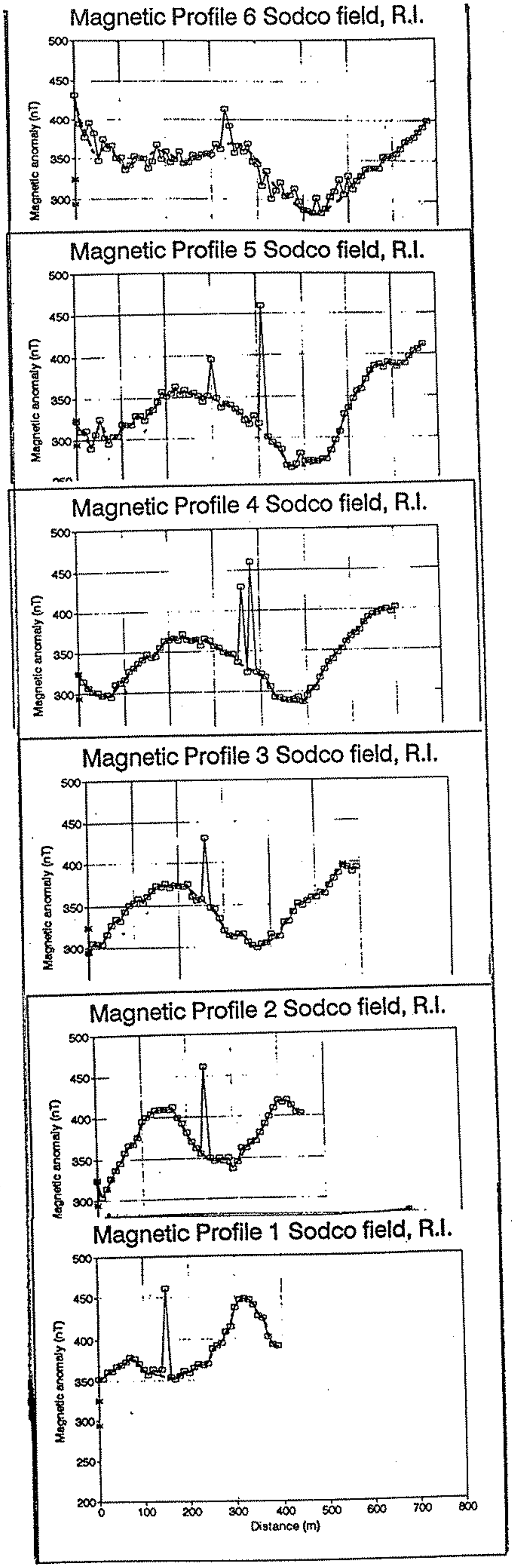


Fig. 4.4B: Location of magnetic profiles across a depression.

Fig. 4.4 C: Magnetic profiles 1 to 6. Marker point (high) identifies the center of the depression.



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Davis, J. L., and A.P. Annan, 1992: Applications of groundpenetrating radar to mining, groundwater, and geotechnical projects: selected case histories. in Ground Penetrating Radar, Geological Survey of Canada, Paper 90-4, p. 49-55.

Frohlich, R.K., 1986: The simple Bouguer gravity of Rhode Island. Report, US Nuclear Regulatory Commission, Washington, D.C.2055. NRC/FIN B5961/2, 24pp.

Frohlich, R.K., 1989: Geoelectrical depth soundings for siting bedrock wells in Aroostook County. Report prepared for the Maine Geological Survey, Department of Conservation, pp. 75

Frohlich, R.K., 1989: Assessment of groundwater pollution, Derecktor Shipyard, NETC Newport, Rhode Island. Report to the NETC, Newport. pp. 36.

Hanson, L.G., 1988: A seismic refraction investigation of the hydrogeology of fractured bedrock. Unpublished master's thesis, Department of Geology, University of Rhode Island, pp. 198.

Holloway, A.L., 1992: Fracture mapping in granite rock using ground probing radar. In Ground Penetrating Radar, Geological Survey of Canada, Paper 90-4, p. 85-98.

Parke, C. D., 1984: Geoelectric estimation of specific yield. Unpublished master's thesis, Department of Geology, University of Rhode Island, pp. 139.

Ross, A.L., and R.K. Frohlich, 1993: Fracture trace analysis with a geographic information system "GIS". Bull. Assoc. Engin. Geol. 30 (1):87-98.

6. Recommended readings (partially annotated)

A list of readings has been selected predominantly from the "white literature" so that the titles are available in university, government, and industry libraries. This does not include in-house reports, as they are, for instance, prepared for funding agencies, which are often difficult to get.

1. GEOELECTRICS

Frohlich, R.K., and W.E. Kelly, 1985: The relation between hydraulic transmissivity and transverse resistance in a complicated aquifer of glacial outwash deposits. Jour. of Hydrology Vol. 79, p. 215-229. (error margins for the interpretation of depth soundings and transmissivities in a complicated aquifer are shown).

Frohlich, R.K., D.W. Urish, J. Fuller, and M. O'Reilly, 1994: Use of geoelectrical methods in groundwater pollution surveys in a coastal environment. Jour. of Appl. Geophysics. Vol.32, p. 139-154. (Detailed information on the freshwater aquifer, sandwiched between nonconducting unsaturated and saltwater saturated zone, is presented with an explanation of the measuring and interpretation problem of depth soundings and Wenner profiling).

Kalinski, R.J., Kelly, W.E., and Bogardi, I, 1993: Combined use of geoelectric sounding and profiling aquifer protection properties. Ground Water Vol.31, p.538-544.

Kosinski, W.K. and W.E. Kelly, 1981: Geoelectric sounding for predicting aquifer properties. Ground Water, Vol.19, p. 163-171. (This paper shows the relationship between hydraulic conductivity and electrical resistivity of a glacial aquifer)

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7. Drilling, Sampling, and Geophysical Exploration

7.1 Drilling Methods

A variety of drilling and sampling methods provide subsurface information of different quality at accordingly different prices. The cost of drilling and sampling depends on the type of rock, whether it is unconsolidated, cohesive, or consolidated. The price also depends on the type of sampling, whether rock fragments are brought up with the drilling fluid, whether cores from hard rock are needed, or whether split spoon samples can be taken. Often water quality needs to be monitored at different depths over a longer time, requiring nested monitor wells.

The following methods are most frequently used:

Wash borings are least expensive. A pipe progresses downward with the drilling fluid. Bedrock, boulders, and sometimes basal till are identified as refusal. The rock formation is evaluated from rock and debris fragments brought up by the drilling fluid. The depth of the material observed in the drilling fluid is uncertain and gravel and clay are not as easily detected as sand. An experienced hydrogeologist/quarternary geologist may obtain from this method some meaningful insight. Though this is the least expensive drilling method, it provides rather lean information on an aquifer.

Hollow stem auger drilling provides oportunities for more detailed sampling, such as split spoon sampling. Sophisticated devices provide a 24 inch barrel of almost insitu conditions. The method is used for unconsolidated and cohesive material to depths of approximately 100 feet. Penetration is obtained with hammer blows of a standard weight. The number of blows per 6 inch advance are counted and present information on the stiffness of the material. The drilling log is usually terminated with the remark "refusal", which is either bedrock or some hard basal till.

Rotary drilling is used in slightly indurated rock to depth beyond 100 feet. A rotating crown breaks the rock into small fragments. The penetration is recorded in minutes per foot at a given down pressure on the tool. The same is accomplished with the *Percussion* and *Cable Tool* drilling, where the rock is crushed by blows and the bits are flushed with the drilling fluid to the surface. This method is faster than the previous one, but it is also more expensive.

Coring is the most expensive method used in consolidated rock. A rotating diamond-studded pipe is driven into the rock, leaving a rock column, the core, inside the pipe. A core catcher keeps the core inside the pipe, while it is being brought up to the surface. The cores reveal the frequency of fractures, rock texture, rock type, and rock boundaries.

Monitor wells are needed for taking water samples at intervals through a filter screen in a casing. This also allows frequent monitoring of the water level after the drilling has been completed. Sometimes nested wells are needed to take water samples from different depth and to monitor changes in piezometric pressure.

Bedrock wells do not need casings, except in the upper part of unconsolidated material. Therefore a water well in bedrock may turn out to be relatively less expensive.

One should not forget that, whatever information a well provides, it is only valid within 2 - 6 inches from the center of the well. This was found to be particularly valid in finding fractures or fracture zones in buried bedrock. In such cases the use of geophysics is not a cost issue, as it is needed to locate borings. Drilling is an invasive exploration method and it can alter the hydraulic condition of the rock. If groundwater pollution is restricted to permeable layers that are separated by silt or clay, borings can destroy the integrity of an aquifer.

7.2 The planning of a combined geophysical and borehole survey

A meaningful combination of geophysics and drilling has to be carefully organized to insure that both surveys complement each other. Timing is of great importance. Too often some geophysics is attached after the drilling has been completed, in order to add "modern" methods to the survey. This does not safe any money and is cosmetics at best. Geophysics should never compete against drilling, as both surveys complement each other. In many cases the cost of exploration, when used within reasonable limits, should not be a dominant issue. Millions of dollars are lost if a construction project must be abandoned or redesigned because of inadequate information on subsurface conditions. In such cases millions of dollars are lost while a few thousands are saved in exploration costs. The following are a series of steps one can take to investigate a site:

First: The problem needs to be understood by looking at old and nearby well logs, geologic and other maps, if available. Some surficial observations and accessibility checks are done at this early stage.

Second: The geophysicist must decide on the use of the most suitable geophysical method(s) by conducting some preliminary field tests, preferably near outcrops or already existing borings.

Third: Next are a series of geophysical profiles that cover the entire area under investigation. Standard interpretation will show where there is nonuniqueness. The geophysicist depicts areas where the geophysical results are unique and other areas where the data are nonunique. In cooperation with the hydrogeologist areas for the first test drilling are selected. Here a good cooperation is most important for the further work of the combined exploration.

Fourth: Both, the geophysicist and hydrogeologist, decide whether the geophysical interpretation is compatible with the well logs. The original interpretation can now be adjusted with the well logs.

Fifth: With the geophysical interpretation method, calibrated with well log data, the geophysicist continues the geophysical survey. The outcome of points four and five will determine how many boreholes relative to geophysical work are needed. Poor correlation will make more boreholes necessary, whereas a good comparison of boreholes with geophysics will require less boreholes. How many test wells and how much geophysics are needed is often decided upon at the very beginning. The survey will be most cost-effective if the decision on the relative amount of boring/geophysics can be postponed until stages four and five are completed.

Sixth: Final test wells will be necessary where the interpretation of geophysical measurements needs to be confirmed and when decisions are necessary regarding locations of highest importance.

7.3 Cost estimates of borings and geophysical surveys

For a specific case cost estimates are presented that would be incurred if the exploration depends on borings alone. These figures will then be compared with cost estimates of combined explorations that include borings and geophysical surveys. The price structure reflects the change in costs if the original borings can be reduced by a certain percentage due to the geophysical survey.

Different sources reported considerable price differences in details, such as mobilization costs, samples, analyses, and type of drilling. Costs will significantly rise if hazardous and toxic substances are expected, and whether an OSHA-trained crew and health and safety equipment are needed. Everybody will probably have a different opinion about the cost; therefore ranges are shown rather than fixed prices.

The area of interest has the size of 1 square mile in which competing land use culminated in a dispute whether the site needs to be protected as it is an extension of an aquifer that supplies water to domestic and some communal wells, or whether the land can be used for a sanitary landfill. The area is glaciated with an average of 100 feet of an overburden over shales.

Table 1 shows a cost estimate of 50 borings (5000 feet) and of a geophysical survey that includes geoelectrics, seismic refraction, and some gravity. It is very difficult to evaluate the increase in information on the subsurface conditions gained by using geophysics (in addition to the drilling) in terms of money. One can argue that additional information gained from geophysics is not really necessary. On the other hand, it is an insurance against "unforeseen" problems. A geophysical survey can, for instance, be used to direct boreholes to critical areas, which then show maximum depth to bedrock, maximum amount of pollution, highest porosity etc. It is very difficult to wage the extra cost of a geophysical survey against such an oriented drilling program, as one can never find out how the project would have progressed with drilling only.

Estimates for drilling a total of 5000 feet with hollow auger stem including well material, water and sample analysis etc. range between 150,000.- $ and 250,000.- $.

The geophysical survey includes preliminary tests, 50 geoelectrical depth soundings, 10 reversed seismic profiles, and two gravity profiles. Including some flexibility of additional measurements depending on the results would cost between 30,000.- $ and 40,000.- $.

Table 1: Cost of combined drilling and geophysical survey in thousands of dollars.

