# Quonochontaug East Beach/Central Beach Wellhead Protection Area

# Assessment of Probabilistic Contributing Areas

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A groundwater nitrogen assessment using the MANAGE nutrient loading model was prepared for the Quonochontaug East Beach/Central Beach Fire District Probabilistic Contributing Area (Probabilistic Contributing Area), and the northern and southern portions of the greater than 10 to 25 percent Probabilistic Contributing Areas (northern and southern 10% Probabilistic Contributing Areas) as delineated by Friesz, P.J. 2010 (Delineation and prediction uncertainty of areas contributing recharge to selected well fields in wetland and coastal settings, southern Rhode Island: U.S. Geological Survey Scientific Investigations Report 2010-5060, 69 p.)

The MANAGE assessment process constitutes a method of looking at a specific land area and determining its potential contaminant load based on land use, and geologic and hydrologic characteristics. Tools included with the MANAGE Method include: automated methods for extracting land use and soils data from GIS systems, an Excel based nutrient loading model and various map based analyses. The tools may be used together or separately, depending upon the final desired output.

The following MANAGE tools were utilized in this study (technical details and specific model customizations are found in later sections of this document):

1. The ArcView extraction model. This model automates the process of obtaining land use and soils information for the study area.
2. Excel loading model. The model utilizes land use, soils and On-site Wastewater Treatment Systems (OWTS) data to calculate nitrogen loading to surface and groundwater.
3. Mapping. Visualization of the study area assists the reader in interpreting the data.

*The following discussion provides an overview of the results of the MANAGE assessment. It must be noted that this assessment is only an estimate based on the data available for the study area. These results should be viewed as estimates for the purposes of obtaining a general idea or range of results for the discussed parameters and fostering further communications between stakeholders. All efforts have been made to obtain the most accurate and up-to-date information available, but as with any model it is only an approximation of reality. When possible, it is best to be able to compare model results with actual field data.*

The Probabilistic Contributing Area is 56 acres and does not contain any sewered areas (figure 1). Four wells are located in the study area, two belonging to each Fire District. Approximately 30% of the whole

Probabilistic Contributing Area is forested or wetlands, and approximately 65% is covered with medium-high density residential uses (figure 2, RIGIS, 2011 land use data). A table exhibiting the land use breakdown in each of the three modeled areas is provided for comparison (table 1).

Medium high density residential areas are defined as having $^1/_8$ to ¼ acre lots or 4-8 houses per acre and are considered to be a high intensity land use: areas with greater potential pollutant loading. Based on Source Water Assessment methodology (Guide to Updating Source Water Assessments and Protection Plans Version 3, December 2010), a HILU percentage greater than 40% is considered an extreme pollutant risk rating. Pollutant risk ratings are designed to warn users of the relative level of potential pollutant loading and are not an indicator of actual or existing pollution in a study area. When a risk rating is elevated, it is an indicator that pollution prevention practices should be designed and followed to reduce risks.

**Table 1 - Land use in Probabilistic Contributing Area**

| | Probabilistic Contributing Area | Northern 10% Probabilistic Contributing Area | Southern 10% Probabilistic Contributing Area |
|---|---|---|---|
| **Study Area (acres)** | 56 | 10 | 12 |
| **Land use in study area (%)** | | | |
| **forested and/or wetlands** | 30 | 0 | 50 |
| **High Intensity Land Use[1]** | 65 | 100 | 38 |
| **Recreation** | 3 | 0 | 12 |
| **Medium Density Residential** | 2 | 0 | 0 |

[1]HILU in the study area consists only of Medium High Density Residential uses

Impervious surface is estimated to cover 20% of the Probabilistic Contributing Area. Impervious surface coverage in the northern and southern 10% Contributing Areas is approximately 30% and 18%, respectively (from Town of Charlestown data). Impervious surface coverage above 10% is associated with reduced ecological functioning and subsequently, higher pollutant loading as well as reduced groundwater recharge rates. Using Source Water Assessment criteria, an impervious surface coverage falling in the range of 15-25% is considered high risk and coverage greater than 25% is considered an extreme risk of pollutant loading (Guide to Updating Source Water Assessments and Protection Plans Version 3, December 2010).

OWTS locations were estimated to be the center of each parcel, to allow comparison of how OWTS may be influenced by soil characteristics. In the Probabilistic Contributing Area 78% of the built lots have non-denitrifying systems, mainly conventional OWTS, which are estimated to remove 10% of the nitrogen in typical residential wastewater. In the northern and southern 10% Probabilistic Contributing Areas 84% and 100%, respectively, of OWTS are non-denitrifying systems. Most of the OWTS within the study areas are located on type B soils, which provide relatively rapid infiltration of water to groundwater (figure 3). Some lots are located on type C and D soils, which generally have slow infiltration, but may directly contribute to wetlands and other surface water bodies. Some of the C/D areas are also identified as densic soils. Densic soils are compact and difficult for roots to penetrate such as till.

The few vacant lots (16 vacant lots out of total of 117 lots or 14%) are disbursed throughout the Probabilistic Contributing Area. Only 2 vacant lots are located in the southern 10% Probabilistic Contributing Area and no vacant lots in the northern area (figure 4). Some of the vacant lots are located on C/D soils that are identified as excessively permeable soils, which would allow for infiltration to groundwater. Generally C/D soils are considered to have low infiltration ability, but some C/D soils have lower soil horizons that consist of highly infiltrative materials such as sand, and this is the case for the soils in this location. It is unknown if some of these vacant lots are preserved from development or have any zoning restrictions.

## MANAGE Scenarios

Utilizing the land use data previously described and parcel based OWTS information provided by the Town of Charlestown, Rhode Island, two MANAGE nutrient loading model scenarios were run to provide estimates of nitrate nitrogen concentrations in groundwater recharge from each of the three study areas (details in Appendices). The first scenario assumed a 3 person per house occupancy. The second used the RIDEM design flow calculations of two persons per bedroom for each bedroom in the house. The specific OWTS types and associated estimated nitrogen removal rates were factored into each scenario, which was not affected by soil type. No commercial OWTS systems were identified within the study area. Multiple "change evaluations" were completed on each of the two scenarios. Each of the scenarios were assessed for the following change evaluations:

***Change evaluation 1: High maintenance lawn***. This evaluation was completed for scenario 1 only, it assumed that 75% of the estimated lawn area was over-fertilized and over-watered. Standard fertilization rates assume that 75% of residential lawns are fertilized at a rate of 175 lbs N/acre/year (4.0 lb N/1000 $ft^2$/year) with 6% leaching to groundwater, and that 15% of residential lawns are over-fertilized and watered (15% leaches to groundwater). The high maintenance lawn scenario assumed that 75% of residential lawn area leaches 15% of the nitrogen load to groundwater.

***Change evaluation 2. Upgrade all existing non-denitrifying OWTS systems to denitrifying systems.*** Throughout the study areas, most of the built lots are non-denitrifying OWTS systems, mainly conventional OWTS (figure 3). It is estimated that these systems only remove 10% of the nitrogen in wastewater. This change evaluation assumed that all existing non-denitrifying OWTS systems were upgraded to denitrifying systems, which are assumed to remove 50% of the nitrogen in wastewater, after removal of the initial 10%.

***Change evaluation 3. Build out to four bedrooms and upgrade/require all denitrifying OWTS.*** This change evaluation upgraded all lots to denitrifying systems, and upgraded all vacant lots and those with less than four bedrooms to four bedroom units. Out of the 117 lots in the Probabilistic

Contribution Area, 16 were identified as vacant lots and 78 as homes with less than four bedrooms. All lots with no bedrooms were assumed to be developable regardless of size or location.

### *Change evaluation 4. Build out to two bedrooms and upgrade/require all denitrifying OWTS.*

This change evaluation upgraded all lots to denitrifying systems, and upgraded all vacant lots and those with less than two bedrooms to two bedroom units. Out of the 117 lots in the Probabilistic Contribution Area, 16 were identified as vacant and one as having less than 2 bedrooms. All lots with no bedrooms were assumed to be developable regardless of size or location. The nitrogen loading to groundwater will be the same in scenario 1 for both the two and four bedroom build-out evaluations because the estimate is based on a three person per house occupancy, regardless of the number of bedrooms.

**Table 2 - MANAGE Nutrient Model Results for Probabilistic Contributing Area.**

| Change evaluation | Scenario 1<br>3 person/house occupancy | Scenario 2<br>RIDEM OWTS calculations |
|---|---|---|
| | Nitrate N loading to groundwater (mg/L) | |
| **None, current land use/OWTS** | 7.5 | 11.8 |
| **1. High maintenance lawn** | 7.9 | NA |
| **2. Upgrade all existing non-denitrifying OWTS to denitrifying systems** | 4.7 | 7.0 |
| **3. Build out to 4 bedrooms & upgrade/require all denitrifying OWTS** | 5.1 | 8.8 |
| **4. Build out to 2 bedrooms & upgrade/require all denitrifying OWTS** | 5.1 | 7.4 |

**Table 3 - MANAGE Nutrient Model Results for Northern 10% Probabilistic Contributing Area.**

| Change evaluation | Scenario 1<br>3 person/house occupancy | Scenario 2<br>RIDEM OWTS calculations |
|---|---|---|
| | Nitrate N loading to groundwater (mg/L) | |
| **None, current land use/OWTS** | 12.6 | 17.5 |
| **1. High maintenance lawn** | 13.2 | NA |
| **2. Upgrade all existing non-denitrifying OWTS to denitrifying systems** | 7.6 | 10.2 |
| **3. Build out to 4 bedrooms & upgrade/require all denitrifying OWTS** | 7.6 | 11.6 |
| **4. Build out to 2 bedrooms & upgrade/require all denitrifying OWTS** | 7.6 | 10.2 |

**Table 4 - MANAGE Nutrient Model Results for Southern 10% Probabilistic Contributing Area.**

| Change evaluation | Scenario 1<br>3 person/house occupancy | Scenario 2<br>RIDEM OWTS calculations |
|---|---|---|
| | Nitrate N loading to groundwater (mg/L) | |
| **None, current land use/OWTS** | 3.9 | 6.7 |
| **1. High maintenance lawn** | 4.3 | NA |
| **2. Upgrade all existing non-denitrifying OWTS to denitrifying systems** | 2.4 | 3.8 |
| **3. Build out to 4 bedrooms & upgrade/require all denitrifying OWTS** | 2.7 | 5.1 |
| **4. Build out to 2 bedrooms & upgrade/require all denitrifying OWTS** | 2.7 | 4.1 |

*These nutrient loading model estimates provide a range of expected nitrate nitrogen concentrations in <u>groundwater recharge</u> in the study areas. Although these values do not provide the actual concentration of nitrate-nitrogen currently within the groundwater of the study areas, they provide a good indicator of levels expected over time. In all scenarios and change evaluations groundwater nitrogen loading from OWTS is the main source of loading (table 6 provides all MANAGE output data).*

Recent well water quality data from the RI HEALTH data base exhibits a range of nitrate values between 2.19 and 6.86 mg/L from 2012 through 2014 for all four wells in the WHPA (table 5). A level of 10 mg/L Nitrate Nitrogen is the Rhode Island Maximum Contaminant Level (MCL). Using the standard guidance for completing Source Water Assessments in Rhode Island, nitrate –nitrogen levels between 2 and 5 mg/L are an indicator of high risk: Nitrate levels in groundwater are higher than background levels, which may indicate contribution from human activity (Guide to Update Source Water Assessments and Protection Plans, Version 3, December 2014). Nitrate-nitrogen levels greater than 5 mg/L are considered an indicator of extreme risk: Nitrate levels in groundwater are higher than half the Rhode Island standard for nitrate (ibid). Nitrate levels in the extreme risk category indicate significant contribution from human activity. A program to reduce nitrate seems warranted.

