

ORLEANS COMPREHENSIVE WASTEWATER MANAGEMENT PLAN

PHASE 6 -- SITE INVESTIGATIONS HYDROGEOLOGIC MODELING AT SITE 241

JANUARY 2009



SECTION 1

INTRODUCTION

1.1 INTRODUCTION

The Town of Orleans is considering several alternative wastewater management plans, one of which involves a facility that would treat wastewater and discharge effluent at the site of the existing Tri-Town Septage Facility. The location of the site is shown in Figure 1. Preliminary groundwater modeling of the proposed wastewater discharge was conducted in 2005 by the U.S. Geological Survey (USGS) on behalf of the Town of Orleans through the Cape Cod Commission (CCC). The purpose of the groundwater modeling effort described in this report was to conduct more detailed site-specific groundwater modeling and analyses that would be appropriate for determining the site's capacity and to lay the groundwork for possible future DEP permitting activities.

The rate of discharge that can be accepted at a given site is based on several limiting factors. These factors include: 1) the ability of site's surficial soils to accept the quantity of discharge; 2) the regulatory requirement to maintain a four-foot separation between the bottom of the discharge structure and the high groundwater table; 3) the potential for groundwater mounding to result in groundwater discharge to areas that do not currently receive groundwater discharge, or the potential for basement flooding or negative impacts on local septic systems; and 4) the need to limit the migration of nitrogen-enriched waters to sensitive ecosystems – in this case Rock Harbor.

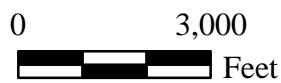
The first of these issues has already been addressed by previous efforts conducted by Wright-Pierce which are described in “Orleans Comprehensive Wastewater Management Plan Phase 6 – Site Investigations, Hydrogeological Investigation at Site 241” (February, 2008). The remainder of the factors listed above are addressed in the current report.



Legend

 Tri-Town Property Boundary

SOURCE: USGS Quad
obtained from MassGIS.



Orleans CWMP
Site Investigations
Site 241
Locus Map

PROJ NO: 10645E DATE: April 2008

FIGURE:

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1

SECTION 2

MODELING METHOD

2.1 MODELING METHOD

The groundwater flow modeling program used in this analysis is the U.S. Geological Survey's three-dimensional groundwater flow model MODFLOW (McDonald and Harbaugh, 1988; and Harlen and others, 2000). The modeling analysis is based on the regional groundwater model of Cape Cod developed by the USGS (Walter and Whealan, 2004). The portion of the Cape Cod model used in this analysis is referred to as the Monomoy Flow Lens and covers the eastern portion of Cape Cod from Bass River (the Yarmouth-Dennis border) in the west to Town Cove (the Eastham-Orleans border) in the east. The USGS model has been the basis for technical studies prepared by the Massachusetts Estuaries Project (Massachusetts Estuaries Project, 2007a, 2007b and 2007c), as well as the prior investigation of potential wastewater discharge at the Tri-Town site (Wright-Pierce, 2005). A smaller sub-regional model was developed from this regional model by means of a process known as telescopic mesh refinement (TMR). An area of primary interest was defined (most of the Town of Orleans and a small portion of Brewster and Eastham) and this portion of the regional model was isolated and extracted from the regional model and a finer grid spacing was developed. The sub-regional Orleans Model area in relation to the regional Monomoy Model is shown in Figure 2.