		Boring		Geophysics		Total	
# of wells	% reduction	Minim.	Maxim.	Minim.	Maxim.	Minim.	Maxim.
50	0	150	250	30	40	180	290
40	20	120	200	30	40	150	240
30	40	90	150	30	40	120	190
25	50	75	125	30	40	105	165

7.5 Finding a geophysical company

A company representative of a geophysical firm will not only have your interest in mind, but also how he can utilize the resources of his company optimally to your benefit. How do you find a suitable geophysical company?

In the northeastern USA there are not as many geophysical companies or consultants as in the Midwest or in the West. But geophysical equipment is portable and a company can be very flexible and mobile.

The Society of Exploration Geophysicists (SEG, Box 707740, Tulsa, OK 74170-2470)

is very helpful, as they support the business aspect of geophysics. Inquiries with companies should also include a request for information on their activities and competence. Often a company specializes in only few of many methods. Small companies have low overheads and can offer more cost-effective services; large companies charge higher overheads, but may be better equipped and offer more methods. But also remember that a large company can afford to make occassionally a mistake, whereas a small company cannot afford to loose its reputation. It is good to have an independent expert available for a second opinion.

There is, of course, much of word-of-mouth recommendation. Geophysical companies and consultants belong to a group of industries that are still competitive on the world market. It is easy to provide glowing company brochures. Ask for company or personal profiles and find out whether they publish in scientific and engineering journals that are anonymously refereed. Anybody who can get his/her paper through a rigorous review, and not only once, has good qualifications.

8.0 Acknowledgement

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Appendix

1. Basics of Groundwater

1.1 Introduction and Definitions

1.2 The Hydraulics of an Aquifer

1.3 The Hydraulic Conditions of Different Rock Types

1.4 The Pumping Well

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2.2 The Bedrock of Rhode Island

2.3 Fracture Trace Analysis

Appendix

1. BASICS OF GROUNDWATER

1.1 Introduction and Definitions

Fresh water is the most valuable commodity; it is something we cannot do without. Competition for its use and its pollution has and does lead to wars between nations, its lack is the cause of hunger and starvation. Bacterially and chemically polluted water is the cause of epidemies which are very typical for slums in Asia and South America but can also affect semi-affluent neighborhoods, like Love Canal in upstate New York.
The storage and flow of water in different types of soil and rock is studied so that we can pump it in sufficient amounts to the surface for drinking, industrial, and agricultural purposes.

Groundwater: Water stored in soil and rock.
Aquifer: Rock material from which water can be pumped at an affordable price.

Aquifer Material

I. **Unconsolidated rock,** also known as soil, is classified by average grain size diameter in inches:

clay	silt	fine	medium sand	coarse	gravel
<0.0002 in	0.0002-0.002	0.005-0.01	0.01-0.02	0.02-0.04	0.08 - 2.5 in

II. **Consolidated rock**: Classification by origin, that is: how did it develop ?

1. **Sedimentary rock:** originated from lithification of unconsolidated rock. During lithification the grains are compacted and cemented with either lime, ironoxide, or silicate. Examples are: shale (originating from clay), siltstone (from silt) , sandstone (from sand), conglomerate (from gravel), limestone (from lime = calcium carbonate).

2.0 **Igneous rocks:** derived from a molten magma that cooled to surface temperatures.

2.1 **Igneous intrusive rocks:** magma cooled at depth very slowly, leaving a rock with very large crystals. Examples: granite, diorite, gabbro.

2.2. **Igneous extrusives**: magma cooled rapidly while it reached the surface in a molten stage. Examples: basalt, tuff, pumice.

3. **Metamorphic rocks:** rocks described in 1. and 2. are subjected to high pressure and temperature, but they do not melt (!), they change to metamorphic rocks. Generally restricted to a few narrow belts but abundant in new England, including Rhode Island.
Examples are: gneiss (originating from granite), greenschist (from basalt), quartzite (from sandstone), marble (from limestone), schist (from shale).

1.2 The Hydraulics of an Aquifer

The usefulness of a soil or rock as an aquifer depends on hydrogeologic parameters, its accessibility and its remoteness from pollutants.

The hydraulic constants:

I. **Hydraulic conductivity**: is a number that characterizes how easily water can flow through the interstitial pores of a rock.

$$K = \frac{g \cdot \rho}{\eta} \cdot P$$ [gallons per minute / ft] or gpm/ft or gpd/ft or cm/sec

g: earth's gravity acceleration
ρ: specific gravity
η : viscosity
P: permeability

K has the dimension of velocity. Typical examples of K are:
silt: 0.30 cm / day; fine sand: 3.0 cm / day; coarse sand: 30 - 300 cm / day; gravel: 3000 cm/d

II. **The transmissivity:** probably the most important aquifer constant is defined as:

$T_R = K * b$ [gallons per minute/ft] or short: gpm/ft or ft /day

where b is the thickness of aquifer.

III. **The porosity:** is given in percent of void space relative to the total volume of soil or rock. This unit tells us how much water can be stored in a rock. As an example, one cubic centimeter sand of 30% porosity has 0.3 cubic centimeter void space and 0.7 cubic centimeter solid rock material.
An aquifer of unconsolidated material has a crossection as shown in Fig.1:

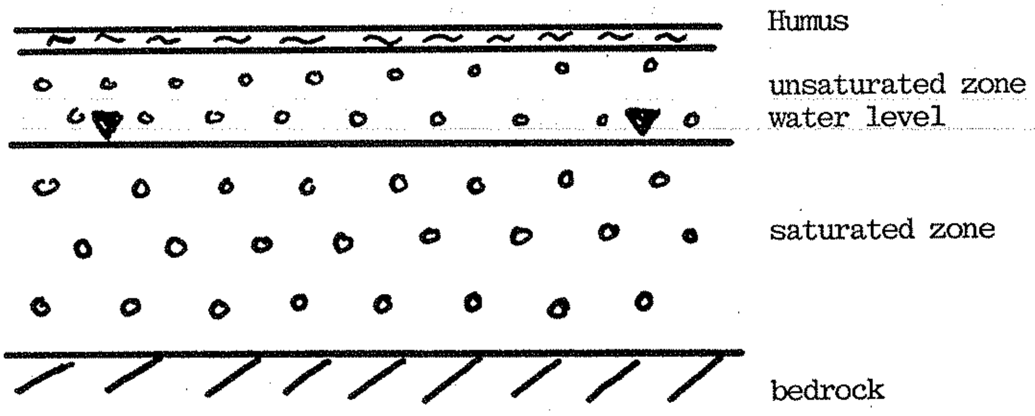

Fig.1: Vertical crossection of an aquifer. Triangles show the water table.

So far we described an aquifer with a uniform grain size. Normally a sand or gravel will have a mixture of grain sizes. An average unconsolidated sediment may have some silt, some fine sand, plenty of medium sand and no coarse sand and no gravel. We are dealing with a "grain size distribution" , which can be uniform, meaning that we have basically one uniform grain diameter. In this case we say the material is well sorted (geologists) or poorly graded (engineers). If the sediment has a mixture of many grain sizes we describe it as poorly sorted (geologists) or well graded (engineers). We can determine the different grain sizes with a sieve analysis.

1.3 The Hydraulic Conditions of different rock types

Unconsolidated rocks, classified by grain size, generally display a hydraulic conductivity that is proportional to the grain size.

* gravel: high K, because of excellent pore connectivity.
* sands: acceptable to very acceptable values of K, but smaller than for gravel.
* silt : substantially lower K, not suitable for an aquifer. The pore channels are so narrow that water sticks to the grain surface. This material is also known as an aquitard, it will let water pass but at an extremely slow rate.
* clay : Extremely low K, water sticks completely to the very small grains. This material is known as an aquiclude. In spite of very high porosities of clays, the water cannot be extracted.

Consolidated rocks are classified by origin. These rocks generally exhibit smaller hydraulic conductivities than unconsolidated rocks, except for secondary permeabilities, acquired during fracturing. When rocks are exposed to tectonic stresses, they break and display faults and fractures.

*Sediments: Due to the cementation of grains K and porosity are smaller than in the unconsolidated state. Sandstones are often used as aquifers. Limestone often shows dissolution voids and channels that can form caves and extensive fracture systems. They form the biggest springs in the world and present an abundance of water. Examples are the Mammouth Cave in Kentucky, Carlsbad Caverns, Province of Guilin in China, Streams in Missouri, Floridian Karst, etc. The dissolution channels in limestone are part of a surface system, knowns as "karst". Besides the caves and water systems it includes certain very typical landforms and collapse structures.

* Igneous Intrusive Rocks: These rocks show a negligible primary porosity and permeability at the time of cooling. They can later acquire a "secondary porosity and permeability", if they are exposed to tectonic stresses. Under these influences they will yield by breaking and faulting. In the first case we have **jointing**, meaning the formation of open spaces. The same happens during **faulting**, but the rocks are also moved against each other. Fractures can be sources of groundwater, particularly if they have wide apertures (openings).

* Igneous Extrusive Rocks: Particularly tuff and pumice, which are the result of explosive volcanism (Mt. St. Helen) can have a very high permeability.

* Metamorphic Rocks: These rocks are usually equally as massive as igneous intrusive rocks. They also show fractures and faults if subjected to tectonic stresses.

1.4 The Pumping Well

Groundwater is brought to the surface by means of pumping from a well. A hole is drilled with a 2 - 4 inch diameter to the bottom of the aquifer. It is cased with a steel pipe that is screened at the bottom. The bottom part is the **screen** through which water is pumped to the surface.
Fig. 2 shows the steady-state water level of the aquifer with the typical drawdown, known as cone of depression. The cone of depression remains stable if the average withdrawal rate does not change.

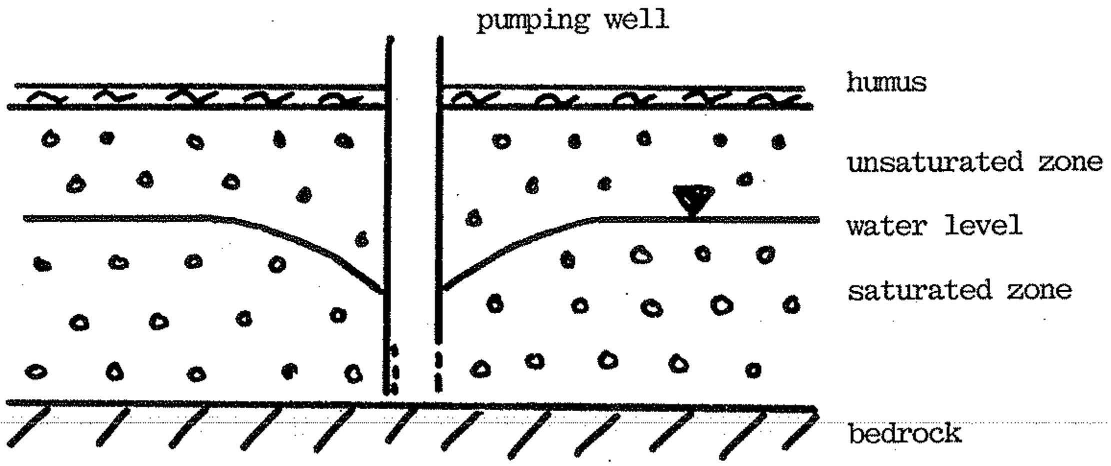

Fig.2: The water level shows a cone of depression during pumping.

When the well is completed, usually a pumping test is done to find out how much water can be pumped safely, that means without pumping the aquifer dry. As a result you will get the **yield,** indicating how many gallons per minute the well produces. Typical values are:

6 - 10 gpm (gallons per minute)	typical bedrock well; sufficient for a small household.
10 - 50 gpm ----------------------	bedrock with fractures
100 - 1000 gpm ----------------	unconsolidated sand and gravel

If more water is pumped than the aquifer can yield, the cone of depression looks like the one shown in Fig.3. The water cannot flow fast enough to the well as it is pumped. We call this water mining. This can happen in wells with a low hydraulic transmissivity. Eventually ther aquifer will be depleted.