**Table 5 - Reported Nitrate-Nitrogen concentrations in wells (RI HEALTH)**

| Central Beach Fire District (RI1647512) | Well 1 | Well 2 |
|---|---|---|
| **3/20/13** | 3.11 | |
| **12/09/13** | | 3.44 |
| **3/20/12** | 3.51 | |
| **12/17/12** | | 2.19 |

| Quonochontaug East Beach Fire District (RI1647511) | Well 1 | Well 2 |
|---|---|---|
| **03/03/14** | 4.44 | 6.53 |
| **01/06/14** | 5.73 | 6.07 |
| **12/09/13** | 5.92 | 6.86 |
| **09/16/13** | 5.52 | 5.49 |
| **03/13/13** | 3.23 | 4.95 |
| **12/18/12** | 4.66 | 5.28 |
| **08/20/12** | 4.92 | 5.44 |

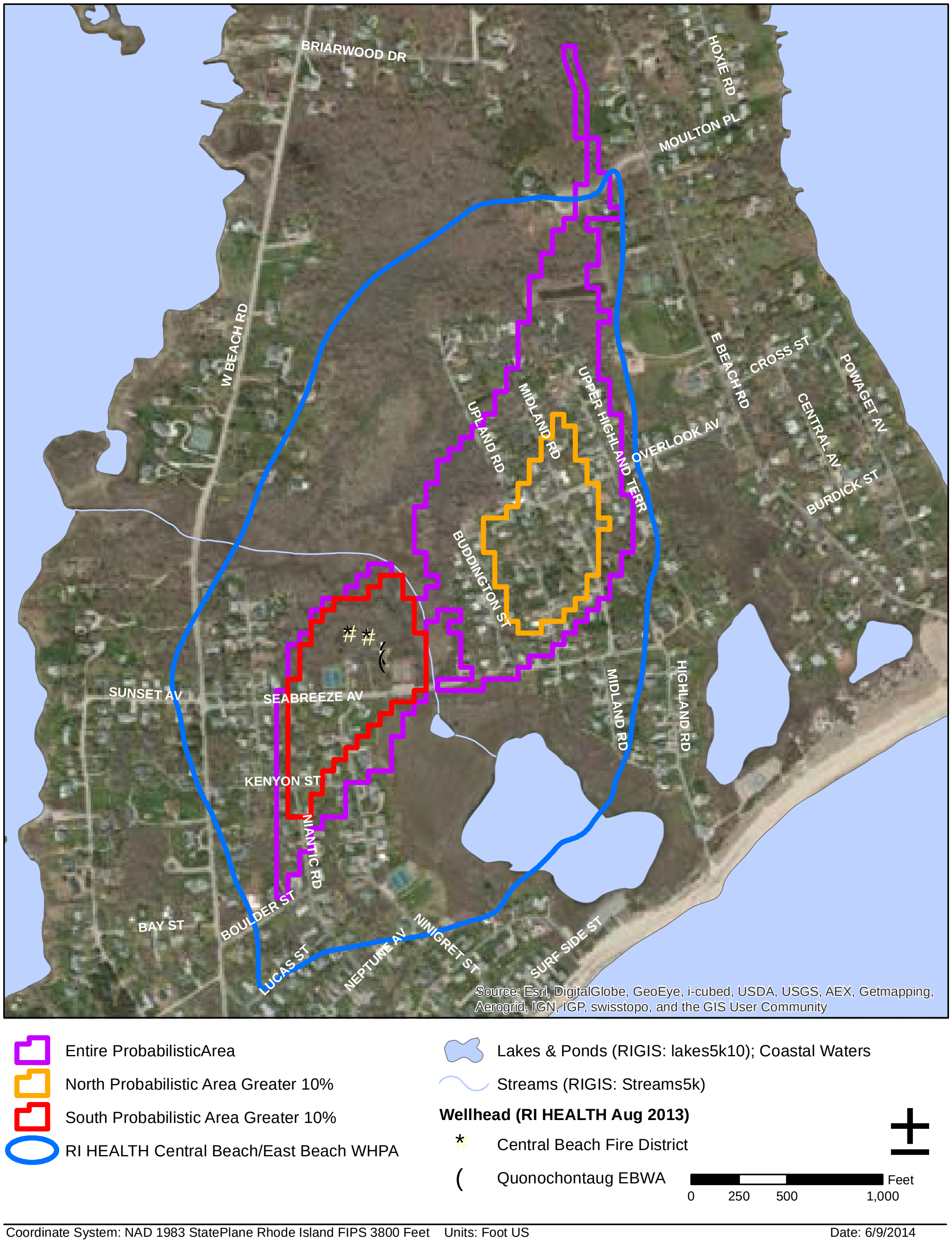



**Figure 1 - East Beach/Central Beach WHPA**

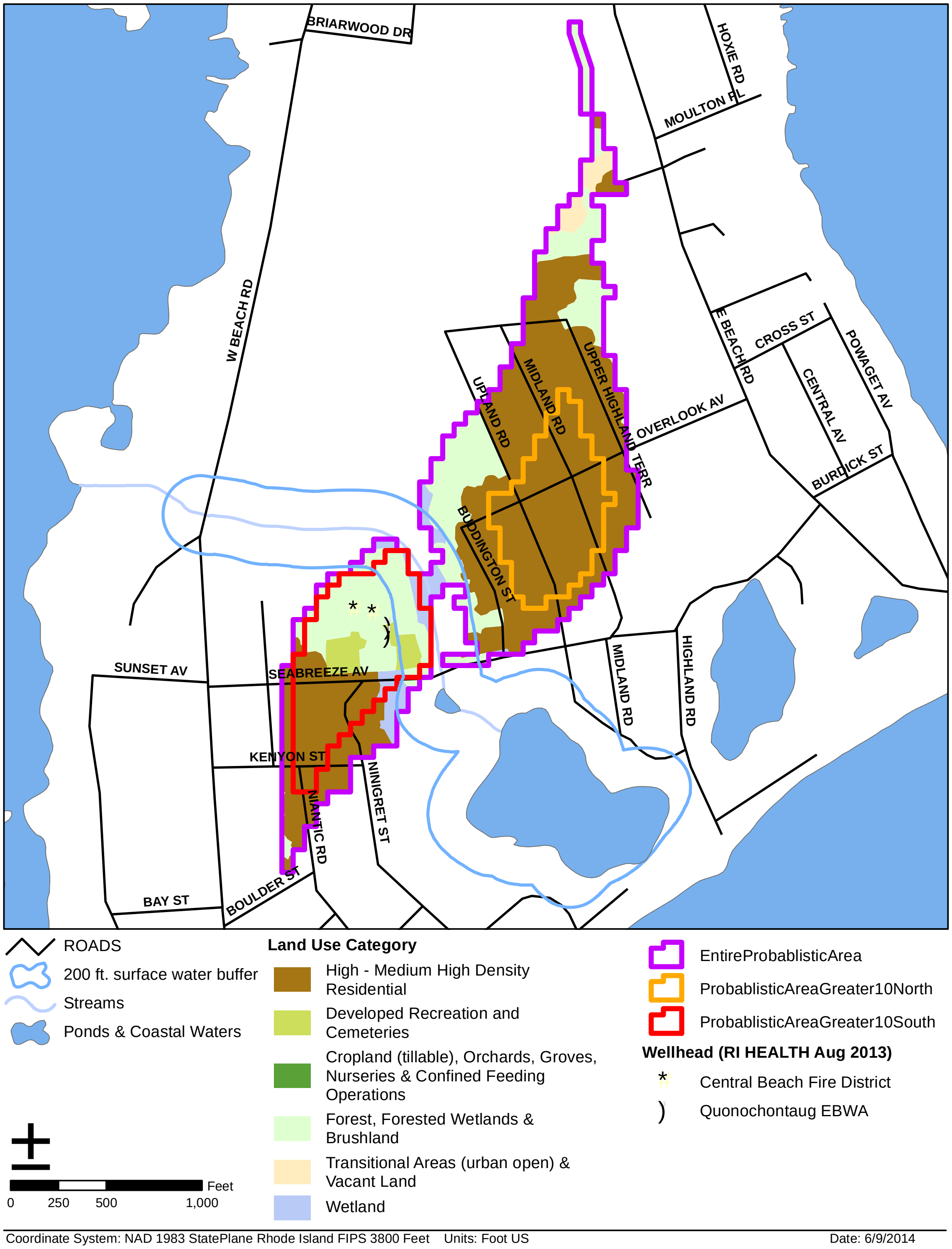



**Figure 2 - Land use within the study area**

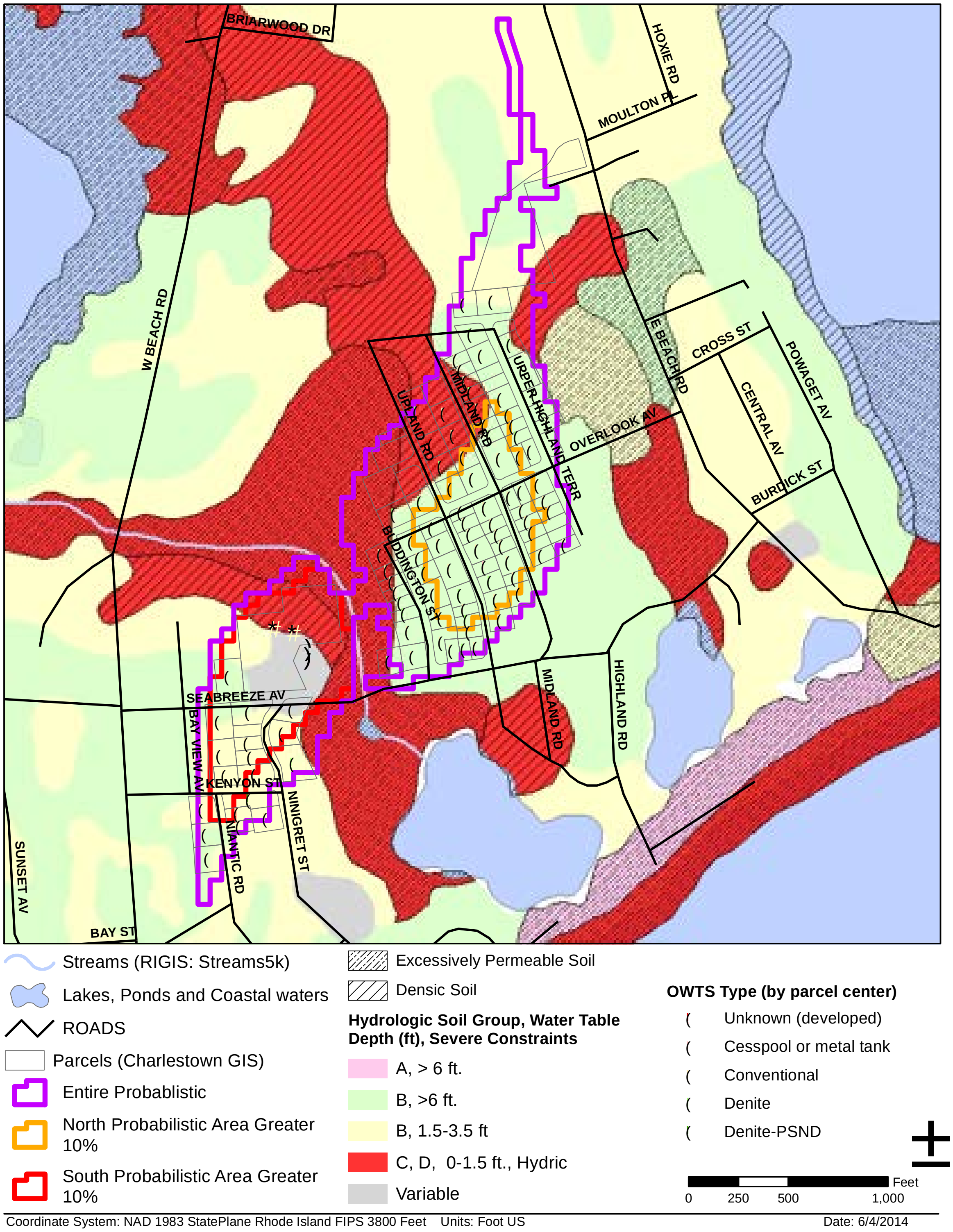



**Figure 3 - Soil hydrologic group and OWTS type in East Beach/Central Beach WHPA**

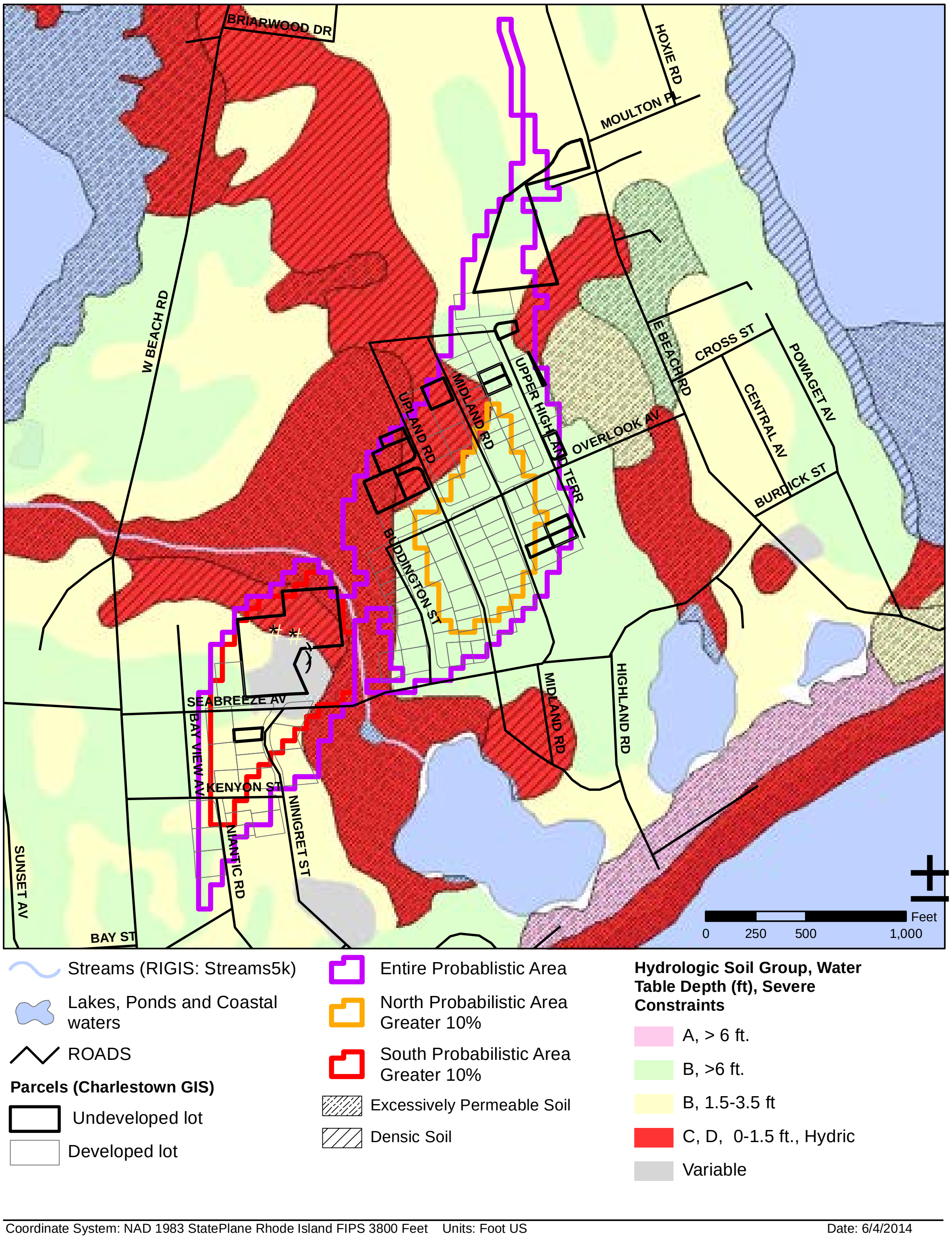



**Figure 4 - Vacant lots in East Beach/Central Beach WHPA**

### Table 6- MANAGE Nutrient Model Results

Data that was the same across all change evaluations and scenarios was removed after the first row to allow ease of data comparison.

**Entire Probabilistic Study Area**

**STUDY AREA STATISTICS**
**STANDARD - NO BMPS**

| | | Study Area Land Use Indicators | | | | | | Riparian Indicators | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Scenario** | **Change Evaluation** | **Acres** | **% Sewer** | **% High Intensity Land Use** | **% Forest** | **% Wetland** | **% Forest & wetland** | **RIP % HILU** | **RIP % Forest** | **RIP % Wetland** | **RIP % Forest and Wetland** |
| 1 | NA | 56 | 0% | 65% | 11% | 19% | 30% | 2% | 3% | 86% | 89% |
| 1 | 1, high maintenance lawn | | | | | | | | | | |
| 1 | 2, upgrade selected OWTS | | | | | | | | | | |
| 1 | 4, build out to 2 bedrooms and upgrade OWTS | | | | | | | | | | |
| 2 | NA | | | | | | | | | | |
| 2 | 2, upgrade selected OWTS | | | | | | | | | | |
| 2 | 3, build out to 4 bedrooms & upgrade OWTS | | | | | | | | | | |
| 2 | 4, build out to 2 bedrooms & upgrade OWTS | | | | | | | | | | |

| Scenario | Change Evaluation | NO3N in GW Recharge mg/l | NO3N to GW recharge lbs/ac/yr | N SW runoff lbs/ac/yr | Total N to study area lbs/ac/yr | % N in SW runoff from Atm. | OWTS | Lawn Fert. | Agri. Fert | Pet Waste | Other |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Estimated Nutrient Loading | | | | Estimated Nitrate-N sources to grw recharge | | | | | |
| 1 | NA | 7.5 | 36.6 | 3.5 | 40.0 | 0.0% | 83% | 8% | 0% | 8% | 1% |