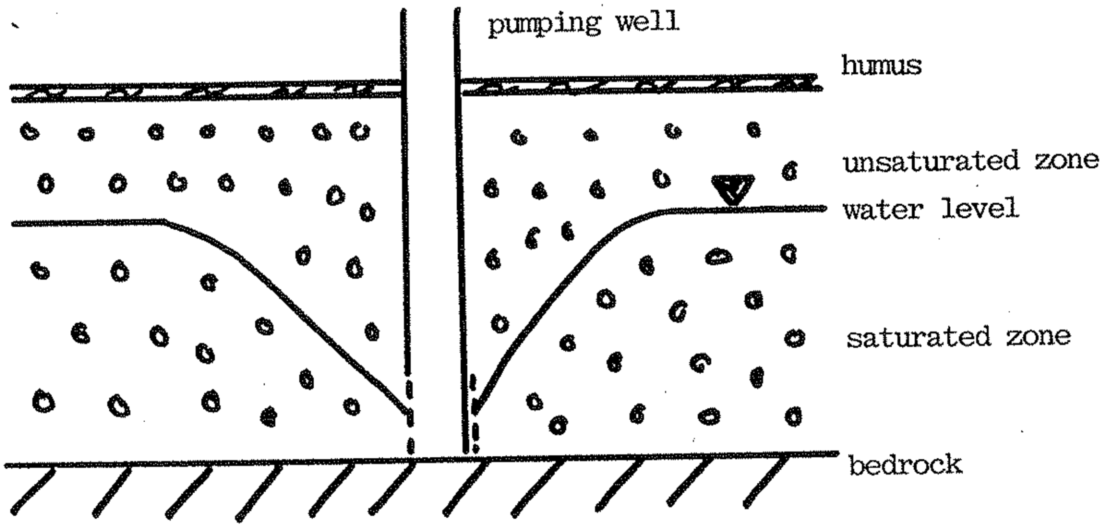

Fig. 3: Cone of depression if too much water is pumped from the aquifer

If the cone of depression is very small, we have an aquifer of large transmissivity, a situation that is not always desirable. The great advantage of having water stored in an aquifer is that it can be purified while it moves toward the well. Dissolved and suspended (small floating particles) that would be objectionable in drinking water are adsorbed by grains of the aquifer. The aquifer acts like a filter, which is most effective for very small particles. Very small particles, however, such as clay and silt, are unsuitable as an aquifer because of the low hydraulic conductivity, as we have learned. Very large particles, such as gravel and solution channels in karst are also unsuitable because of their low filtration potential. In many cases one cannot be too selective and one must take what is there. But extreme caution is necessary to make sure that vulnerable aquifers without a filtration potential, like karst and gravel, are not polluted by carelessness, industrial activity, or intentional polluters.

1.5 GROUNDWATER POLLUTION

Groundwater pollution, or in a milder form contamination, has been a problem since the creation of homo sapiens. Pollutants, undesirable matter, enter either intentionally or through carelessness the groundwater aquifer. **POINT SOURCE** pollution enters the groundwater at a certain location, such as waste dumps, leachates from a sanitary landfill, a buried leaky oiltank, or an industrial site. A continued supply of the pollutants enters the groundwater at one point and spreads (diffuses) through the aquifer, where it forms a pollution plume. The longer it spreads, the more diffuse and widespread the plume becomes. **NON POINT SOURCE** pollution is more difficult to locate and assess. They cause a gradual degradation of the groundwater quality from causes, such as overfertilization, highway salt, and domestic septic systems.

Pollutants fall into three categories:

1. Bacterial Pollution 2. Toxic Pollutants 3. Dissolved Solids

1. Is caused by poor water management and inadequate sanitary conditions, common in the slums of South America, Africa (Ebola Virus), and Asia. The two other kinds of pollutants are of main concern in the USA. 2. Toxic pollutants are carcinogens, such as gasoline, benzene, chlorinated solvents and many other organic compounds. Equally as dangerous are certain metals, such as Arsenic, Cadmium, and Mercury. The third group is the least harmfull as it only affects the taste of water. It becomes objectionable if salts are dissolved as ions. As an example, Sodium Chloride (NaCl) known as halite and used as table salt, not only dissolves, like sugar crystals, but it also <u>dissociates.</u> The elements are separated to positive and negative ions, Na^+ and CL^-, Na being a cation and CL being an anion. The concentration is given in parts per million (ppm). This is the same as 1 milligram / liter = 1mg/l.

Measuring systems:

1 liter: 1 gallon has 3.8 liters.
1 milligram is 1/1000 of a gram;
1 gram is 1/1000 of a kilogram;
1 kilogram (kg) has 2.2 pounds (lbs).

The water quality is defined by the ppm of dissolved solids in the water. Very pure water of less than 50 ppm is not good for drinking, as the water would take minerals out of the body. Too much has a bad taste and the tolerable limit is set at 500 ppm or mg/l. of total dissolved solids TDS. Some industries require a water quality of less than 300 mg/l.

The availability of a certain amount of daily water in gallons per day at a certain favourable price is often the key issue whether an industry will settle in a certain area, like R.I. or whether it will prefer, say Pennsylvania. Generally the USA has quite strict standards for admissible metals and TDS. In this respect we have a good government by knowing what should be right. A major problem is to enforce these standards. It is usually too late when it is discovered that somebody had polluted an aquifer.

2.0 HYDROGEOLOGY

2.1 GLACIAL DEPOSITS AND THE GLACIAL HISTORY OF NEW ENGLAND

New England, Canada, and the remaining northern part of the USA were covered by an ice sheet that reached its southern **terminus**, the southern advance of the glacier, about 21,000 years ago. It is known as the **Laurentide Ice Sheet**, which had its most southern advance south of Long

Block Island, Marthas Vineyard, and Nantucket. The advance of the ice and its retreat by melting generated deposits known as "glacial sediments". They have names as follows:

Glacial till: Poorly sorted and poorly rounded, partially worked up bedrock, deposited at the bottom and at the front of a glacier.
Stratified glacial drift: Meltwater deposits, synonym with glacial outwash which is differentiated into:

> **Glacial fluvial:** Meltwater stream deposits of sand and gravel (good aquifers).
> **Lacustrine or Lake Deposits:** Made up of fine sand, silt and sometimes clay deposits. Clay is rare in New England. Fine sand can be useful as aquifer, but generally Lacustrine deposits have a too small permeability.

Most important for groundwater is the stratified drift. Its thickness varies between few and 300 feet. The large thicknesses are obtained in the glacial stream channels, which are preglacial valleys that were carved by glaciers and later filled with sediments. In these stream channels we find many good aquifers.

2.2 THE BEDROCK OF RHODE ISLAND

The origin of the rocks and particularly their structural history of alterations up to the metamorphic state, is still a matter of ongoing scientific dispute, mainly, because of a collision of an Archetype-African with the American Plate. Having an ancient plate collision of such gigantic extent passing through little Rhode Island, naturally fills the geologist with pride. However, it also presents us with a number of problems that still need to be solved. The more or less safely established facts wrapped into reasonable plate tectonic concepts are published on the new bedrock geologic map of Rhode Island, published by O.D. Hermes, P. Gromet, and D.P. Murray, 1994. Tectonic stresses did not only affect the rock during the gigantic plate collision, they also reoccurred later in episodes causing fractures and faults. They are potential sources of groundwater.

Fractures are openings of consolidated rock due to stress. If a fracture is associated with a dislocation of the rock, meaning that one part of the rock was sheared against the other part, we have a FAULT. If we cannot show shearing, the opening is a JOINT. Without any commitment, we simply talk about fractures, meaning any type of opening. Fractures have been studied in outcrops, with geophysics, and with fracture trace analysis by using satellite photos (Ross and Frohlich, 1992). Worldwide, fractures are of interest to engineering geologists, geological engineers, civil engineers, groundwater engineers, and hydrogeologists. They can be a major groundwater resource. The search of high level nuclear repository and sanitary landfill sites concentrates on massive rock that is not fractured. Recognizing fractures is important for any heavy construction project, such as dams, highways, large buildings, and large oiltanks.

Fractures occur as single break in the rock with an aperture.

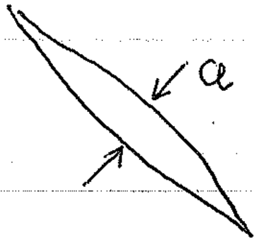

Fig.4. Fracture with an aperture

Often they occur in an en-echelon pattern.

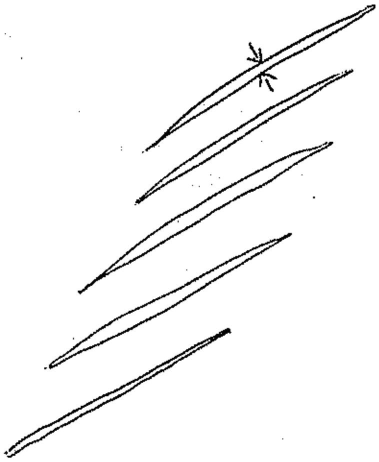

Fig.5: En echelon fracture system

Of interest for the hydrogeologist are fracture zones They are bounded either by an abrupt or gradual transition. The width of the zonew can be as small as few inches and as large as 0.5 kilometers, as in the Watch Hill Lineament of southern Rhode Island.

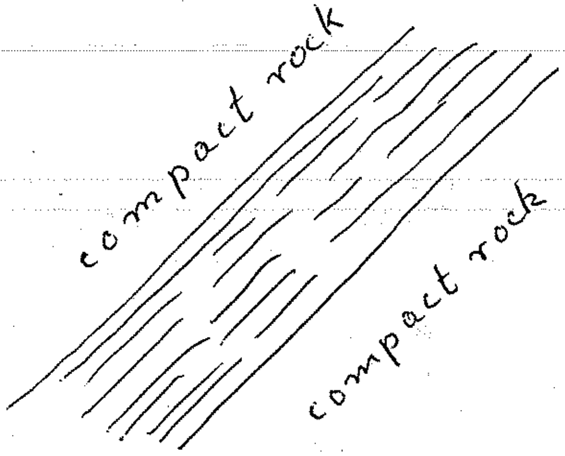

Fig.6: Fracture zone

2.3 Fracture Trace Analysis

Because of the great effect of fractures on the foundation of buildings, dams, bridges and on groundwater flow, any method is valuable that can locate and describe fractures. Large fracture zones extend over long distances of several miles. They are visible from the air and space, where they are recognized as **lineaments**.They appear on photos, which are derived from 3 sources:

1. Satellites - Landsat Thematic Mapper Imagery
2. Aeroplane - Side-Looking Airborne Radar (SLAR)
3. Airphoto - normal photo taken from a plane

Lineaments usually point out areas where the surface topography shows a small depression or less frequently a grate. They very frequently point out trends of high permeability in the bedrock. Sometimes the valleys are distinct, so that one can see them clearly on a topographic map. Other lineaments are more subtle showing a line of ponds or stream diversions.

A major difference between Landsat and SLAR is that SLAR shows more detail, as the plane flies at a lower altitude than a satellite. The disadvantage is that SLAR does not show lineaments that are oriented perpendicularly to the flight direction. Two lineament maps of Rhode Island are available, a Landsat and SLAR imagery map. Can you find out from a comparison, in which direction did the SLAR-plane fly? E-W or N-S ?

Fracture trace analysis is a typical reconnaissance method. It has been used to help the RI Solid Waste Landfill Corporation (RISWLC) locate alternate landfill sites. In siting a landfill we enter politically hot territory, where scientists and engineers often take a backseat. Always remember that this is a reconnaissance method. If you have located a lineament the next step is to find "ground truth", not a nice word. It simply means to go to the ground and see or use ground methods, like geoelectrics. You want to know whether this really was a high permeability fracture zone or something else. We have discovered cases, where an impressive lineament shows no evidence of high permeability and, vice versa, we found high yield wells away from any lineament. Using fracture trace analysis is not a safe way of finding high permeability fracture zones. It is a means of reducing the odds of finding such zones.

Airborne methods, including satellite photos, are very popular over enemy or terrorist's country, like many parts of Africa. You don't need to go to the ground. Rumors have been spread that the US-spy satellites can read the newspaper from space, that is only the heading, of course. You could read "The New York Times", for instance. This only shows you the accuracy of satellite photos, we may get in the future, as long as peace can be maintained between the super powers.

Geophysics in general is not a safe way of finding water or avoiding high permeability zones. But its prudent use will eventually render financial benefits and savings that can never be acquired with drilling only.

Project No. 4

Start: 1996
End: Jan, 1997

Project Title: ACID PHOSPHATASE ACTIVITY AS AN INDICATOR OF PHOSPHORUS STATUS IN RIPARIAN FOREST SOILS

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Focus Categories: NU WL MET

Congressional district: 2nd

Keywords: Phosphorus, Soil Biochemistry, Runoff, Riparian Forests, Acid Phosphatase

Problem and Research Objectives

Increased phosphorus concentrations have accelerated the eutrophication of inland lakes and reservoirs in the northeastern U.S. (Frink 1991). Forested riparian areas are among the best management practices (BMPs) recommended for amelioration of nutrients and other pollutants in runoff (National Research Council 1993). Riparian wetland areas, because of their flatter slopes and high surface roughness, tend to accumulate sediment-bound P that originates from upland areas (Lowrance et al. 1984; Peterjohn and Correll 1984; Vought et al. 1994). In addition to sediment trapping, P removal in riparian areas occurs via plant and microbial uptake and adsoprtion to soil particles (e.g. Lyons et al., 1998). Long-term exposure of riparian areas to elevated P levels can affect the ability of plants, microorganisms, and soil particles to act as sinks for P. There is a need for sensitive, fast, and inexpensive method to evaluate the performance of riparian forest soils with respect to P status. The National Research Council's committee on Long-Range Soil and Water Conservation has identified the long-term effectiveness of riparian zones in nutrient and sediment removal as a major concern (National Research Council 1993).

Soil acid phosphatases catalyze the hydrolysis of organic phosphate esters to *ortho*-phosphate, and thus constitute an important link between biologically unavailable and bioavailable P pools in the soil (Speir and Ross 1978). Acid phosphatase is ubiquitous in soil and is produced by microorganisms in response to low levels of inorganic P, and its production and activity are inhibited by elevated levels of inorganic P. To test the performance of acid phosphatase as an indicator of P status, we evaluated: (1) the sensitivity of acid phosphatase activity to inputs of inorganic P, and inorganic P and N in simulated runoff over the course of a year within a riparian forest area, as a function of landscape position, and (2) the temporal variation (within and between seasons) of the response of acid phosphatase activity to inorganic P, and inorganic P and inorganic N. We investigated the effects of inorganic P, and P and N, on short and long-term turnover pools of acid phosphatase activity.

This research addresses Research Priority Area A, Watershed/Ecosystem Management, and specifically subsection d, Effective management strategies for riparian zones and wetlands protection and assessment of their role in the retention and recycling of nutrients and toxicants. We evaluated soil acid phosphatase activity as an indicator of the P status of soil, and thus of potential P saturation and reduced biological removal in riparian forest soils. To the best of our knowledge, the only study on phosphatase activity in riparian forest soils is the one published recently by Amador et al. (1997). Thus, the present study is the first one on the potential use of phosphatase activity as an indicator of P status of riparian forest soils. The results of this study will be of use to land and water managers and land-use planners in monitoring the performance of riparian areas and in assessing their role in water quality enhancement.

Methodology

The study was conducted in moderately well drained (MWD) and somewhat poorly drained (SPD) soil within a drainage catena in a forested riparian area of the Peckham Farm research area of the University of Rhode Island in Kingston, RI (approx. 41°30' N, 71°45' W). The soil in the upland portion of the catena is mapped as a Hinckley sandy loam (sandy-skeletal, mixed, mesic Typic Udorthent), whereas the soils in the lower portions of the catena are mapped as Walpole sandy loam (sandy, mixed, mesic Aeric Haplaquept) and Scarboro mucky sandy loam (sandy, mixed, mesic Histic Humaquept) (Soil Survey Staff 1981).

The experiment consisted of three treatments: (I) control amended with distilled deionized water; (II) simulated runoff containing P only; and (III) simulated runoff containing P and N. Both drainage classes received all three treatments. Within each drainage class, each treatment was replicated four times in a randomized block design. Treatment replicates consisted of 1 m X 1 m square plots separated from each other by a 0.5-m wide buffer. Plots received 1 cm of simulated runoff. Application of simulated runoff was made monthly from September through November 1999 and April through October 2000 for a total of eight applications. Simulated runoff was applied evenly to the surface of the plot using a watering can. In all treatments the litter layer was placed on a removable screen that was replaced after the treatments were applied. Nutrients were applied at a rate of 0.75 kg PO_4-P/ha (Treatment II) or 0.75 kg PO_4-P/ha and 3 kg NO_3-N/ha (Treatment III) on every application.

Soil cores (2-cm dia.) were collected below the litter layer (0-5 cm) from each plot in September, October, November, and December 1999 and March, April, May, June, July, August, September, October, and November 2000 approximately four weeks after simulated runoff treatments were applied. In April 2000, soil samples were collected one, two, and four weeks after treatments were applied. Four samples were collected and bulked randomly from within each plot. Soil samples were screened through 2-mm-mesh sieve, placed in sealable plastic bags, and stored in the dark at 4°C for no more than one week. Storage of soil samples for six to eight weeks under these conditions has been shown to have no significant effect on phosphatase activity (Speir and Ross 1975; Gerritse and van Dijk 1978).

Phosphatase activity was assayed twice for each sampling time: once using field-moist soil samples immediately after collection ("Total" activity, TPASE) and a second time using soil samples that were air-dried for two months ("Recalcitrant" activity, RPASE). The difference between Total and Recalcitrant activity is referred to as "Labile" activity (LPASE). Phosphatase activity was assayed using the method of Tabatabai and Bremner (1969), modified as described by Duxbury and Tate (1981) and Amador et al. (1997) for soils with a high organic matter content. Soil organic matter content was determined by loss-on-ignition for 4 h at 550°C (Karam 1993). Soil moisture content was determined gravimetrically at 105°C (Parent and Caron 1993). Soil pH was measured using a 1:10 soil/water (wt:vol) ratio and a pH meter (Hendershot et al. 1993). The amount of bicarbonate-extractable inorganic P was determined colorimetrically (Alpkem 1986) after extraction of soil (Olsen and Sommers 1982).

Principal Findings and Significance

Total phosphatase activity (TPASE) was higher in MWD than in SPD soil throughout the course of the study (Fig. 1). Both MWD and SPD soils exhibited the highest levels of TPASE in April and May of 2000, with minima apparent in October of 1999 and in July of 2000. No statistically significant differences were observed in TPASE activity between the control treatment and treatments that received either P or N + P applications on any of the sampling dates in either soil. Temporal trends in TPASE were identical for all three treatments in both MWD and SPD soil.

Levels of bicarbonate-extractable phosphate (Fig. 2) were significantly higher in MWD than in SPD soil on all sampling dates. The highest levels of phosphate were observed in June of 2000 and the lowest levels in April of 2000 in both MWD and SPD soils. No statistically significant differences were observed in levels of phosphate between control treatments and treatments receiving either P or N + P applications on any of the sampling dates in either soil. Temporal trends in phosphate levels were identical for all three treatments in both MWD and SPD soil.

Recalcitrant phosphatase activity (RPASE) was higher in SPD than in MWD soil throughout the course of the study (Fig. 3). RPASE followed the same temporal trend in MWD and SPD soil, with the highest levels of activity observed in April of 2000 and the lowest levels in October 1999 and July 2000. No statistically significant differences in RPASE were observed between the control treatment and treatments receiving either P or N + P on any sampling date for either soil. Temporal trends in RPASE were identical for all three treatments in both MWD and SPD soil.

Labile phosphatase activity (LPASE) was higher in MWD than in SPD soil on most sampling dates, particularly after December 1999 (Fig. 4). LPASE appeared to have a different temporal trend in MWD and SPD soil. LPASE maxima in SPD soil were apparent in October 1999 and April and July 2000, with the lowest levels observed in December 1999. By contrast, in MWD soil LPASE activity was highest in May 2000 and lowest in October 1999. There were no statistically significant differences in LPASE between the control treatment and treatments containing P or N + P in either MWD or SPD soil. Temporal trends in LPASE activity were similar for all three treatments within a particular soil.

None of the phosphatase activities tested appeared to respond to additions of either P or N+P at any time during the course of a year. The levels of P and N+P applied are on the order of those found in runoff waters in the Northeastern U.S. Thus, it appears that phosphatase activity may not be a good indicator of P pollution at the levels normally found in runoff in this region. Examination of the levels of bicarbonate-extractable phosphate shows that additions of either P or N+P had no significant effect on P levels in either soil. The absence of an effect of either P or N + P inputs on soil P levels can be attributable to rapid uptake by both plants and microorganisms and/or complexation by iron and aluminum oxides in the soil. The latter mechanism would be expected to be more important in MWD soil because of the presence of higher levels of metal oxides in these soils (e.g. Lyons et al., 1998).

The absence of enhanced levels of P in these soils may explain the lack of response in phosphatase levels to nutrient additions. Phosphatase production is halted by the presence of elevated levels of phosphate in the soil. Since nutrient additions failed to increase P levels, phosphatase levels -- especially those for the total and labile enzyme activity – would not be expected to decrease. The absence of a response to nutrient inputs by recalcitrant activity was not unexpected, since this activity is attributable to enzyme that is complexed by soil particles and thus not subject to metabolic control by either microbial or plant cells.

In conclusion, total, labile, and recalcitrant phosphatase activity in soil from a riparian forest failed to respond to P and N and P inputs at levels commonly found in runoff in southern New England. As such, it appears that phosphatase activity may not be a good indicator of P pollution in these landscape features.

Resulting Publications

Savin, M. C., H. Taylor, J. H. Görres, and J. A. Amador. 2000. Seasonal variation in acid phosphatase activity as a function of landscape position and nutrient inputs. *Agronomy Abstracts* **92:** 391.

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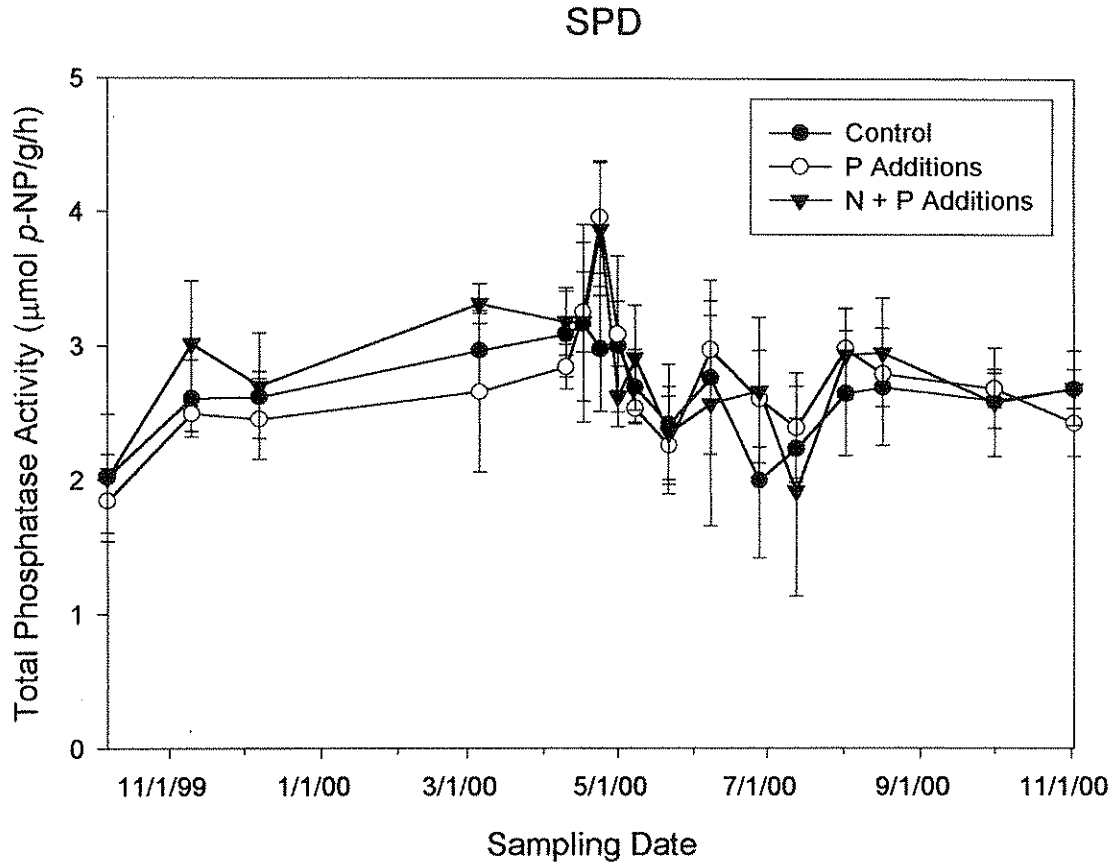
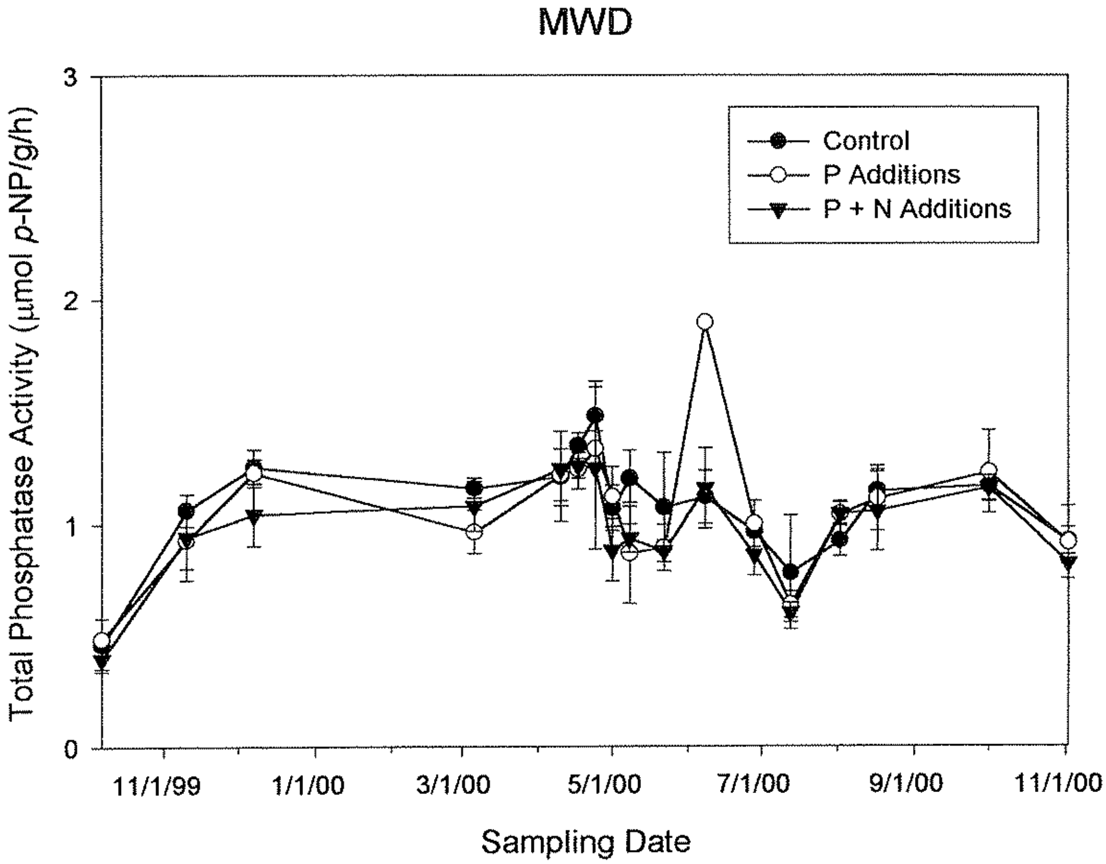
Application of Results