| 1 | 1, high maintenance lawn | 7.9 | 38.6 | | 42.1 | | 79% | 13% | | 8% | 1% |
| 1 | 2, upgrade selected OWTS | 4.7 | 23.1 | | 26.5 | | 73% | 13% | | 13% | 1% |
| 1 | 4, build out to 2 bedrooms and upgrade OWTS | 5.1 | 25.8 | | 29.2 | | 76% | 12% | | 11% | 1% |
| 2 | NA | 11.8 | 70.3 | | 73.7 | | 91% | 4% | | 4% | 0% |
| 2 | 2, upgrade selected OWTS | 7.0 | 42.0 | | 45.5 | | 85% | 7% | | 7% | 1% |
| 2 | 3, build out to 4 bedrooms & upgrade OWTS | 8.8 | 61.6 | | 65.1 | | 90% | 5% | | 5% | 0% |
| 2 | 4, build out to 2 bedrooms & upgrade OWTS | 7.4 | 45.9 | | 49.4 | | 87% | 7% | | 6% | 0% |

| | | Soil hydrologic groups | | | | SWAP | Estimated Water Budget / Runoff / Recharge | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Scenario** | **Change Evaluation** | ***% A*** | ***% B*** | ***% C*** | ***% D*** | **HILU on A soil** | **# OWTS** | **OWTS /Acre** | **Precip Inches** | **ET Inches** | **Avail. Precip Inches** | **SW runoff Inches** | **Net recharge Precip. Inches** | **OWTS recharge Inches** |
| 1 | NA | 0% | 72% | 0% | 28% | 0% | 101 | 1.80 | 45 | 18 | 27 | 9.0 | 18.0 | 3.6 |
| 1 | 1, high maintenance lawn | | | | | | 101 | 1.80 | | | | | | 3.6 |
| 1 | 2, upgrade selected OWTS | | | | | | 101 | 1.80 | | | | | | 3.6 |
| 1 | 4, build out to 2 bedrooms and upgrade OWTS | | | | | | 117 | 2.08 | | | | | | 4.2 |
| 2 | NA | | | | | | 101 | 1.80 | | | | | | 8.4 |
| 2 | 2, upgrade selected OWTS | | | | | | 101 | 1.80 | | | | | | 8.4 |
| 2 | 3, build out to 4 bedrooms & upgrade OWTS | | | | | | 117 | 2.08 | | | | | | 13.0 |
| 2 | 4, build out to 2 bedrooms & upgrade OWTS | | | | | | 117 | 2.08 | | | | | | 9.3 |

**Estimated Water Budget / Runoff / Recharge**

| Scenario | Change Evaluation | SW runoff % avail. | GW recharge % avail | Precip Mgal/yr | ET Mgal/yr | Avail. Precip Mgal/yr | surface runoff Mgal/yr | Avg.net recharge precip. Mgal/yr | OWTS recharge Mgal/yr | If 100% forested surface runoff Mgal/yr | Lost recharge from 100% forested Mgal/yr |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | NA | 33% | 67% | 69 | 27 | 41 | 14 | 27 | 6 | 4 | 10 |
| 1 | 1, high maintenance lawn | | | | | | | | 6 | | |
| 1 | 2, upgrade selected OWTS | | | | | | | | 6 | | |
| 1 | 4, build out to 2 bedrooms and upgrade OWTS | | | | | | | | 6 | | |
| 2 | NA | | | | | | | | 13 | | |
| 2 | 2, upgrade selected OWTS | | | | | | | | 13 | | |
| 2 | 3, build out to 4 bedrooms & upgrade OWTS | | | | | | | | 20 | | |
| 2 | 4, build out to 2 bedrooms & upgrade OWTS | | | | | | | | 14 | | |