The data collected in this study willbe of use to state and federal agencies charged with monitoring and enhancing water quality (e.g. RIDEM and USEPA). It may also be of use to land managers involved in making decisions about landscape features and their importance of riparian areas to water quality. Our resultsindicate that the threshold for a statistically significant response of soil phosphatase activity to either P or N + P additions has not been reached. Higher levels of P may be required to saturate the capacity of these ecosystems to take up P. These data will be used to establish a threshold for response of phosphatase activity to P inputs in these soils.


SPD
Total Phosphatase Activity (µmol p-NP/g/h)
0
1
2
3
4
5
11/1/99
1/1/00
3/1/00
5/1/00
7/1/00
9/1/00
11/1/00
Sampling Date
Control
P Additions
N + P Additions


MWD
Total Phosphatase Activity (µmol p-NP/g/h)
0
1
2
3
11/1/99
1/1/00
3/1/00
5/1/00
7/1/00
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11/1/00
Sampling Date
Control
P Additions
P + N Additions

Fig. 2

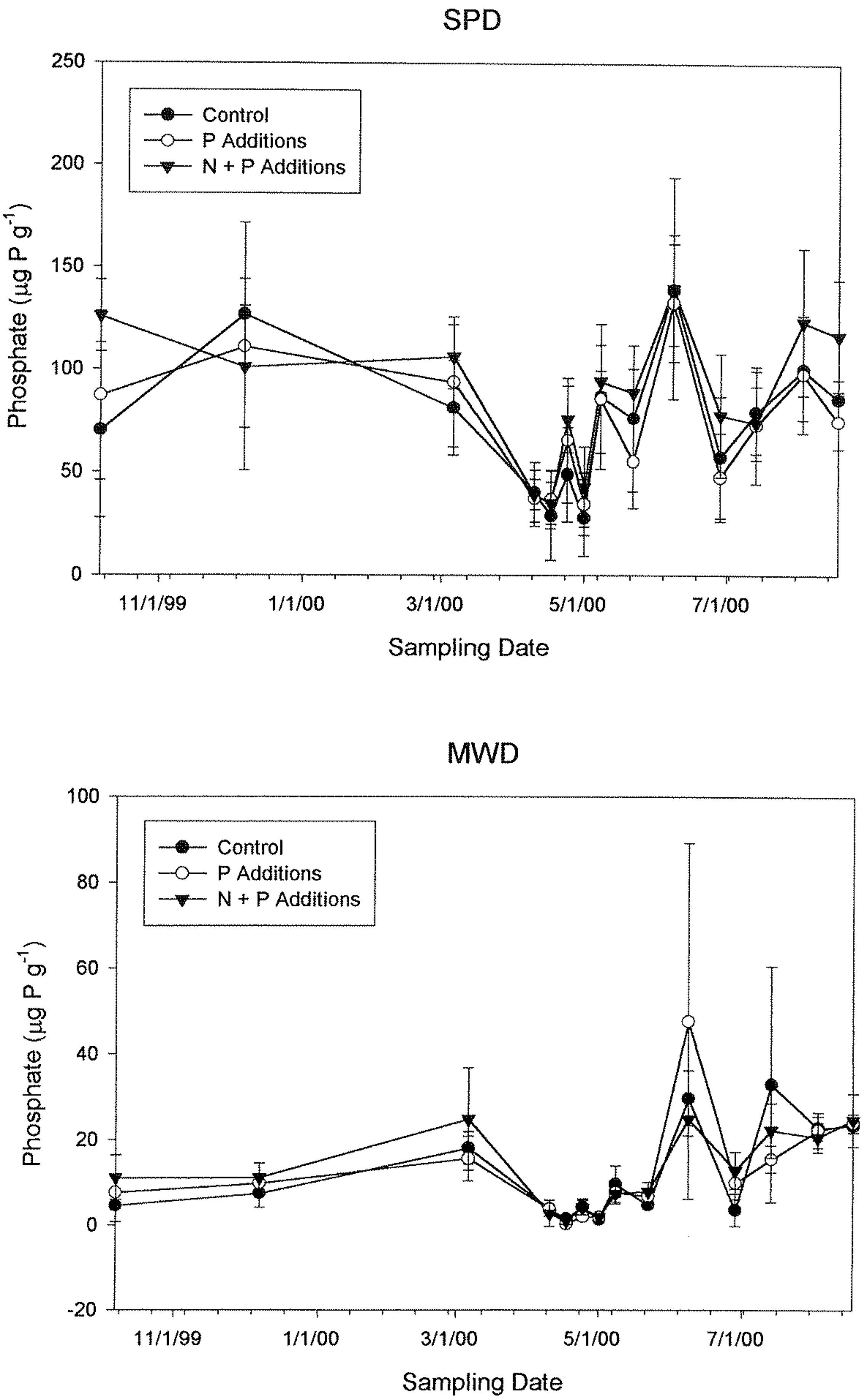
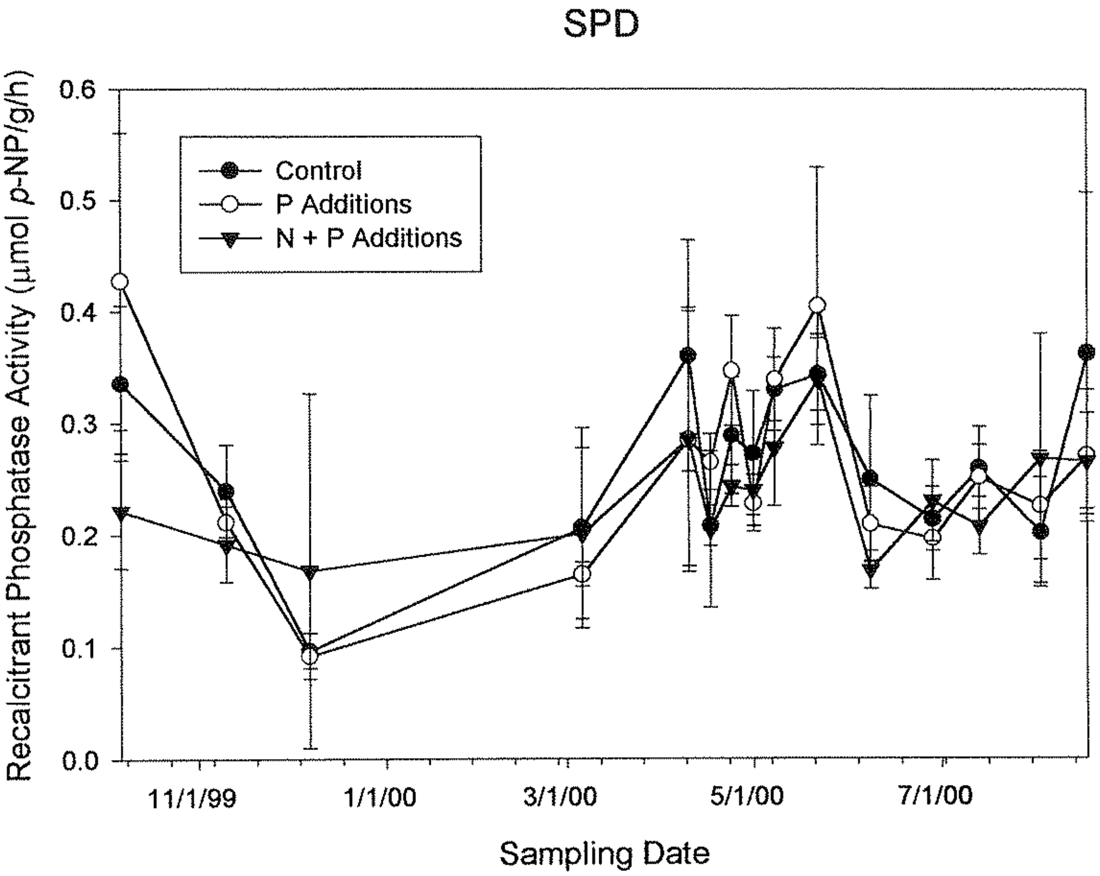
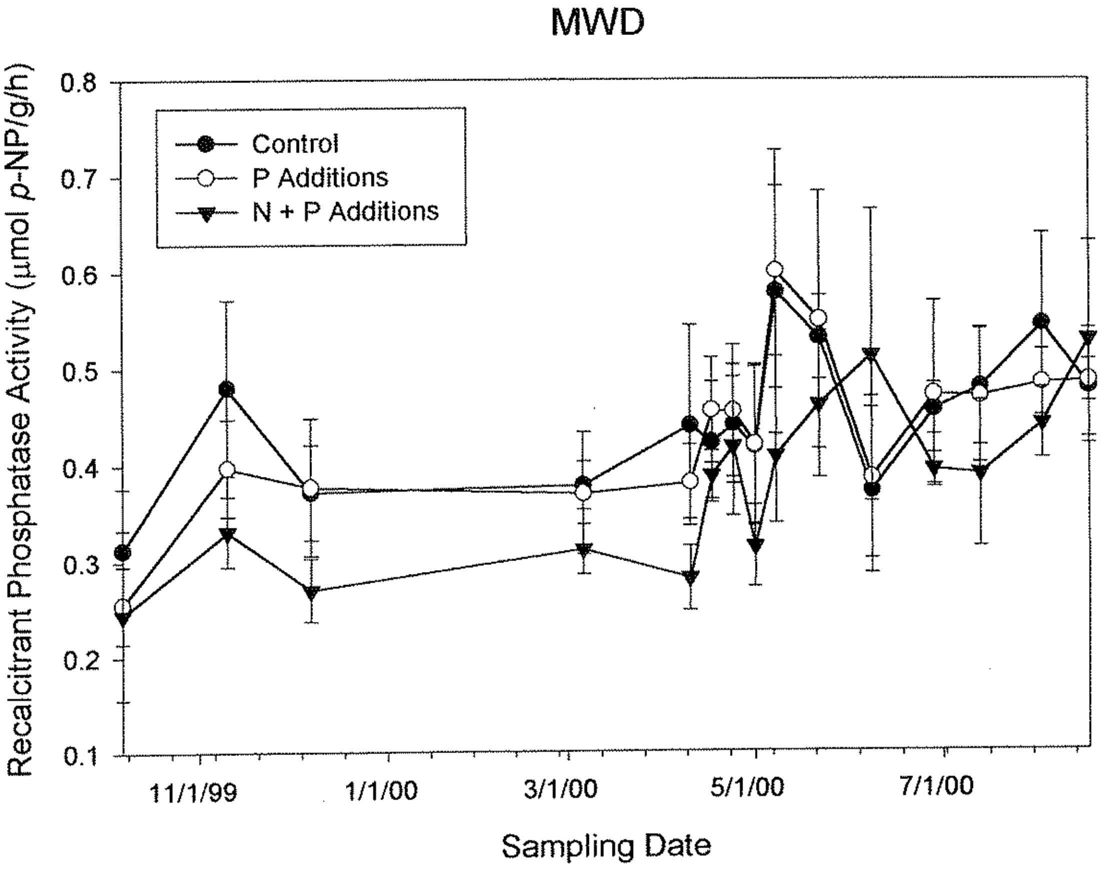

SPD
Control
P Additions
N + P Additions
Phosphate (µg P g-1)
250
200
150
100
50
0
11/1/99
1/1/00
3/1/00
5/1/00
7/1/00
Sampling Date
MWD
Control
P Additions
N + P Additions
Phosphate (µg P g-1)
100
80
60
40
20
0
-20
11/1/99
1/1/00
3/1/00
5/1/00
7/1/00
Sampling Date

Fig. 3


SPD
Recalcitrant Phosphatase Activity (µmol *p*-NP/g/h)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Control
P Additions
N + P Additions
11/1/99
1/1/00
3/1/00
5/1/00
7/1/00
Sampling Date


MWD
Recalcitrant Phosphatase Activity (µmol *p*-NP/g/h)
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Control
P Additions
N + P Additions
11/1/99
1/1/00
3/1/00
5/1/00
7/1/00
Sampling Date

Field Performance of Hydrodynamic Separators
Phase II

Proposal

Prepared By:

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Kingston, Rhode Island

August, 2008

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1 Project Identification

The title of this project is "Field Performance of Hydrodynamic Separator Units – Phase II." The PI for this project is Leon T. Thiem who will be assisted by Michael DeRotta. Leon T. Thiem is an associate professor in the Civil and Environmental Engineering Department at the University of Rhode Island. He has been a PI for several RIDOT grants involving the measurement of roadway runoff as well as the first phase of this study. Michael DeRotta is a principal engineering with the RIDOT and is the "in-house" expert on roadway drainage. He has worked on Phase I of this project. Professor Thiem will assist Michael DeRotta in sampling and in data analysis.

2 Problem Statement

Numerous reports/studies have concluded that urban roadways contribute large amounts of suspended solids/sediment, heavy metals, petroleum hydrocarbons, deicing chemicals, bacteria and other constituents to receiving waterways. The EPA National Urban Runoff Program (NURP) indicated that lead, zinc and copper were the pollutants most likely to be found in urban stormwater runoff. The occurrence of toxic heavy metals from Rhode Island highways, verified in a report completed by Thiem, Bade & Alkhatibe in 1998, showed that cadmium, chromium, copper, lead, nickel and zinc exceeded EPA's acute and/or chronic water quality criteria. Toxic organic compounds bind to soil particles and are washed into water bodies, causing a decrease in overall stream diversity.

As a result of efforts to comply with local and national stormwater quality discharge standards as well as current regulations for environment protection, Rhode Island Department of Transportation (RIDOT) Projects have included the installation of more than twenty stormwater treatment units (hydrodynamic separators) between 1997 and 2002. These structural Best Management Practices (BMP's) were installed in an attempt to lessen pollutant loads to receiving waterways. The majority of these units are typically designed to provide a net annual removal of total suspended solids (TSS) of about 80% for the more frequent rainfall events e.g. the 2-month storm. Unverified manufacturer's data is currently relied upon for "Stormwater Treatment Unit" selection and, as such, is insufficient for science-based selection to address specific applications.

The focus of this project is to select two hydrodynamic separator units and investigate removal efficiencies of specific contaminants such as, toxic heavy metals (e.g. total cadmium, total copper, total iron, total lead, total zinc) and total suspended solids (TSS) and suspended sediment concentrion for the unit tested. The information obtained from this study will assist in developing guidelines for Stormwater Treatment Unit Selection.

3 Background and Significance of the Study

Hydrodynamic Separator Units have been installed in many locations throughout the United States and abroad as Best Management Practices (BMP). Regardless of their location, these units are designed to treat stormwater runoff by capturing floatable debris, oil & grease and reducing Total Suspended Solids (TSS) concentrations. The U.S. Environmental Protection Agency (EPA), through their NPDES (National Pollutant Discharge Elimination System) Phase II program (established through the Clean Water

Act of 1972), requires that each State develop a stormwater management plan for regulating pollution to receiving waterways. One of RIDOT's efforts in working towards establishing such a plan is through their recently completed inspection and inventory of in-place hydrodynamic separator units.

The Rhode Island D.O.T. has installed a number of hydrodynamic separator units based upon unverified manufacturer's data. Hence, before specifying (and subsequently installing) hydrodynamic separators for future stormwater treatment applications, testing and monitoring of their performance/effectiveness needs to be carried out. In order to address current and future stormwater discharge policies in accordance with the Rhode Island Department of Environmental Management (RIDEM) and Coastal Resources Management Council (CRMC), and to insure proper expenditure of tax dollars, it would be prudent for the RIDOT to perform its own independent testing and sampling of existing units.

Recommendations from other "stormwater treatment unit" studies include (a) the need for measuring sediment accumulations within the units to determine if previously captured pollutants were retained (or not), (b) considering a different standard (since 80% TSS cannot be precisely confirmed) and (c) the need to characterize the whole range of contaminants in runoff, accounting for rainfall intensity, antecedent conditions, particle sizes, traffic volumes, impervious areas and flow (Barbaro, 2001). These studies also suggest that source control measures such as catch basin cleaning; street sweeping; the use of more efficient maintenance equipment; reducing the amount of sand used in winter operations and public programs (e.g. litter pick-up) should not be overlooked. This project will make a concerted effort in addressing most of these recommendations.

The purpose of this project is to evaluate the overall performance of one hydrodynamic separator (stormwater treatment units) through manual sampling and associated laboratory analysis of targeted pollutants. A minimum of four (4) storms are to be sampled per unit for a one (2) year period and antecedent conditions (e.g. days without rain & temperature) will be documented between storms. A qualified storm event is one in which rainfall depths are at least 0.1 inch or greater.

4 Objectives of the Study

The objectives are to (a) develop a sampling plan to determine actual BMP field performance and compare the results with manufacturer's documented data for similar storm events (to the extent practicable) and (b) use the field performance data to assist in determining whether hydrodynamic separator use is suitable for environmental applications.

5 Implementation

The overall goal of this work is to provide the tools for RIDOT to evaluate the effectiveness of existing stormwater treatment units and to make recommendations for future use of these units. This project will also provide training for employees of RIDOT in stormwater management. The results from this project will be disseminated by publication of these results in an appropriate journal as well as presentations at conferences and seminars.

contaminants be evaluated. Monetary constraints and current laboratory fees will dictate the number of storms and associated samples for evaluation.

Hence, evaluation of the subject BMP's will be based on a minimum of six (4) rainfall events having at least 0.1 inch of total rainfall and a minimum inter-event period of at least 6 hours. After meeting the requirements of a rainfall event (through rain gauge monitoring), influent and effluent flow-weighted (and, perhaps, time-proportion (for comparison)) samples will be collected from both units and will be taken to a laboratory for testing of targeted pollutants (e.g. total cadmium, total copper, total iron, total lead, total zinc and total suspended solids (TSS)) where EPA approved analytical methods shall be closely followed. After each rainfall event, the sample bottles will be cleaned in accordance with procedures as described in the EPA's Title 40—Protection of the Environment, Part 136 of the Code of Federal Regulations (40 CFR Part 136) and returned to the reprogrammed samplers for the next storm event.

Sediment sampling (grab samples within the sumps) shall also be conducted at each site in order to provide a typical particle-size profile. Incidental information including, but not limited to, weather, inspection and maintenance of the units as well as monitoring equipment malfunction shall also be documented.

The following analytical methods will be used for constituent analysis:

Pollutant	Analytical Method	Sampling Protocol
Total Lead (Pb)	200/7000 Series	Manual sampling
Total Zinc (Zn)	200.7/6010B	Manual sampling
Total Iron (Fe)	200.7/6010B	Manual sampling
Total Copper (Cu)	200.7/6010B	Manual sampling
Total Cadmium (Cd)	200.7/6010B	Manual sampling
TSS	160.2	Manual sampling
Sediment Analysis	ASTM D 422	Manual sampling

The following tasks are part of the work plan. Even though they are listed in order, most of the tasks will be worked on in parallel.

Task Description
Site selection
Watershed delineation
Unit preparation
Laboratory preparation
Sampling
Data analysis and draft report preparation
Final report submission

7 Work Schedule

This work schedule has been developed based upon a two year study duration. Quarterly progress reports will be submitted when due. Due to the nature of wet weather sampling, (required antecedent dry period, rainfall duration and intensity) sampling dates cannot be predicted far in advance. The sampling of rainfall events in the summer months as well as the winter months are planned to highlight differences in water quality.

Task Description	Beginning Month	Ending Month	Duration, mo.
Site selection	January 2009	February 2009	2
Watershed delineation	February 2009	April 2009	3
Unit preparation	March 2009	April 2009	2
Laboratory preparation	March 2009	June 2009	4
Sampling	June 2009	October 2010	17
Data analysis and draft report preparation	June 2009	November 2010	18
Final report submission	October 2010	December 2010	3

8 Budget Estimates

Required resources will include pertinent technical reports from the National Transportation Research Board (NTRB), Federal Highway Administration (FHWA), U.S. Environmental Protection Agency (USEPA) and various State D.O.T.'s as well as previously completed monitoring studies. The protocols mentioned earlier in this Proposal will be used as guides in the development and completion of this Sampling and Analysis Report.

The following equipment and materials will be required for this research project:

- American Sigma Model 2459 Rain Logger data logging rain gauge
- Telogers Professional Software for downloading rainfall data
- Swing Sampler with bottle attachment for grab sampling
- Survey rod for measuring sediment depth
- Non-phosphorous based soap for washing sample bottles
- Standard cooler for transporting samples
- Catch basin pick for opening manhole covers
- Flashlights
- Work/Rubber Gloves

- Reflective safety vests
- Rain wear
- Safety items (respirators, first-aid kit, goggles, insect repellant, etc.)

In addition the above equipment laboratory supplies such as compressed gases, standards, sampling containers, acids, measurement devices and labels will need to be purchased.

	Year 1 Request	Year 2 Request	Total Request
A. Personnel			
Leon Thiem	7,500	7,600	15,100
1 Graduate Student Level II hourly, A/Y	7,175	7,462	14,637
2 Graduate Student Level II hourly, Summer	2,790	2,902	5,692
TOTAL PERSONNEL COSTS	17,465	17,964	35,429
B. Fringe Benefits			
TOTAL FRINGE BENEFITS	-	-	-
C. Equipment	- -	- -	-
TOTAL EQUIPMENT	-	-	-
D. Travel	3,000	3,000	6,000
TOTAL TRAVEL	3,000	3,000	6,000
E. SUPPLIES	23,320	23,250	46,570
TOTAL SUPPLIES	23,320	23,250	46,570
F. OTHER COSTS			
TOTAL OTHER COSTS	-	-	-
TOTAL DIRECT COSTS	43,785	44,214	87,999
TOTAL MODIFIED DIRECT COSTS	43,785	44,214	87,999
INDIRECT COST 25% (MTDC)	10,946	11,053	22,000
TOTAL REQUESTED FROM AGENCY	54,731	55,267	109,998

9 Deliverables

Number	Task Description	Percentage
1	Site selection	5
2	Watershed delineation	10
3	Unit preparation	10
4	Laboratory preparation	15
5	Sampling	30
6	Data analysis and draft report preparation	20
7	Final report submission	10

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United States Environmental Protection Agency (USEPA). NPDES Storm Water Sampling Guidance Document. Report No. EPA 833-B-92-001. July 1992.

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The Rhode Island
Stormwater Management and Treatment Demonstration Facility
(RI SDF)

A Joint-Proposal

Submitted by

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September 07, 2010

Introduction

Numerous reports/studies have concluded that urban roadways contribute large amounts of suspended solids/sediment, heavy metals, petroleum hydrocarbons, deicing chemicals, bacteria and other constituents to receiving waterways. The EPA National Urban Runoff Program (NURP) indicated that lead, zinc and copper were the pollutants most likely to be found in urban stormwater runoff. The occurrence of toxic heavy metals from Rhode Island highways, verified in a report completed by Thiem, Bade & Alkhatibe in 1998, showed that cadmium, chromium, copper, lead, nickel and zinc exceeded EPA's acute and/or chronic water quality criteria. Besides toxic metals, stormwater also contains petroleum hydrocarbons, nutrients, and microbial matter as well as many other chemical compounds (Goebel et al., 2007). These toxic stormwater constituents are easily washed into water bodies, causing a decrease in overall stream diversity. In addition, toxic compounds often bind to soil particles and, upon entering drainage and runoff treatment structures, have to be removed and safely disposed of.

As a result of efforts to comply with local and national stormwater quality discharge standards as well as current regulations for environment protection, the Rhode Island Department of Transportation (RIDOT) has installed many structural Best Management Practices (BMP's) in an attempt to lessen pollutant loads to receiving waterways. For instance, between 1997 and 2007 more than 70 hydrodynamic separator units were installed by RI DOT. The selection of the various, commercially available BMP systems relies mostly on unverified manufacturer's data or is based on performance reports from other parts of the country where local environmental conditions are much different than those in Rhode Island. In general, there is insufficient data for science-based selection of the most appropriate BMP for addressing specific applications in Rhode Island. The focus of this joint-proposal is on providing RI DOT and the URI transportation community with a new facility where BMP structures can be evaluated against the manufacturer's claims and under environmental conditions prevailing in our state. This facility will be known as the "*Rhode Island Stormwater Management and Treatment Demonstration Facility*" (RI SDF).