**North 10% Probabilistic Area**

**STUDY AREA STATISTICS: North 10% area**

STANDARD - NO BMPS

| | | | | Study Area Land Use Indicators | | | | Riparian Indicators | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Scenario** | **Change evaluation** | **Acres** | **% Sewer** | **% High Intensity Land Use** | **% Forest** | **% Wetland** | **% Forest & wetland** | **RIP % HILU** | **RIP % Forest** | **RIP % Wetland** | **RIP % Forest and Wetland** |
| 1 | NA | 10 | 0% | 100% | 0% | 0% | 0% | NA | NA | NA | NA |
| 1 | 1, high maintenance lawn | | | | | | | No riparian area | | | |
| 1 | 2, upgrade selected OWTS | | | | | | | | | | |
| 1 | 3, build out to 4 bedrooms & upgrade OWTS | No Change from denite upgrade since model uses occupancy rate, not bedrooms for calculations and there were no new OWTS since no vacant lots in this study area. | | | | | | | | | |
| 1 | 4, build out to 2 bedrooms & upgrade OWTS | | | | | | | | | | |
| 2 | NA | | | | | | | | | | |
| 2 | 2, upgrade selected OWTS | | | | | | | | | | |
| 2 | 3, build out to 4 bedrooms & upgrade OWTS | | | | | | | | | | |
| 2 | 4, build out to 2 bedrooms & upgrade OWTS | | | | | | | | | | |

| | | Estimated Nutrient Loading | | | | | Est. Nitrate-N sources to grw recharge | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Scenario** | **Change evaluation** | **NO3N in GW Recharge mg/l** | **NO3N to GW recharge lbs/ac/yr** | **N SW runoff lbs/ac/yr** | **Total N to study area lbs/ac/yr** | **% N in SW runoff from Atm.** | **OWTS** | **Lawn Fert.** | **Agri. Fert** | **Pet Waste** | **Other** |
| 1 | NA | 12.6 | 64.2 | 4.5 | 68.7 | 0.0% | 87% | 6% | 0% | 7% | 0% |
| 1 | 1, high maintenance lawn | 13.2 | 66.9 | | 71.5 | | 83% | 10% | | 7% | |
| 1 | 2, upgrade selected OWTS | 7.6 | 38.7 | | 43.3 | | 78% | 11% | | 11% | |
| 1 | 3, build out to 4 bedrooms & upgrade OWTS | | | | | | | | | | |
| 1 | 4, build out to 2 bedrooms & upgrade OWTS | | | | | | | | | | |
| 2 | NA | 17.5 | 120.4 | | 125.0 | | 93% | 3% | | 4% | |
| 2 | 2, upgrade selected OWTS | 10.2 | 70.4 | | 75.0 | | 88% | 6% | | 6% | |
| 2 | 3, build out to 4 bedrooms & upgrade OWTS | 11.6 | 94.9 | | 99.4 | | 91% | 4% | | 5% | |
| 2 | 4, build out to 2 bedrooms & upgrade OWTS | 10.2 | 71.1 | | 75.6 | | 88% | 6% | | 6% | |

| | | Soil hydrologic group | | | | SWAP | | | Estimated Water Budget / Runoff / Recharge | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Scenario | Change evaluation | *% A* | *% B* | *% C* | *% D* | HILU on A soil | # OWTS | OWTS /Acre | Precip Inches | ET Inches | Avail. Precip Inches | SW runoff Inches | Net recharge Precip. Inches | OWTS recharge Inches |
| 1 | NA | 0% | 99% | 0% | 1% | 0% | 31 | 3.18 | 45 | 18 | 27 | 10.9 | 16.1 | 6.4 |
| 1 | 1, high maintenance lawn | | | | | | | | | | | | | 6.4 |
| 1 | 2, upgrade selected OWTS | | | | | | | | | | | | | 6.4 |
| 1 | 3, build out to 4 bedrooms & upgrade OWTS | | | | | | | | | | | | | |
| 1 | 4, build out to 2 bedrooms & upgrade OWTS | | | | | | | | | | | | | |
| 2 | NA | | | | | | | | | | | | | 14.4 |
| 2 | 2, upgrade selected OWTS | | | | | | | | | | | | | 14.4 |
| 2 | 3, build out to 4 bedrooms & upgrade OWTS | | | | | | | | | | | | | 20.0 |
| 2 | 4, build out to 2 bedrooms & upgrade OWTS | | | | | | | | | | | | | 14.7 |

| Scenario | Change evaluation | SW runoff % avail. | GW recharge % avail | Precip Mgal/yr | ET Mgal/yr | Avail. Precip Mgal/yr | surface runoff Mgal/yr | Avg.net recharge precip. Mgal/yr | OWTS recharge Mgal/yr | If 100% forested surface runoff Mgal/yr | Lost recharge from 100% forested Mgal/yr |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | NA | 41% | 59% | 12 | 5 | 7 | 3 | 4 | 2 | 0 | 2 |
| 1 | 1, high maintenance lawn | | | | | | | | 2 | | |
| 1 | 2, upgrade selected OWTS | | | | | | | | 2 | | |
| 1 | 3, build out to 4 bedrooms & upgrade OWTS | | | | | | | | | | |
| 1 | 4, build out to 2 bedrooms & upgrade OWTS | | | | | | | | | | |
| 2 | NA | | | | | | | | 4 | | |
| 2 | 2, upgrade selected OWTS | | | | | | | | 4 | | |
| 2 | 3, build out to 4 bedrooms & upgrade OWTS | | | | | | | | 5 | | |
| 2 | 4, build out to 2 bedrooms & upgrade OWTS | | | | | | | | 4 | | |

**South Probabilistic Area**

**STUDY AREA STATISTICS: South 10% Area**
**STANDARD - NO BMPS**

| | | | | Study Area Land Use Indicators | | | | Riparian Indicators | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Scenario** | **Scenario** | **Acres** | **% Sewer** | **% High Intensity Land Use** | **% Forest** | **% Wetland** | **% Forest & wetland** | **RIP % HILU** | **RIP % Forest** | **RIP % Wetland** | **RIP % Forest and Wetland** |
| 1 | NA | 12 | 0% | 38% | 21% | 29% | 50% | 0% | 1% | 82% | 83% |
| 1 | 1, high maintenance lawn | | | | | | | | | | |
| 1 | 2, upgrade selected OWTS | | | | | | | | | | |
| 1 | 3, build out to 4 bedrooms & upgrade OWTS | | | | | | | | | | |
| 1 | 4, build out to 2 bedrooms & upgrade OWTS | Same as data for 4 bedroom build out as calcs. Based on occupancy, not bedrooms | | | | | | | | | |
| 2 | NA | | | | | | | | | | |
| 2 | 2, upgrade selected OWTS | | | | | | | | | | |
| 2 | 3, build out to 4 bedrooms & upgrade OWTS | | | | | | | | | | |
| 2 | 4, build out to 2 bedrooms & upgrade OWTS | | | | | | | | | | |

| | | Estimated Nutrient Loading | | | | | Est. Nitrate-N sources to grw recharge | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Scenario | Scenario | NO3N in GW Recharge mg/l | NO3N to GW recharge lbs/ac/yr | N SW runoff lbs/ac/yr | Total N to study area lbs/ac/yr | % N in SW runoff from Atm. | OWTS | Lawn Fert. | Agri. Fert | Pet Waste | Other |
| 1 | NA | 3.9 | 18.9 | 2.5 | 21.3 | 0.0% | 76% | 14% | 0% | 9% | 2% |
| 1 | 1, high maintenance lawn | 4.3 | 20.6 | | 23.0 | | 70% | 21% | | 8% | 2% |
| 1 | 2, upgrade selected OWTS | 2.4 | 11.7 | | 14.2 | | 61% | 22% | | 14% | 3% |
| 1 | 3, build out to 4 bedrooms & upgrade OWTS | 2.7 | 13.3 | | 15.8 | | 66% | 19% | | 13% | 2% |
| 1 | 4, build out to 2 bedrooms & upgrade OWTS | | | | | | | | | | |
| 2 | NA | 6.7 | 35.7 | | 38.2 | | 87% | 7% | | 5% | 1% |
| 2 | 2, upgrade selected OWTS | 3.8 | 20.1 | | 22.6 | | 77% | 13% | | 8% | 2% |
| 2 | 3, build out to 4 bedrooms & upgrade OWTS | 5.1 | 29.0 | | 31.5 | | 84% | 9% | | 6% | 1% |
| 2 | 4, build out to 2 bedrooms & upgrade OWTS | 4.1 | 22.4 | | 24.8 | | 80% | 11% | | 8% | 1% |

| | | Soil hydrologic group | | | | SWAP | Estimated Water Budget / Runoff / Recharge | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Scenario** | **Scenario** | ***% A*** | ***% B*** | ***% C*** | ***% D*** | **HILU on A soil** | **# OWTS** | **OWTS /Acre** | **Precip Inches** | **ET Inches** | **Avail. Precip Inches** | **SW runoff Inches** | **Net recharge Precip. Inches** | **OWTS recharge Inches** |
| 1 | NA | 0% | 62% | 0% | 38% | 0% | 9 | 0.76 | 45 | 18 | 27 | 7.2 | 19.8 | 1.5 |
| 1 | 1, high maintenance lawn | | | | | | 9 | 0.76 | | | | | | 1.5 |
| 1 | 2, upgrade selected OWTS | | | | | | 9 | 0.76 | | | | | | 1.5 |
| 1 | 3, build out to 4 bedrooms & upgrade OWTS | | | | | | 11 | 0.92 | | | | | | 1.9 |
| | 4, build out to 2 bedrooms & upgrade OWTS | | | | | | | | | | | | | |
| 2 | NA | | | | | | 9 | 0.76 | | | | | | 3.7 |
| 2 | 2, upgrade selected OWTS | | | | | | 9 | 0.76 | | | | | | 3.7 |
| 2 | 3, build out to 4 bedrooms & upgrade OWTS | | | | | | 11 | 0.92 | | | | | | 5.6 |
| 2 | 4, build out to 2 bedrooms & upgrade OWTS | | | | | | 11 | 0.92 | | | | | | 4.0 |

| Scenario | Scenario | SW runoff % avail. | GW recharge % avail | Precip Mgal/yr | ET Mgal/yr | Avail. Precip Mgal/yr | surface runoff Mgal/yr | Avg.net recharge precip. Mgal/yr | OWTS recharge Mgal/yr | If 100% forested surface runoff Mgal/yr | Lost recharge from 100% forested Mgal/yr |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | NA | 27% | 73% | 15 | 6 | 9 | 2 | 6 | 0 | 1 | 1 |
| 1 | 1, high maintenance lawn | | | | | | | | 0 | | |
| 1 | 2, upgrade selected OWTS | | | | | | | | 0 | | |
| 1 | 3, build out to 4 bedrooms & upgrade OWTS | | | | | | | | 1 | | |
| 1 | 4, build out to 2 bedrooms & upgrade OWTS | | | | | | | | | | |
| 2 | NA | | | | | | | | 1 | | |
| 2 | 2, upgrade selected OWTS | | | | | | | | 1 | | |
| 2 | 3, build out to 4 bedrooms & upgrade OWTS | | | | | | | | 2 | | |
| 2 | 4, build out to 2 bedrooms & upgrade OWTS | | | | | | | | 1 | | |

## APPENDICIES

*A: MANAGE Method Customizations for Study Area*

*B: MANAGE ArcView data model and Excel nutrient model customization*

*C: Electronic copies of MANAGE runs and parcel database*

# Appendix A. MANAGE Method Customizations for Study Area

MANAGE is a method of looking at a specific land area and determining its potential contaminant load based on land use, geologic and hydrologic characteristics. Tools included with the MANAGE Method include: automated methods for extracting land use and soils data from GIS systems, an Excel based nutrient loading model and various map based analyses. The tools may be used together or separately, depending upon the final desired output. For example, in a streamlined source water assessment GIS may be used to extract the acreages of various land uses within a wellhead protection area to determine risk based on the percentage of high intensity land use within the WHPA. Alternatively, a GIS may be used to intersect soils and land use where the output is imported into an Excel based model to calculate estimated nutrient loading to a WHPA or watershed. This model may include information on the actual or estimated number of OWTS, commercial OWTS and other parcel based information.