This proposal is organized around three tasks. Task I revolves around the set-up of the RI SDF facility. Task II focuses on the contaminant removal efficiencies of several commercial hydrodynamic separator/water quality (WQ) units, while the Task III seeks to evaluate the performance of both pervious concrete amended with organo-soils as well as a tree-box filter. Task II and III will be the first projects to take advantage of the newly built RI SDF site.

In the following we describe each task's goals and objectives, the work plans and the work schedule, including the deliverables. Each task description is followed by a budget and budget justification. The project supports two URI graduate students. Task I and II are proposed directly to RI DOT, while Task III is proposed to the URI Transportation Center. The overall amount of funding requested from RI DOT is $176,127 and $74,377 from URI TC. While Tasks II and II have a one year project horizon, we view Task I as a long-term commitment. That is, in the future, we seek support from RI DOT/URI TC to operate the RI SDF facility for the three years following the set-up of the facility. Afterwards we expect to support RI SDF with fees and revenues generated from testing BMPs and other structures for commercial customers.

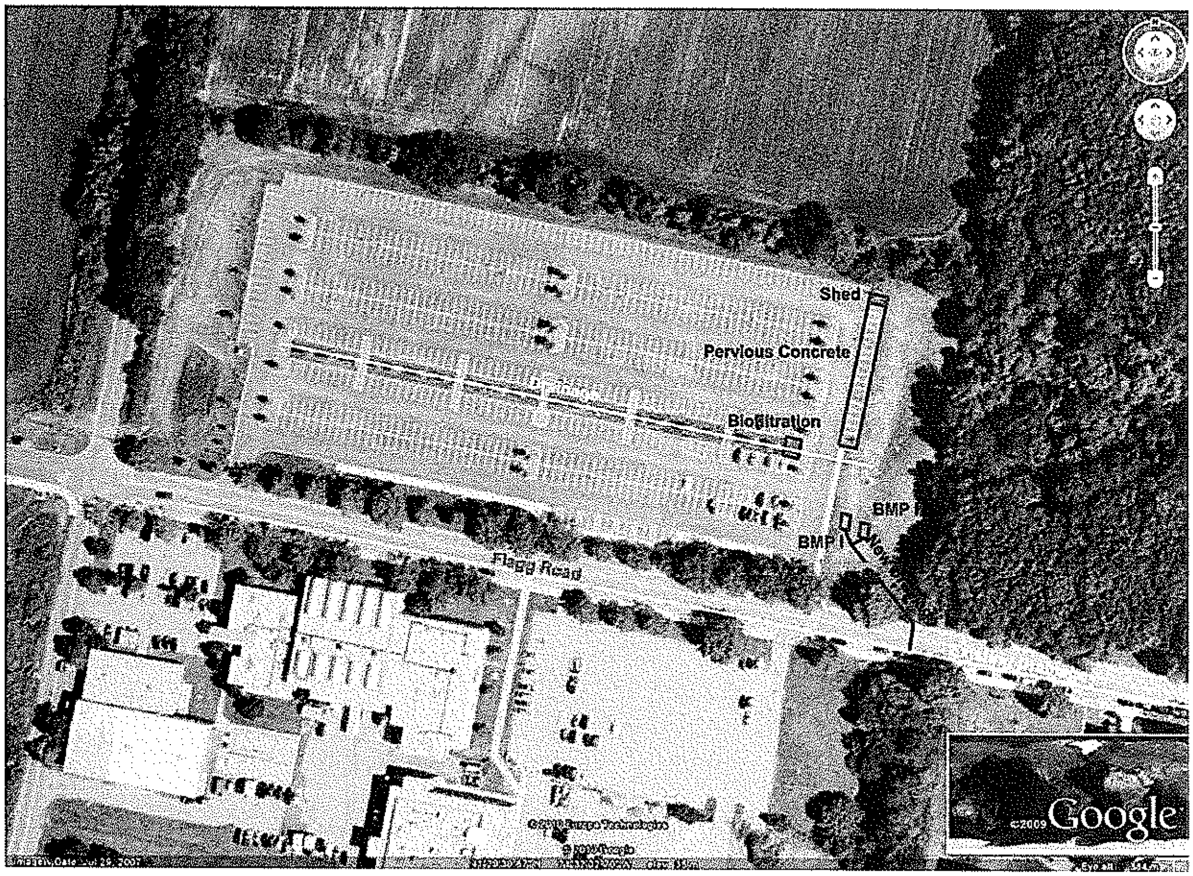

Figure 1: Schematic of the proposed stormwater management and treatment demonstration facility (RI SDF) on the URI campus in Kingston, RI. There are two drainage systems to which BMPs can be connected to either treat the runoff generated on the surface of the parking lot (yellow) or from Flagg Road (red). Shown are the tentative locations for the hydraulic separator (BMP I, Task I) and the pervious pavement (Task II). Also shown are the tentative locations of other treatment structures, such as a biofiltration unit and another BMP.

TASK I: Instalation of Stormwater Management and Treatment Demonstration Facility

(Lead: Boving; all others assist)

Goals and Objectives: Under *Task I*, we will set-up a demonstration facility for testing innovative stormwater treatment systems and best management pratices on the URI Kingston Campus. This facility will be known as the "*Rhode Island Stormwater Management and Treatment Demonstration Facility*" (RI SDF) and will provide the test grounds for evaluating commercial or innovative in-situ best management practices (BMP). Such a facility is needed in Rhode Island because it will enable testing and demonstration of BMPs and novel strategies for the effective treatment of the stormwater runoff under conditions prevalent in Rhode Island. The RI SDF ties into an existing catch basin structure (Figure 1), which permits direct comparison of this conventional treatment approach to other more innovative ones to be tested at this new installation. Task II (hydraulic separator/WQ unit) and Task III (permeable concrete) are the first projects to be implemented. In additon, one company has already requested to install an innovative BMP systems for treating stormwater runoff at RI SDF.

Work Plan: The RI SDF will focus on the treatment of suspended solids, toxic metals and petroleum hydrocarbons, nutrients and other relevant water quality parameters. Special emphasis will be paid to investigating the "first flush" performance, i.e. the runoff resulting from the first inch of rain, long-term performance monitoring, and seasonality in BMP performance include extreme weather conditions. The data generated by RI SDF can, for example, be used to address *Phase II* requirements. In addition, RI SDF will eventually promote research focused on exploring the potential reuse of treated stormwater for domestic, agricultural and commercial uses and generic water resources protection. URI researchers will independently evaluate BMP systems based on parameters such as:
Implementation, operation, and maintenance: simple, sustainable solutions that do not requiring massive maintenance are preferred.
Scalability and transferability: systems ideally can be used at different scales from residential to commercial.
Resiliency: systems must be able to survive and perform well under severe conditions (e.g. hurricanes, flooding, snow and ice, changing weather patterns).
Materials: most of the construction materials should be produced using "green engineering" principles to minimize environmental impact and enhance sustainability.
Cost: implementation, operational, and disposal cost associated with the technologies have to be known.
RI SDF will be located on the URI, Kingston Campus – adjacent to a parking lot on Flag Road. We have already obtained a letter from URI that supports this project and the proposed test site location. This site was selected because minimal construction is required to prepare the site for our purposes.

Site Characteristics: By tying into the existing drainage system (Figure 1), the runoff water from an existing parking lot will be used to conduct all tests. In addition, we propose to connect the Flag Road storm runoff drainage system to the site. This will provide us with even greater flexibility in conducting our tests, plus it may provide a secondary runoff stream with slightly different chemical characteristics. The runoff water will feed one or more treatment units (see Task II and III), allowing a direct performance comparison of treated versus untreated runoff quality. Dedicated sample ports at the influent and effluent sides together with ports inside the treatment unit(s) will provide the data needed for performance evaluation. Whenever possible, on-site probes and loggers will be used to guarantee semi-continuous data collection. Monitoring construction and operating cost together with maintenance requirements will provide BMP specific cost data. The closeness to our URI laboratories ensures quick analysis turnaround times and provides our students with important field experience.

Work Schedule and Deliverables: This a one-year project. Project activities will begin immediately upon funding of the project. We are currently applying for RI SDF set-up cost (Task I). We will submit a separate budget for the following year of operation at a later time.

TASK I: Set-Up of proposed URI/RIDoT Testing Facility

Leader : Boving, URI - CVE/GEO

Proposed Start: Summer 2010
Project Duration: 1 year

		No. of Units	Cost per Unit	Total Cost
1. Personnel				
Dr. Boving (0.75 month summer)		0.75	$10,602	$7,951
	Total:			**$7,951**
2. Benefits				
None		0	$0	$0
	Total:			**$0**
3. Operational				
None		0	$0	$0
	Total:			**$0**
4. (Fabricated) Equipment				
Field testing equipment (loggers, samplers, computer etc)		1	$15,000	$15,000
Consumables (pipes, wire, etc)		1	$4,500	$4,500
	Total:			**$19,500**
5. Travel				
none		0	0	$0
	Total:			**$0**
5. Other				
Outreach and Advertisement of new test site		1	$1,500	$1,500
Site design and installation (subcontract)		1	$30,000	$30,000
	Total:			**$31,500**
Total Cost				**$58,951**
Indirect Cost (25% rate *25% on first $25,000 of subcontract				**$8,613**
	Total Project Cost			**$67,564**

Justification for Start-Up Budget

The start-up budget covers the cost of setting up the RI SDF demonstration site on the URI campus and preparing it for Task II and III. We have identified an area adjacent to the parking lot on Flag Road across from the URI Purchasing Office building as the tentative site. The amount of $19,500 is requested to design, install, and equip the demonstration site with monitoring and testing equipment, incl. landscaping, fencing, and shelter. We plan to subcontract some or all site design and installation activities ($30,000). The installation of the BMP test units is covered under Tasks II and III, respectively. PI Boving requests 0.75 month of summer salary to supervise the set-up of the demonstration facility. The amount of $1,500 covers outreach and advertisement activities to inform potential RI SDF site users of its existence and capabilities. An indirect cost rate of 25% applies to all expenses except fabricated equipment over $5,000. 25% overhead is charged by URI on the first $25,000 of subcontract.

TASK II: Field Performance Testing of Hydrodynamic Separator Unit

(Lead: Thiem; all others assist, incl. DeRotto).

Goals and Objectives: The objective of Task II is to investigate the overall performance of a commercial hydrodynamic separator (Vortechs® or similar) and potentially an ADS Water Quality Unit (as manufactured by Advanced Drainage Systems, Inc.). This study will be performed on the new *Rhode Island Stormwater Management and Treatment Demonstration Facility* (RI SDF). Hydrodynamic separators are designed to treat stormwater runoff by capturing floatable debris, oil & grease and reducing Total Suspended Solids (TSS) concentrations. ADS WQ Units work on the principles of water treatment i.e. settling chambers are incorporated into the design, removing a percentage of particles in the process. Under the Phase II program, each State develops a stormwater management plan for regulating pollution to receiving waterways. Our goal is that the information obtained from this study will assist RIDOT in assessing the Hydrodynamic Separator performance /effectiveness on the background of current and future stormwater discharge policies developed by the Rhode Island Department of Environmental Management (RIDEM) and Coastal Resources Management Council (CRMC). Also, this project will compare our results with manufacturer's documented data for similar storm events (to the extent practicable). Based on the field performance data and review of the pertinent literature, we will make recommendations to RIDOT whether hydrodynamic separator/WQ unitis suitable for environmental applications typical for Rhode Island. The Technology Assessment Protocol – Ecology (January, 2008) ("TAPE"), The Technology Acceptance Reciprocity Partnership (updated July, 2003) ("TARP"), Urban Stormwater BMP Performance Monitoring (ASCE, April, 2002) and APPENDIX J of the RI Stormwater Design and Installation Standards Manual will be used as guidance for the proposed BMP field testing.

Work Plan: Recommendations from other "stormwater treatment unit" studies include (a) the need for measuring sediment accumulations within the units to determine if previously captured pollutants were retained (or not), (b) considering standards other than "80% TSS removal", which cannot be precisely confirmed and (c) the need to characterize the whole range of contaminants in runoff, accounting for rainfall intensity, antecedent conditions, particle sizes, traffic volumes, impervious areas and flow (Barbaro, 2001). These studies also suggest that source control measures such as catch basin cleaning; street sweeping; the use of more efficient maintenance equipment; reducing the amount of sand used in winter operations and public programs (e.g. litter pick-up) should not be overlooked. This project will make a concerted effort to address most of these recommendations. This project will also provide training for employees of RIDOT and URI students in stormwater management. The results from this project will be disseminated by publication of these results in an appropriate journal as well as presentations at conferences and seminars.

A commercial hydrodynamic separator as well as an innovative water quality unit will be installed on or immediately adjacent to the RI SDF site. EPA's "Environmental Technology Verification Program" (ETV) and the "Stormwater Best Management Practice Demonstration, Tier II Protocol for Interstate Reciprocity" that has been endorsed by California, Massachusetts, New Jersey, Pennsylvania and Virginia, are two protocols that we will apply to the performance verification of the hydrodynamic separator. We will use these protocols as guides only, i.e., evaluation of the hydrodynamic separator will be based on a minimum of six (6) rainfall events having at least 0.25 inch of total rainfall and a minimum inter-event period of at least 6 hours. Preference will be given to intense storms that generate more than 0.25 in of rain. After meeting the requirements of a rainfall event (through rain gauge monitoring), influent and effluent flow-weighted (and, perhaps, time-proportion for comparison) samples will be collected from the unit and will be analyzed for the targeted pollutants (e.g. total cadmium, total copper, total iron, total lead, total zinc and total suspended solids TSS). EPA approved analytical and QA/QC methods will be closely followed. Sediment sampling (grab samples) will be conducted to provide typical particle-size profiles. Incidental information including, but not limited to, weather, inspection and maintenance of the units as well as monitoring equipment malfunction shall also be documented.

Work Schedule and Deliverables: Task II will completed within one year (see timeline below). The performance testing begins after the hydrodynamic separator unit has been installed and found fully functional. Due to the nature of wet weather sampling, i.e., required antecedent dry period, rainfall duration and intensity, sampling dates cannot be predicted far in advance. Testing for three months is covered under this project. Subsequent testing will be conducted under a second year grant. Overall, the sampling of rainfall events in the summer months as well as the winter months are planned to highlight differences in water quality.

TASK II: Field Performance Testing of Hydrodynamic Separator Unit

Leader : Thiem, URI - CVE

Project Start: Summer 2010
Project Duration: 1 year

1. Personnel		**No. of Units**	**Cost per Unit**	**Total Cost**
Graduate Research Assistant				
Academic Year (Sept through May)		1	$14,924	$14,924
Summer (50%)		0.5	$11,608	$5,804
Supervisors				
Dr.Thiem (0.75 month summer)		0.75	$9,890	$7,417
	Total:			**$28,145**
2. Benefits (exempt from indirect cost)				
Graduate Research Assistant				
Summer FICA (June through Aug)*		1	$888	$888
Health Insurance and fees		1	$1,269	$1,269
	Total:			**$2,157**
3. Operational				
Consumable field and lab supplies (incl. lab analysis)		1	$46,570	$46,570
	Total:			**$46,570**
4. Equipment				
None		0	$0	$0
	Total:			**$0**
5. Travel				
Out State (Conferences)		1	$2,500	$2,500
	Total:			**$2,500**
6. Tuition (exempt from indirect cost)				
Graduate Research Assistant (In-State)		1	$9,887	$9,887
	Total:			**$9,887**
Total Project Cost (per year)				**$89,259**
Indirect Cost (25% rate; per year)				**$19,304**
	Total			**$108,563**

Task II Budget Justification

The overall amount requested from RIDoT is $108,563. The budget covers a stipend ($14,924 AY and $5,804 50% summer) and in-state tuition ($11,608) plus health benefits and fees ($2,157) for one graduate student. PI Thiem requests 0.75 month of summer salary to supervise the project ($7,417)

Under Operational, the amount of $46,570 is requested to plan for and install a commercial hydrodynamic separator on the RI SDF site, purchase consumable field and lab supplies, and for testing water and other media. $2,500 is requested for out of state travel and conference participation. An indirect cost rate of 25% applies to all expenses except tuition and benefits.

TASK III: Pervious Concrete for Enhanced Pollutant Removal

(Lead: Craver, all others assist,)

Goals and Objectives: The focus of Task III is on the development and study of enhanced pervious concrete system at different scales (laboratory and pilot scale). This study will be performed on the new *Rhode Island Stormwater Management and Treatment Demonstration Facility* (RI SDF). Pervious materials are an alternative to impermeable surfaces – especially as an effective method of stormwater runoff control. Organically modified clays promise to further enhance the pollutant removal efficiency of these pervious materials. Because of its benefits in controlling stormwater runoff and pollution prevention, pervious concrete amended with organo-soils has the potential to help earn a credit point in the U.S. Green Building Council's Leadership in Energy & Environmental Design (LEED) Green Building Rating System (Sustainable Sites Credit 6.1), increasing the chance to obtain LEED project certification. The specific objectives are (1) evaluate at laboratory scale the potential use of organically modified Rhode Island soil to enhance the effectiveness of pervious concrete for the removal of organic and inorganic compounds dissolved in urban stormwater runoff and (2) create an educational facility for local schools visits and support courses at URI. This project will provide new information regarding the enhancement of the pollutant load attenuation in stormwater runoff in parking lots, local roads and sidewalks under conditions typical for Rhode Island, including extreme loading and weather conditions

Work Plan: The objectives will be achieved in three stages (1) laboratory testing, (2) field performance study on the RI SDF site, and (3) report preparation. Our preliminary data proves the potential of organo-soil for the simultaneous removal of heavy metals and volatile organic compounds. Compared to natural clays, organo-soils are organo-philic and increase the sorption capacity for relatively non-polar organic solutes [1, 2]. To our knowledge, no other study has used organo-soil to improve the pollutant removal efficiencies of pervious concrete systems.

During the first stage, we will synthesize two organo-soils from local clay, using two quaternary ammonium compounds: HDTMA bromide [$(CH_3)_3NC_{16}H_{33}Br$] and BTEA chloride [$(C_2H_5)_3NCH_2C_6H_5Cl$]. The organo-soils will then be brought in contact with synthetic stormwater runoff having representative average concentrations similar to that of RI SDF runoff. We will build a plexiglass chamber (Fig. 2) to determine the removal performance of pervious concrete with and without soil amendment. On the top of the chamber a series of sprinklers will produce artificial rain to generate the synthetic stormwater runoff. This small-scale system permits easy modification of the structural components and the environmental conditions, such as runoff temperature. The performance of the systems will be evaluated in term of BOD, Nitrate, Lead , PAH, and mineral oil hydrocarbons. During the second state, field tests will be performed on a pervious concrete system build by Massachusetts Concrete & Aggregate Producers Association (MaCapa) on the RI SDF (URI Kingston Campus).

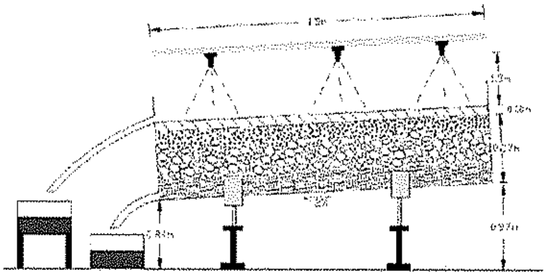

Figure 2. Scheme of the pervious concrete chamber. System components are (bottom to top) subgrade soil, organo-clay, gravel base, and pervious concrete.

Figure 1 depicts the planned location of the pervious concrete test system. The dimension of the system is 21x160 ft (3,360 sqft). The field test system will have several samples points to collect permeate for performance assessment and will be designed based on the previous lab research findings. Design consideration will follow recommendations from manufacturers and research developed at the University of New Hampshire Stormwater center. Figure 3 presents a cross-section detail of a typical pervious pavement faciliti

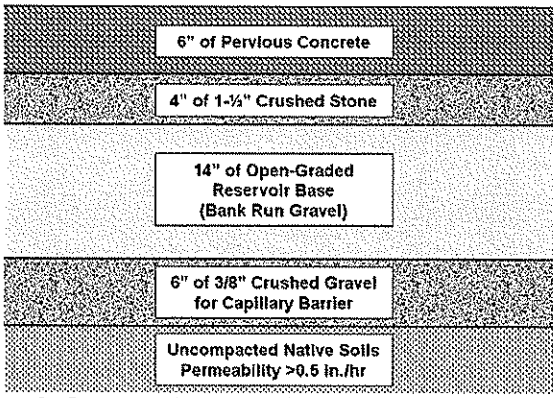

Figure 3. Cross-section area of the pervious concrete facility

Work Schedule and Deliverables: This is a one year project. The pervious concrete system will be build during the summer of 2010. During Fall, we will prepare organo-soils and start tests using the pervious concrete chamber without organo-soil, followed by tests with organo-soil. At the same time, sampling of the pervious concrete system at the RI SDF test site will be carried out. The results from this project will be disseminated by publication in an appropriate journal and presentations at conferences and seminars.

TASK III: Pervious Concrete for Enhanced Pollutant Removal

Leader : Craver, URI - CVE

Project Start: Summer 2010
Project Duration: 1 year

	No. of Units	Cost per Unit	URI TC	Match	3rd Party Match	Total Project
1. Personnel						
Graduate Research Assistant						
Academic Year (Sept through May)	1	$ 14,450	$ 14,450	$ -	$ -	$ 14,450
Summer (50%)	1	$ 10,806	$ 10,806	$ -	$ -	$ 10,806
Supervisors						
Dr.Craver	1	$ 71,750	$ 1,993	$ 12,198	$ -	$ 14,191
Dr. Lee	1	$ 120,882	$ 3,358	$ 14,506	$ -	$ 17,864
Honoraria for final review				$ 500	$ -	$ 500
Total:			**$ 30,607**	**$ 27,203**	**$ -**	**$ 57,810**
2. Benefits						
Graduate Research Assistant						
Summer FICA (June through Aug)*	1	$ 860	$ 860	$ -	$ -	$ 860
Health Insurance and fees	1	$ 1,269	$ 1,269	$ -	$ -	$ 1,269
Vinka Craver				$ 5,489	$ -	$ 5,489
K.Wayne Lee				$ 5,222	$ -	$ 5,222
Total:			**$ 2,129**	**$ 10,711**	**$ -**	**$ 12,840**
3. Operational						
Lab Supplies	1	$ 7,000	$ 7,000	$ -	$ -	$ 7,000
Printing of Final Report	1	$ 500	$ -	$ 500	$ -	$ 500
Total:			**$ 7,000**	**$ 500**	**$ -**	**$ 7,500**
4. Equipment						
Pervious concrete Falg Rd	1	$ 5,000	$ 5,000	$ -	$ 16,000	$ 21,000
Total:			**$ 5,000**	**$ -**	**$ 16,000**	**$ 21,000**
5. Travel						
None	0	$ -	$ -	$ -	$ -	
Total:			**$ -**	**$ -**	**$ -**	
6. Tuition (exempt from indirect cost)						
Graduate Research Assistant (In-State)	1	$ 10,170	$ 10,170	$ -	$ -	$ 10,170
Total:			**$ 10,170**	**$ -**	**$ -**	**$ 10,170**
Total Project Cost (per year)			**$ 54,906**	**$ 38,414**	**$ 16,000**	**$ 109,320**
Indirect Cost (25% rate; per year) (exempt: 4. and 6.)			**$ 19,471**	**$ 18,823**	**$ -**	**$ 38,294**
Total			**$ 74,377**	**$ 57,237**	**$ 16,000**	**$ 147,614**

Task III Budget Justification

The overall amount requested from URI TC is $74,377. This amount is matched by $57,237 in-kind and $16,000 3rd party contributions.

The budget covers a stipend ($14,450 AY and $10,806 100% summer) and in-state tution ($10,170) plus health benefits and fees ($2,129) for one graduate student. PIs Craver and Lee requets 0.25 month of summer salary ($1,992 and $3,358, respectively). $500 are required for external review honorarium.

Under operational, the amount of $7,500 is requested for lab supplies and printing of the final report. Under equipment, $5,000 are requested for completing the pervious concreate system. An overhead rate of 49% is charged to all except tution and equipment.

Monthly Timeline and Project Responsibilities

Proposed start date: January 2011.

Task	1	2	3	4	5	6	7	8	9	10	11	12	Task Leader
Task I: RI SDF Installation													Boving
Planning and Design	▨												
Contracting		▨											
Construction			▨	▨	▨	▨	▨	▨	▨	▨	▨		
Facility shake-down										▨	▨	▨	
Reporting												▨	
Task II: Hydrodynamic Separator Testing													Thiem
Literature Review	▨	▨	▨	▨	▨	▨							
Planning and Design	▨												
Contracting		▨	▨										
Construction				▨	▨								
Field testing						▨	▨	▨	▨	▨	▨	▨	
Reporting												▨	
Task III: Pervious Concrete Testing													Craver
Laboratory Testing	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		
Field Testing						▨	▨	▨	▨	▨	▨	▨	
Reporting												▨	

Shown is the timeline (by month) for tasks I through III including the responsible task leader. All project activities are supported by URI graduate students. Although the current project duration is one year, we ask RI DoT to consider funding at least two additional years of testing and evaluating BMPs at the RI SDF. Although the construction period will continue into the winter period, we anticipate to have completed most major construction (porous pavement construction and connecting drainage system to Flagg Road) before weather becomes an issue.

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