## *Overview of specific customizations, tools and process used for the MANAGE analysis of Quonochontaug East Beach/Central Beach Probabilistic Contribution Areas for:*

The 2014 MANAGE analysis for the Quonochontaug East Beach/Central Beach Probabilistic Contribution Area (Friesz, P.J., 2010) included:

1. Use of the ArcView extraction model to obtain information on land use and soils in the study area, the results of which were input into the MANAGE Excel based nutrient loading model.
2. Use of the MANAGE nutrient loading model to provide estimates of nutrient loading based on various scenarios.
3. Map based inquiry to provide context to the data.

### ArcView extraction model

Details on the ArcView extraction model are provided in Appendix B. Briefly, the most recent versions of land use (2011) and soils (2014) data as obtained from the Rhode Island Geographic Information System (RIGIS) were the main data sources utilized in the extraction model. The land use data were modified to move forested wetlands from the "forest" category in the RIGIS data to the "wetlands" category, for the purposes of this study. Riparian areas were defined as 200 feet in radius.

### MANAGE nutrient loading model

Using the land use and soils data extracted using the data extraction model, the Excel based MANAGE model was run. Standard runoff and land use nitrogen loading values were utilized. The specific number and type of OWTS for each study area were extracted from the Town of Charlestown GIS by selecting parcels with their centroid within the study area.

OWTS types were grouped as: Cesspool (cesspools, metal tanks and privys), Conventional (conventional, failing and substandard systems), denite (all adv. treatment systems except denite PSND and composting), denitrifying with PSND, holding tank , none or no data.

*Two MANAGE scenarios were then run through the Excel model. The first scenario utilized the standard MANAGE assumptions:*

- 3 person per house occupancy

- Number of housing units was based on the OWTS data from Charlestown.
- 50 Gallons water use PP Per Day
- Rainfall = 45 inches annually (based on RI Stormwater Manual)
- Evapotranspiration set at 18 inches/year (40% of rainfall)
- 75% of residents apply fertilizer at rates of 175 lb N acres with 6% leaching to groundwater and 15% of residents apply at the same rate but with 15% leaching to groundwater to simulate the small percentage of homeowners who over fertilize and over water.
- OWTS type for each house was based on OWTS data from Town of Charlestown.
- Water use was based on actual number of occupied parcels (those with OWTS)
- Residential OWTS removal rates and effluent concentrations were calculated from:
  - 46.0 mg/L N in untreated residential effluent. (this is the concentration before enters septic tank).
    - URI Septic Tank Effluent monitoring in South Kingstown and Charlestown coastal area shows 62 mg/l TN avg for Septic Tank Effluent and 52 gal/day per person waster use with an average home occupancy of 2.25)
- Actual table of mg/L used and loading per house in lb N/year assuming 3 persons per house and 50 gallons of water per person per day (BELOW).

| System type | Removal rate[1] (%) | Treated Effluent Conc. (mg N/L ) |
|---|---|---|
| **Cesspool/metal tank** | 0 | 46.0 |
| **Conventional system (including failing and substandard)** | 10 | 41.4 |
| **Denite - all adv treatment units and composting** | 10% then additional 50% | 20.7 |
| **Denitrifying with PSND** | 10 % then additional 50% and then an additional 30 % | 14.5 |
| **Holding tank** | 100 | 0.0 |
| **None or no data** | 10% (same as conventional) | 41.4 |

[1]Denite systems have a step removal system. Assumes 10% loss in tank and then continued treatment. With PSND, continued treatment in the field.

- Commercial OWTS numbers were based on data from Charlestown (no commercial systems were identified in the Quonochontaug East Beach/Central Beach Probabilistic Contribution Areas). Design flows were provided by Charlestown and utilized in the study. OWTS removal rates for commercial systems were set as the same as residential systems and calculated from:

- 78 mg/L N untreated influent (this is the concentration before enters septic tank) for commercial use (non-restaurant)
- For restaurant use 111 mg/l N for untreated influent (before enters septic tank) (personal communication, Brian Moore, RIDEM 5/1/14; higher for food service facilities).

| OWTS type | Removal rate[1] (%) | Restaurant treated effluent (mg N/L) | Non-restaurant treated effluent (mg N/L) |
|---|---|---|---|
| **Cesspool/metal tank** | 0 | 111 | 78 |
| **Conventional system (including failing and substandard)** | 10 | 99.9 | 70.2 |
| **Denite - all adv treatment units and composting** | 10% then additional 50% | 49.95 | 35.1 |
| **Denite with PSND** | 10 % then additional 50% and then an additional 30 % | 34.965 | 24.57 |
| **Holding tanks** | 100 | 0 | 0 |
| **None/No data** | 10% (same as conventional) | 99.9 | 70.2 |

[1]Denite systems have a step removal system. Assumes 10% loss in tank and then continued treatment. With PSND, continued treatment in the field.

*The second scenario assumed RIDEM design flows for calculation of water and nitrogen loads from OWTS, which are based on the number of bedrooms in a house. The assumptions for scenario 2 are as follows:*

- All assumptions same as scenario 1 except those outlined below.
- Commercial OWTS removal rates and effluent concentrations were the same as scenario 1 (no commercial systems were identified in this study area).
- Use RIDEM Residential design flow per bedroom (2 person occupancy) which is 115 GPD
- Residential OWTS removal rates and effluent concentrations were calculated from RIDEM method, which assumes 42 mg N/L as untreated influent for residential systems(this is the concentration before enters septic tank). Remvoal rates were the same as scenario 1.
- Actual table of mg/L used and loading per house in lbN/year assuming 1 bedroom with 2 person occupancy.

| System type | Removal rate[1] (%) | Treated Effluent Conc. (mg N/L) |
|---|---|---|
| **Cesspool/metal tank** | 0 | 42 |
| **Conventional system (including failing and substandard)** | 10 | 37.8 |
| **Denite - all adv treatment units and composting** | 10% then additional 50% | 18.9 |
| **Denitrifying with PSND** | 10 % then additional 50% and then an additional 30 % | 13.23 |
| **Holding tank** | 100 | 0 |
| **None or no data** | 10% (same as conventional) | 37.8 |

[1]Denite systems have a step removal system. Assumes 10% loss in tank and then continued treatment. With PSND, continued treatment in the field.

*Future change evaluations*

Changes to scenario 1 and 2 were prepared to evaluate how changes in development, lawn fertilization rates and OWTS types would affect nitrogen loading values for the study area. Four separate change evalautions were completed on each of the two scenarios.

1. Change evaluation 1: High maintenance lawn
    a. Only completed for scenario 1
    b. It is assumed that 75% of residents over fertilize and over water their lawns. [fertilize at 175 lb N acre and 15% of N leaches to groundwater (26 lb N/acre)].
    c. Standard assumption was that 75% of residents apply fertilizer at rates of 175 lb N acres with only 6% leaching to GW and 15% of residents over fertilize and over water so that 15% leaches to groundwater.
2. Change evaluation 2: Upgrade select OWTS
    a. All existing cesspools and conventional systems upgraded to denitrifying OWTS systems.
    b. All other assumptions stay the same.
3. Change evaluation 3: Built-out to 4 bedrooms and upgrade OWTS.
    a. All existing residential buildings and vacant lots expanded to 4 bedrooms with denitrifying OWTS systems.

b. Existing denitrifying and denitrifying with PSND do not change.
c. Note that this evaluation affects scenario 1 less than scenario 2 as the assumption in scenario 1 is that each house is still only occupied by 3 persons.
d. Zoning was disregarded in this exercise to obtain worst case scenario.
e. No other changes.

4. Change evaluation 4: Build out to 2 bedrooms and upgrade OWTS
    a. All existing residential houses and vacant lots expanded to 2 bedrooms with denitrifying OWTS systems.
    b. Existing denitrifying and denitrifying with PSND do not change.
    c. Note that this evaluation affects scenario 1 less than scenario 2 as the assumption in scenario 1 is that each house is still only occupied by 3 persons.
    d. Zoning was disregarded in this exercise to obtain worst case scenario.
    e. No other changes.

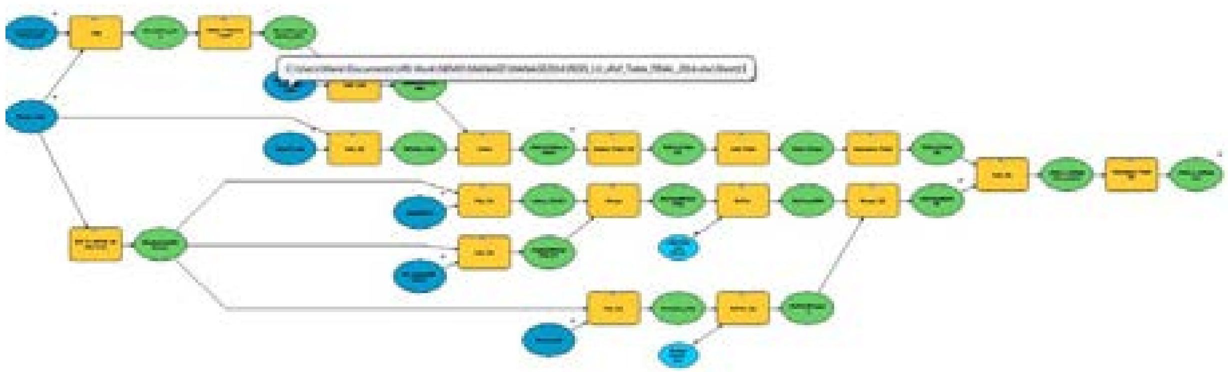
# Appendix B.

### *MANAGE Documentation:*

#### Technical details on the ArcView 10.2 extraction model.

Creation of the extraction model automated iterative processes including clipping data to the study areas and joining land use and soils data. The model presented here may be used as a starting point for other study areas, as it is unlikely that the model presented here can be utilized without modification due to file location information, desired changes in buffered areas, etc.  The final output of this model is the land use and soils data needed for input into the Excel MANAGE model.

**Visual representation of the No Sewer model created for Data Extraction for Charlestown**



## NOSewer

### Title NOSewer

### Summary

Automated process to obtain coverages needed in Excel based MANAGE model. Process used for watersheds with no sewer coverage.

General Process:

1. Land use is clipped to study area and joined to the MANAGE Land Use cross reference table to join MANAGE land use codes to RIGIS Land use codes. **Note that the standard RIGIS land use data must be adjusted to account for forested wetlands. This process will be described below**
2. Soils are clipped to study area
3. Clipped soils and land use are unioned

4. Unioned soils/land use data are processed to remove unneeded fields and then a field for "acres" is added and calculated. Acres field reflects the area of the updated unioned polygons. This unioned layer is a model output.
5. Study area is buffered to 200 feet to take into account any water bodies or streams that may be outside the study are but within 200 ft of the study area. Such a waterbody when buffered would create an area of riparian area that could be missed if the pre-buffering of the study area is not completed first. The size of this buffer should be the same as the lakes, streams and coastal areas buffer. The standard is 200ft but it can be changed in the model.
6. Lakes, streams and coastal areas are clipped by the buffered study area
7. Clipped coastal areas and lakes are merged and then buffered (200 ft is standard buffer distance, but can be changed)
8. Clipped streams are buffered (200 ft is standard buffer distance, but can be changed)
9. Buffered coastal/lakes areas and buffered streams are merged to create a riparian area or all surface waters coverage, which is an output
10. Unioned soils/land use data are clipped by the buffered riparian areas to create an output of soils/land use in the riparian area.  Area was then recalculated in this output.
11. ***Notes: If the study area encompasses Narragansett Bay, salt ponds or other areas where there is not land use data, then it will be necessary to remove the "null" land use data from the resulting soil/land use files for the full area and the riparian zone, prior to putting into the Excel MANAGE model. This is necessary because there are many areas of subaqueous soils data where there are no land use data, so you have to remove those records.
12. ****Notes: It will be necessary to identify those soils that have a restrictive layer as the Excel portion of the MANAGE model requires that information. Use the field "Rest_TYPE" which will be found in the exported soils/land use data for the full study area and the riparian area. Create a new field and code it "YES" if the field "Rest_TYPE" is any value other than "none".

****Process for modifying 2011 RIGIS land use to account for changes in wetland coding. In the 2011 data, forested wetlands are coded as "forest". The MANAGE model, models wetlands very differently than forest. Forested wetlands act more as wetlands than forest for the purposes or runoff and infiltration, so they need to be located and re-coded for proper modeling in MANAGE.

1. Extract out and save from RIGIS 2011 land use the non-forested land uses (LULC not equal to 410, 420 and 430).
2. Extract out and save the forested land use from RIGIS 2011 land use data (LUCL = 410, 420 and 430).
3. Intersect the forested land use layer and RIGIS soils. Note that soils data does not extend across the rhode island border like the land use data. Therefore, there will be some records where there is land use but no soils, you can either delete these records, which will leave holes, or just be aware that you are not coding for forested wetlands outside Rhode Island.
4. Select records with hydric soils from the intersected forested land use and soils. Use the field "Hydric", select those records where "Hydric" = "Y". For the selected records, re-code the field "Desc" as "Forested wetland" and field LULC as "610" ..
5. Delete out all soils fields from the intersected forest landuse and soils field
6. Append the updated forested land use layer with the non forested land use layer and save as a new file.

## Usage

This model will provide outputs for Excel portion of the MANAGE analysis. Once run, export the files into DBF format and open into excel. Then pivot the tables for input in the Excel based MANAGE model. **Model is set to run with geodatabase.

## Syntax

NOSewer (Lakes5k10, Streams5k, BufferedAllSW, SoilLU_inRiparian_output, RI_CoastalWaters, Study_area, LULC2011_WFWetlands, SoilLUPolys_output, Lake_Coastal_Buffer_size__ft_, Stream_Buffer__ft_, Soils14_shp, MANAGE_RIGIS_XRef_Table)

| Parameter | Explanation | Data Type |
|---|---|---|
| Lakes5k10 | **Dialog Reference**<br><br>RIGIS Lakes5k10 data. This file is buffered to determine riparian area within the study area.<br><br>There is no python reference for this parameter. | Feature Layer |
| Streams5k | **Dialog Reference**<br><br>RIGIS Streams5k data. This file is buffered to determine riparian area within the study area.<br><br>There is no python reference for this parameter. | Feature Layer |
| BufferedAllSW | **Dialog Reference**<br><br>OUTPUT - Exported buffered surface water (includes streams/hydrolines, ponds/hydropolys and coastal areas).<br><br>There is no python reference for this parameter. | Feature Class or Table |
| SoilLU_inRiparian_output | **Dialog Reference**<br><br>OUTPUT - Soil and land use polygons in the ripairan area<br><br>There is no python reference for this parameter. | Feature Class |
| RI_CoastalWaters | **Dialog Reference**<br><br>Rhode Island coastal waters data provided by DOA. In the southern areas of Rhode Island boardering the Atlantic Ocean, the salt ponds and other waterbodies/bays are poorly represented in the available lakes5k10 dataset (and are not well represented in any other data source). Therefore, it is necessary to use this coastal waters data set | Feature Layer |

| | | |
|---|---|---|
| | to get delineations of the coastal salt ponds and waterbodies.<br><br>There is no python reference for this parameter. | |
| Study_area | **Dialog Reference**<br><br>Study area watershed or wellhead protection area.<br><br>The Central Beach/East Beach 10% probabilistic contributing area, the northern portion of the 10% probabilistic area and the southern portion of the 10% probabilistic area. The probabilistic study area was provided by RI HEALTH as obtained from: USGS Contribution 2010-5060 [Friesz, P.J., 2010, Delineation and prediction uncertainty of areas contributing recharge to selected well fields in wetland and coastal settings, southern Rhode Island: U.S. Geological Survey Scientific Investigations Report 2010–5060, 69 p. (Also available online at http://pubs.usgs.gov/sir/2010/5060.)] The data provided by RI HEALTH was point based data (rather than a polygon), therefore data was converted back to raster blocks (polygons) 60 x 60 feet (page 42 of 2010-5060 report). The outline of the polygon blocks was then traced to create the one polygon representing the 10% Northern and 10% Southern probabilistic areas.<br><br>There is no python reference for this parameter. | Feature Layer |
| LULC2011_WFWetlands | **Dialog Reference**<br><br>RIGIS 2011 land use with the forested wetlands called out as a separate category. Forested wetlands were obtained by determining areas with forested land use (LULC codes of 410, 420 and 430) that intersected with areas with hydric soils (as per 2014 soils data coverage). These areas were then coded as Forested wetland LULC 610.<br><br>There is no python reference for this parameter. | Feature Layer |
| SoilLUPolys_output | **Dialog Reference**<br><br>OUTPUT - soils and land use polygons created by union of soils and polygon data.<br><br>There is no python reference for this parameter. | Feature Class |

| | | |
|---|---|---|
| Lake_Coastal_Buffer_size__ft_ | **Dialog Reference**<br><br>Buffer size of the merged lakes and coastal areas data. Used in determining the riparian area along with stream buffer. Standard size is 200 ft.<br><br>There is no python reference for this parameter. | Linear unit or Field |
| Stream_Buffer__ft_ | **Dialog Reference**<br><br>Buffer size (standard 200f t) of streams/rivers. Should be same size as lake and coastal buffer.<br><br>There is no python reference for this parameter. | Linear unit or Field |
| Soils14_shp | **Dialog Reference**<br><br>2014 RIGIS soils<br><br>There is no python reference for this parameter. | Feature Layer |
| MANAGE_RIGIS_XRef_Table | **Dialog Reference**<br><br>Table cross referencing MANAGE groupings of land use with RIGIS. THis is an Excel based table.<br><br>There is no python reference for this parameter. | Table View or Raster Layer or Raster Catalog Layer or Mosaic Layer |

## Code Samples

There are no code samples for this tool.

## Tags

MANAGE, No Sewer

## Credits

RINEMO 2014

## Use limitations

This model will provide outputs for the Excel portion of the MANAGE analysis. Once run, export the files into DBF format and open into excel. Then pivot the tables for input in the Excel based MANAGE model. **Model is set to run with geodatabase.**. This model was built to support the 2014 Charlestown, Rhode Island wastewater management zone process. It should only be used for other areas after specifically reviewed for compatibility.  This model should only be used in areas where there is no sewer coverage.

MANAGE Land Use classification codes cross referenced to RIGIS Land Use data (2011).

| RIGIS Land use cateogry ID | RIGIS Description | MANAGE Land use Group | MANAGE ID | High intensity land use |
|---|---|---|---|---|
| **120** | Commercial & Services | COMMERCIAL | 6 | x |
| **147** | Other transportation | COMMERCIAL | 6 | x |
| **151** | Commercial/residential mixed | COMMERCIAL | 6 | x |
| **152** | Commercial/Industrial mixed | COMMERCIAL | 6 | x |
| **130** | Industrial | INDUSTRIAL | 7 | x |
| **220** | Cropland | CROPLAND | 15 | x |
| **240** | Confined feeding operations | CROPLAND | 15 | x |
| **230** | Orchards, groves, nurseries | ORCHARDS | 16 | x |
| **300** | Brushland | BRUSH | 17 | |
| **400** | Forest lands | FOREST | 18 | |
| **410** | Deciduous forest | FOREST | 18 | |
| **420** | Coniferous forest | FOREST | 18 | |
| **430** | Mixed forest | FOREST | 18 | |
| **111** | High density residential | HDR | 1 | x |
| **112** | Medium high density residential | MHDR | 2 | x |
| **161** | Developed Recreation | RECREATION | 12 | |
| **163** | Cemeteries | RECREATION | 12 | |
| **170** | Institutional | INSTITUTION | 13 | x |
| **115** | Low Density Residential | LDR | 5 | |
| **113** | Medium Density Residential | MDR | 3 | |
| **114** | Medium Low Density Residential | MLDR | 4 | |
| **146** | Power Lines | PASTURE | 14 | |
| **210** | Pasture | PASTURE | 14 | |
| **250** | Idle Agriculture | PASTURE | 14 | |
| **730** | Rock outcrop | BARREN | 19 | |
| **740** | Strip mines, quarries, gravel pits | BARREN | 19 | |
| **760** | Mixed barren | BARREN | 19 | |
| **710** | Beaches | BARREN | 19 | |
| **720** | Sandy areas other than beaches | BARREN | 19 | |
| **750** | Transitional Areas | MDR | 3 | |
| **141** | Roads | ROADS | 8 | x |
| **142** | Airports | AIRPORTS | 9 | x |
| **143** | Railroads | RAILROADS | 10 | x |

| | | | | |
|---|---|---|---|---|
| **162** | Urban Open Space | RECREATION | 12 | |
| **145** | Waste Disposal Areas | JUNKYARDS | 11 | x |
| **144** | Water and Sewage Treatment Facilities | INSTITUTION | 13 | x |
| **600** | Wetland | WETLAND | 20 | |
| **610** | Forested Wetland | WETLAND | 20 | |
| **500** | Water | WATER | 21 | |

***Technical details for Excel MANAGE model*** (taken from: RINEMO/URI. 2006. *Database Development, Hydrologic Budget and Nutrient Loading Assumptions for the "Method for Assessment, Nutrient-loading, And Geographic Evaluation of Nonpoint Pollution" (MANAGE) including the GIS-Based Pollution Risk Assessment Method, 2006 update*, accessed from: http://www.uri.edu/ce/wq/nemo/Tools/PDFs/MANAGE/MANAGEassumptionsREV2006.pdf)

## APPENDIX B: SURFACE RUNOFF COEFFICIENTS

The runoff coefficient for each Soil/Land use combination is estimated using the formula presented by Adamus and Bergman (1993). This calculation is presented below.

$$C = LLC + (ULC - LLC) * X$$

C = runoff coefficient
LLC = lower limit runoff coefficient for a particular land use
ULC = upper limit runoff coefficient for a particular land use
X = 0 for soil type A; 1/3 for soil type B; 2/3 for soil type C; 1 for soil type D.

TABLE B1: Upper and Lower Limit Runoff Coefficients for each Soil/Land use combination

| | Reference Values | | Calculated Runoff Coefficient (C) Based on Soil Hydrogroup | | | |
|---|---|---|---|---|---|---|
| **Land Use** | **LLC** | **ULC** | **A** | **B** | **C** | **D** |
| HDR[a] | 0.37 | 0.55 | 0.37 | 0.43 | 0.49 | 0.55 |
| MHDR[a] | 0.18 | 0.37 | 0.18 | 0.24 | 0.31 | 0.37 |
| MDR[a] | 0.15 | 0.18 | 0.15 | 0.16 | 0.17 | 0.18 |
| MLDR[a] | 0.12 | 0.15 | 0.12 | 0.13 | 0.14 | 0.15 |
| LDR[a] | 0.11 | 0.12 | 0.11 | 0.11 | 0.12 | 0.12 |
| COMMERCIAL[b] | 0.5 | 0.85 | 0.50 | 0.62 | 0.73 | 0.85 |
| INDUSTRIAL[b] | 0.5 | 0.85 | 0.50 | 0.62 | 0.73 | 0.85 |
| ROADS[a] | 0.7 | 0.82 | 0.70 | 0.74 | 0.78 | 0.82 |
| AIRPORTS[a] | 0.7 | 0.82 | 0.70 | 0.74 | 0.78 | 0.82 |
| RAILROADS[a] | 0.7 | 0.82 | 0.70 | 0.74 | 0.78 | 0.82 |
| JUNKYARDS[a] | 0.7 | 0.82 | 0.70 | 0.74 | 0.78 | 0.82 |
| RECREATION[b] | 0.1 | 0.3 | 0.10 | 0.17 | 0.23 | 0.30 |
| INSTITUTION[c] | 0.33 | 0.39 | 0.33 | 0.35 | 0.37 | 0.39 |
| PASTURE[d] | 0.05 | 0.25 | 0.05 | 0.12 | 0.18 | 0.25 |
| CROPLAND[d] | 0.15 | 0.5 | 0.15 | 0.27 | 0.38 | 0.50 |
| ORCHARDS[d] | 0.05 | 0.25 | 0.05 | 0.12 | 0.18 | 0.25 |
| BRUSH[b] | 0 | 0.1 | 0.00 | 0.03 | 0.07 | 0.10 |
| FOREST[d] | 0 | 0.1 | 0.00 | 0.03 | 0.07 | 0.10 |
| BARREN[b] | 0.05 | 0.8 | 0.05 | 0.30 | 0.55 | 0.80 |
| WETLAND[c] | 0 | 0.1 | 0.00 | 0.03 | 0.07 | 0.10 |
| WATER | 1 | 1 | 1.00 | 1.00 | 1.00 | 1.00 |

Notes:

[a] Calculation of ULC and LLC for Residential is based on Schueler's (1987) Simple Method:
$C = 0.05 + 0.9\,I$
I = fraction of site imperviousness (e.g. 30% impervious would have I = 0.3)

The percentage of site imperviousness for each land use is provided in Appendix H. The fraction of site imperviousness (I) for the calculation of residential ULC and LLC was set at the updated MANAGE values (2003) for site impervious surface. The ULC for each residential land use was set as the residential LLC of the more intense residential development (ie: the ULC for MHDR is set as the LLC for HDR). The fraction of impervious surface for roads, airports, railroads and junkyards was set at theTR55 value for industrial to determine the ULC and commercial to determine the LLC.

[b] Based on data presented by Novotny and Olem (1994), p. 146.

[c] Assuming INSTITUTION is hydrologically similar to MHDR, unless otherwise specified by the user.

[d] Based on best professional judgement, using Curve Number Method as a guide.

[e] Generally WETLANDS will occur on D soils. It is assumed that wetlands are similar to forests on D soils, and for this reason wetlands are set using the same coefficients as the FOREST category.

[f] It is assumed that Evapotranspiration and surface runoff will vary through the year.

## APPENDIX D: TOTAL NITROGEN EXPORT COEFFICIENTS TO SURFACE WATER

Although nitrogen is generally not considered to be the limiting nutrient in fresh water systems, it has been found to be the nutrient promoting growth of algae and aquatic plants in coastal waters. In order to estimate the total load of nitrogen reaching a coastal embayment, both contributions from surface runoff, as well as from groundwater seepage must be estimated. The surface runoff contribution of nitrogen can be calculated the same way as the phosphorus contribution (Appendix C). Like phosphorus, nitrogen can be transported from malfunctioning septic systems via overland flow to the receiving surface water. Estimation of the nitrogen load from malfunctioning septic systems is done in the same way as estimation of the phosphorus load, using soil properties and increasing the nitrogen loading for systems located within the riparian areas. The nitrogen loading factors listed below include contributions from diverse sources such as atmospheric deposition, fertilizers, and small animal waste. The loading factors on surface water reflect direct atmospheric deposition only. Using a similar formula to that used to calculate the runoff coefficient, a "most likely" nitrogen export coefficient for a particular land use is calculated for each SOIL/LAND USE combination as:

$$NC = LNC + (HNC - LNC) * X$$

NC = "most likely" nitrogen export coefficient
LNC = low nitrogen export coefficient for a particular land use
HNC = high nitrogen export coefficient for a particular land use
X = 0 for soil type A; 1/3 for soil type B; 2/3 for soil type C; 1 for soil type D.

TABLE D1: Total Nitrogen Export Loading Coefficients (lb/acre/yr) for each Soil/Land use Combination

| | Reference Values | | Calculated Runoff Coefficient (C) Based on Soil Hydro Group | | | |
|---|---|---|---|---|---|---|
| **LAND USE CATEGORY** | **LNC[a]** | **HNC[a]** | **A** | **B** | **C** | **D** |
| HDR[b] | 7 | 10.2 | 7.0 | 8.1 | 9.1 | 10.2 |
| MHDR[b] | 3.3 | 7 | 3.3 | 4.5 | 5.8 | 7.0 |
| MDR[b] | 2.8 | 3.3 | 2.8 | 3.0 | 3.1 | 3.3 |
| MLDR[b] | 2.3 | 2.8 | 2.3 | 2.5 | 2.6 | 2.8 |
| LDR[b] | 2.1 | 2.3 | 2.1 | 2.2 | 2.2 | 2.3 |
| COMMERCIAL | 2 | 20 | 2.0 | 8.0 | 14.0 | 20.0 |
| INDUSTRIAL | 2 | 15 | 2.0 | 6.3 | 10.7 | 15.0 |
| ROADS[c] | 2 | 20 | 2.0 | 8.0 | 14.0 | 20.0 |
| AIRPORTS[c] | 2 | 20 | 2.0 | 8.0 | 14.0 | 20.0 |
| RAILROADS[c] | 2 | 20 | 2.0 | 8.0 | 14.0 | 20.0 |
| JUNKYARDS[c] | 2 | 20 | 2.0 | 8.0 | 14.0 | 20.0 |
| RECREATION | 1.5 | 4 | 1.5 | 2.3 | 3.2 | 4.0 |
| INSTITUTION[d] | 3.3 | 7 | 3.3 | 4.5 | 5.8 | 7.0 |
| PASTURE[e] | 2 | 5.5 | 2.0 | 3.2 | 4.3 | 5.5 |
| CROPLAND[f] | 4 | 50 | 4.0 | 19.3 | 34.7 | 50.0 |
| ORCHARDS | 4 | 35 | 4.0 | 14.3 | 24.7 | 35.0 |

| LAND USE CATEGORY | Reference Values LNC[a] | HNC[a] | Calculated Runoff Coefficient (C) Based on Soil Hydro Group A | B | C | D |
|---|---|---|---|---|---|---|
| BRUSH | 0.9 | 2.9 | 0.9 | 1.6 | 2.2 | 2.9 |
| FOREST | 0.9 | 2.9 | 0.9 | 1.6 | 2.2 | 2.9 |
| BARREN | 0.9 | 2.9 | 0.9 | 1.6 | 2.2 | 2.9 |
| WETLAND | 0 | 0 | 0.0 | 0.0 | 0.0 | 0.0 |
| WATER[g] | 8 | 8 | 8.0 | 8.0 | 8.0 | 8.0 |

[a] These nitrogen export coefficients were selected based on literature reviews by Rast and Lee (1983), Frink (1991), and Budd and Meals (1994), and by considering values given by RIDEM(1993b), Novotny and Olem (1994), and Stigall and others (1993), followed by discussions with Arthur J. Gold at the University of Rhode Island

[b] Based on RIDEM (1993b) and assuming 45 inches of precipitation annually (Allen and others, 1966).

[c] Assuming these land uses are similar to COMMERCIAL land uses.

[d] Assuming INSTITUTION is similar to MHDR land use, unless otherwise specified by the user.

[e] If pasture is grazed, or if manure is applied, values will be higher (Reckhow and others (1980) show rotational grazing 7.0 lb/ac/yr; continuous grazing or forage fertilized 27.0 lb/ac/yr (p. 60, 97))

[f] Assuming no conservation tillage or terracing. If BMP's are in place, they will be applied.

[g] Atmospheric deposition only based on northeastern U.S. (Ollinger et al. 1993 and Yang 1996). Some authors (e.g., Reckhow and others (1980) and Horsley & Witten (1994)) suggest 3 different loading rates to the surface of a water body, depending upon the dominant land use in the watershed: forest, agricultural/rural, urban.

Loading from malfunctioning residential septic systems in the unsewered portion of the watershed is calculated as follows:

Septic systems within the 200 ft riparian buffer:

See Appendix G for the proportion of total number of septic systems which malfunction. The total nitrogen loading from malfunctioning riparian septic systems (within 200 ft of surface water) is set at 7.0 lb/cap/yr. If it assumed that there is 2.4 cap/residential septic system (1990 RI Census) then there is 16.8 lb N/malfunctioning residential septic system within the 200 ft. buffer.

Septic systems outside the riparian areas:

See Appendix G for proportion of total number of septic systems which malfunction. The total nitrogen loading from malfunctioning septic systems outside the riparian area is set at 5.6 lb/cap/yr. If it is assumed that there is a 2.4 cap/residential septic system (1990 RI Census), this comes to 13.4 lb N/malfunctioning residential septic system outside the 200 ft. buffer.

Note:
Background concentration of N in RI Surface Water (no human influence) is ~ 0.25 ppm based on sampling from ponds whose watersheds are subject to little human influence (data from Watershed Watch 1994, Linda Green). [Art Gold suggests 0.2 to 0.35 mg/l ].

## APPENDIX E: NITRATE-NITROGEN LOADING TO GROUNDWATER

The long-term water quality of an aquifer can be inferred from the quality of the recharge water (Hantzsche and Finnemore, 1992). Using a mass-balance approach, the average concentration of nitrate found in the infiltrating recharge water can be estimated by dividing the total N loading from various and diverse land use above the aquifer by the recharge volume from precipitation and such artificial sources as septic systems (similar to Frimpter and others (1990); Horsley & Witten (1994); and several other models). There are many complex mechanisms in the nitrogen cycle which are not directly accounted for. However, because nitrate-nitrogen generally behaves conservatively once it reaches the water table, some simplifying assumptions can be made.

$$\text{Average N concentration} = \frac{\text{Annual N load from diverse land uses}}{\text{Annual recharge (natural + septic systems)}}$$

Sources of nitrogen to groundwater include:

i. Septic systems
ii. Lawn fertilizers
iii. Agricultural fertilizers
iv. Large animals (cows, horses)
v. Pet waste
vi. Stormwater infiltration

Sources of recharge include:

i. Precipitation
ii. Septic systems

**A) LOAD**

Calculate total annual nitrogen load to groundwater, based on land use:

**1. Septic systems:**

Estimate the total number of residential septic systems in unsewered areas based on housing density. Commercial, Industrial, and Institution areas are all treated as MDR.

Assumptions:
2.4 cap/dwelling unit (Appendix F).
7 lb N/person/yr leaves the septic tank.
50 gal/person/day.
90% of N leaches to the groundwater (Siegrist and Jenssen, 1989).

In Rhode Island where conventional ISDS are typically buried deeper, and gravel fill is brought in, 90% may be a more accurate estimate. This is supported by Lamb and others, 1988).

If only RIGIS land use data is available, estimate the number of homes based on the residential land use category, excluding areas served by sewer systems (see table below). MANAGE assumes a 100% occupancy rate, to determine the worst potential impact (this may not be appropriate for all watersheds).

Table E1: Estimation of the Number of Septic Systems per Acre Based on Land Use

| Land Use | Mean Dwelling Unit Density (unit/acre) (Number of Septic Systems/acre) | Assumptions |
|---|---|---|
| HDR | 8.00 | |
| MHDR | 3.60 | |
| MDR | 1.00 | |
| MLDR | 0.50 | |
| LDR | 0.20 | |
| Other: | | |
| COMMERCIAL | 1.00 | Assume these are similar to MD Residential. Also, we |
| INDUSTRIAL | 1.00 | Assume that septic system use in recreational areas is |
| RECREATION | 0.50 | Seasonal (6 months out of the year). |
| INSTITUTION | 1.00 | |

## 2. Lawns

Estimate lawn area in watershed:

Table E2: Estimation of the Fraction of Lawn Area Associated with Each Land use

| Land Use | Fraction of Land Use Attributed to Lawn Area |
|---|---|
| HDR | 0.25 |
| MHDR | 0.35 |
| MDR | 0.50 |
| MLDR | 0.35 |
| LDR | 0.25 |
| COMMERICAL | 0.05 |
| INDUSTRIAL | 0.10 |
| RECREATION | 0.70 |
| | (golf courses to be estimated separately) |
| INSTITUTION | 0.25 |

Assumptions: 75% of residents apply lawn fertilizer.
Fertilizer is applied at a rate of 175 lb N/ac/yr (4 lb/1000 sq. ft./yr)
Leaching rate is 6%, yielding a load of 10.5 lb N/ac/yr leached to the groundwater.
(most models use significantly higher leaching rates (30 to 60 %); a lower estimate is used here due to low leaching rates found by Gold and others (1990), and Morton and others (1988) in Rhode Island outwash soils, and assuming some mismanagement, such as over-watering, bare spots, compacted soil, and improper fertilizer application.

### 3. Agriculture (CROPLAND and ORCHAR land use)

Assume a fertilizer application rate of 215 lb N/ac/yr, 30% of which leaches to the groundwater.

### 4. Pet Waste in Residential Areas

0.41 lb N/person/yr is assumed to leach to the groundwater from pet waste. (Koppleman, 1978)

### 5. Forests and Unfertilized Lawns

Gold and others (1990) show a loading of 1.2 lb/ac/yr from forest (FOREST, PASTURE and BRUSH land use) and unfertilized lawn (unfertilized lawn area = 25% of total lawn area).

**B) RECHARGE**

Calculate total annual groundwater recharge, based on land use:

1) Natural recharge:

Average annual infiltration = Annual precipitation - Annual ET - Annual RO

I. Average annual precipitation = 45 inches (Allen and others, 1966)
II. Average annual evapotranspiration (ET) = 18 inches (Johnston and Dickerman, 1985)
III. Average annual run off (RO) is calculated from runoff coefficients for each land use category.
Annual RO = (Annual PPT)*(RO coefficient (C))

Wetlands represent a complex system of interaction between surface and groundwater. It is assumed that there is no runoff from a wetland area. The equation above then implies that wetlands recharge 27 inches to groundwater, which is almost never the case. It is assumed that groundwater generally flows into wetlands, rather than water from wetlands percolating to groundwater. If this assumption is made the total area of wetlands in the watershed X 27 inches must be subtracted from the total volume of average annual recharge to groundwater.

2) Recharge from septic systems

Recharge from septic systems = (total # of septic systems) (2.4 cap/dwelling) (50 gal/cap/day) (365 days/yr)

## APPENDIX F: 1990 RI CENSUS FIGURES

| | Number persons/dwelling unit[a] | Vacancy Rate[b] |
|---|---|---|
| State of RI | 2.6 | 8.8% |
| Bristol County | 2.6 | 5.4% |
| Kent County | 2.6 | 5.2% |
| Newport County | 2.5 | 12.8% |
| Providence County | 2.5 | 6.9% |
| Washington County | 2.6 | 21.2% |

[a] Based on number of occupied (vs. vacant) dwelling units. Does not include seasonally occupied dwelling units.
[b] Vacancy rate includes seasonally occupied dwelling units.
Source: 1990 Census Data from RI Department of Administration, One Capitol Hill, Providence, RI 02908.
Note: We will use 2.6 persons/dwelling unit. The two counties, Newport and Providence, with an average of 2.5 persons/dwelling unit (reflecting a higher number of apartments, which tend to have fewer occupants) are heavily sewered. Occupancy rates may be further refined using US Census block data and building permits.
[c] Values for occupancy rate are often adjusted in the MANAGE model based on the input of local officials and the census figures.

## APPENDIX H: IMPERVIOUSNESS OF DEVELOPED LAND

Table H1: Estimated Percent Impervious Surface for Land Use Used in SWAP Report (Original MANAGE Impervious Values)

| Land Use | Low | High | Original Values used in MANAGE (and SWAP reports) |
|---|---|---|---|
| | Estimated % Impervious | | |
| HDR[a] | 65 | 80 | 72 |
| MHDR[a] | 38 | 65 | 50 |
| MDR[a] | 20 | 38 | 30 |
| MLDR[a] | 12 | 20 | 16 |
| LDR[a] | 5 | 12 | 8 |
| COMMERCIAL[b] | 50 | 94 | 72 |
| INDUSTRIAL[b] | 50 | 94 | 72 |
| ROADS[c] | 72 | 85 | 72 |
| AIRPORTS[c] | 72 | 85 | 72 |
| RAILROADS[c] | 72 | 85 | 72 |
| JUNKYARDS[c] | 72 | 85 | 72 |
| RECREATION | 5 | 28 | 10 |
| INSTITUTION[d] | 38 | 65 | 50 |

Notes:

[a] Based on estimate of impervious fraction used in TR55 (1975).

[b] Calculated from low and high runoff coefficients estimated from Novotny and Olem (1994), p. 146.

[c] Based on TR55. Low is that of Industrial and high is commercial.

[d] Assuming INSTITUTION is hydrologically similar to MHD residential, unless otherwise specified by the user.

Table H2: Updated Estimated Percent Impervious Surface for Land Use Used in MANAGE

| Land Use Category | TR 55 USDA | New Jersey DEP[a] | Center for Watershed Protection[b] | Value Used in MANAGE[c] (updated 2003) |
|---|---|---|---|---|
| | Estimated Site Impervious (%) | | | |
| HDR (1/8 acre lot) | 65 | 59 | 33 | 55 |
| MHDR (1/4 acre lot) | 38 | 39 | 28 | 36 |
| 1/3 acre lot | 30 | 34 | | |
| 1/2 acre lot | 25 | 27 | 21 | |
| MDR (1 acre lot) | 20 | 18 | 14 | 14 |
| MLDR (2 acre lot) | 12 | 12 | 11 | 11 |
| LDR (> 2 acre lot) | | 9.6 | | 9 |
| AGRICULTURE | | | 2 | |
| OPEN URBAN | | | 9 | |
| TOWN HOUSE | | | 41 | |
| MULTIFAMILY | | | 44 | |
| COMMERCIAL | 85 | | 72 | 72 |
| INDUSTRIAL | 72 | | 53 | 54 |
| ROADS | | | 80 | 72 |
| AIRPORTS | | | | 72 |
| RAILROADS | | | | 72 |
| JUNKYARDS | | | | 72 |
| RECREATION | | | | 10 |
| INSTITUTION | | | 34 | 34 |

[a] New Jersey DEP
[b] CWP 2002. The Watershed Treatment Model. Ellicott City MD. www.stormwatercenter.net
[c] Values for impervious surface are in the MANAGE code.

## APPENDIX I: SEPTIC SYSTEM PARAMETERS

| | | SOURCE |
|---|---|---|
| Residential Wastewater Flow | 66 gal/cap/day | Brown and Assoc. (1980) |
| | 45 gal/cap/day | USEPA (1980) |
| | 45 gal/cap/day | Canter and Knox (1985) |
| | 65 gal/cap/day | Frimpter and others (1990) |
| | 33.8 gal/cap/day (=128 liters) | Gold and others (1990) |
| | 45 gal/cap/day (=170 liters) | Postma and others (1992) |
| | 55 gal/cap/day | Horsley & Witten (1994) |
| | 45 - 60 gal/cap/day | RIDEM (Galen Howard, 1995) |
| Number of people/dwelling | 3.5 cap/dwelling | Brown and Assoc. (1980) |
| | 2.7 cap/dwelling | Valiela and Costa (1988) |
| | 3.0 cap/dwelling | Buzzards Bay Project (1990) |
| | 2.7 cap/dwelling | Frimpter and others (1990) (as cited in Weiskel and Howes (1991) |
| | 3.0 cap/dwelling | Horsley & Witten (1994) |
| Phosphorus in effluent | 16.4 mg/l (mean from lit review) (3.3 lb/cap/yr @ 66 gcd) | Brown and Assoc. (1980) |
| | 3 - 5 g/cap/day (in wastewater) | USEPA (1980) |
| | 18 - 29 mg/l (in wastewater) | USEPA (1980) |
| | 15 mg/l (2 lb/cap/yr @ 45 gcd) | Canter and Knox (1985) |
| | 1.4 kg/cap/yr (3.1 lb/cap/yr) | Valiela and Costa (1988) |
| | 1.45 kg/cap/yr (3.2 lb/cap/yr) | Olem and Flock (1990) |
| | 13 mg/l (1.8 lb/cap/yr @ 45 gcd) | Postma and others (1992) |
| | 0.5 - 1.5 kg/system/yr (1.1 - 3.3 lb/system/yr) | Budd and Meals (1994) |
| | 7 - 40 mg/l | Budd and Meals (1994) |
| | 3.2 lb/cap/yr | Horsley & Witten (1994) |
| Nitrogen in effluent | 44.6 mg/l (mean from lit review) | Brown and Assoc. (1980) |
| | 11.2 g/cap/day (9 lb/cap/yr) | Brown and Assoc. (1980) |
| | 6 - 17 g/cap/day (in wastewater) | USEPA (1980) |
| | 35 - 100 mg/l (in wastewater) | USEPA (1980) |
| | [USEPA assumes 10% removal in septic tank; Gold and others (1990) found up to 21% removal] | |
| | 40 mg/l (5.5 lb/cap/yr @ 45 gcd) | Canter and Knox (1985) |
| | 3.8 kg/cap/yr (8.4 lb/cap/yr) | Valiela and Costa (1988) |
| | 6.72 lb/cap/yr | Buzzards Bay Project (1990) |
| | 40 mg/l (Nitrate-N) (includes 5 mg/l background concentration) | Frimpter and others (1990) |
| | 5 lb/cap/yr | Frimpter and others (1990) |
| | 3.1 kg/cap/yr (7 lb/cap/yr) | Gold and others (1990) |
| | 30 - 60 mg/l | Budd and Meals (1994) |
| | 33.9 mg/l (WHPA) (5.7 lb/cap/yr @ 55 gcd) | Horsley & Witten (1994) |