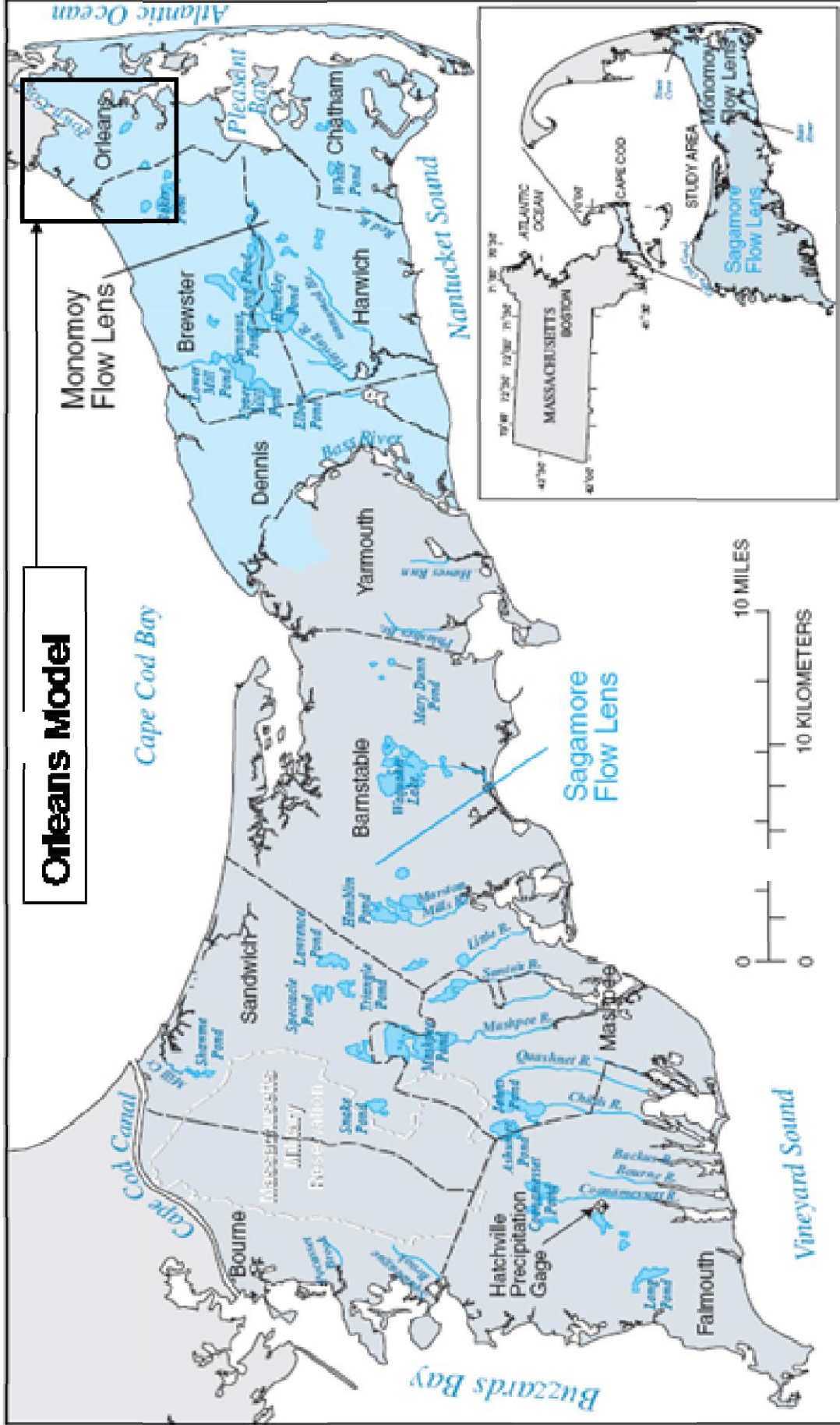
Groundwater Vistas (Environmental Simulations, Inc., 2004) was used as a graphical processor for the TMR process and subsequent model runs. Once the sub-regional model was defined and developed, some site-specific changes were made to the model to reflect more detailed local conditions. These changes to the original model are discussed below.

The approach to the development of the Orleans sub-regional model was to use the input parameters of the regional USGS model as much as possible, and to only make changes that: 1) were necessary to develop a finer model grid and smaller model domain and 2) were supported by more detailed sub-surface data that were not included in the regional model.

70°41'52"
41°40'00"

69°55'01"

Orleans Model



Base from U.S. Geological Survey topographic quadrangles, Chatham, Cotuit, Dennis, Falmouth, Harwich, Hyannis, Orset, Orleans, Pocasset, Sagamore, Sandwich, and Woods Hole, Massachusetts, Universal Transverse Mercator grid. Polyconic projection, zone 19 NAD, 1:25,000

EXPLANATION

	SAGAMORE FLOW LENS
	MONOMOY FLOW LENS
	TOWN BOUNDARY
	PRECIPITATION GAGE

Orleans CWMP
Site Investigations
Site 241
Model Extents

SECTION 3

CONCEPTUAL MODEL OF AQUIFER

3.1 CONCEPTUAL MODEL OF AQUIFER

The Monomoy Lens of the Cape Cod Aquifer is composed primarily of glacial deposits of the Pleistocene Epoch. Details on the surficial geology of the site vicinity are presented in Oldale and others (1971). The subsurface materials are a combination of coarse stratified outwash deposits (sands and gravels) and finer-grained lake deposits (fine sands, silts and clays). These finer-grained deposits interfinger near the site and this interfingering may be further complicated by later glacial re-advance.

The original USGS regional model simulated the aquifer in this region as a simple water table aquifer with hydraulic conductivity values ranging from 30 to 150 ft/day (a range comparable to fine to coarse sand). However, boring logs in the vicinity of the existing septage facility and surrounding area (DeSimone and Barlow, 1996) (GZA, 1981) (Wright-Pierce, 2005 and 2008) indicate the widespread presence of layers of very fine sand, silt and possibly clay. Although these layers do not appear to be extensive enough to represent significant confining units, they do act locally as semi-confining units. Work by DeSimone and Barlow (1996) and others suggest that the complex stratigraphy may have resulted in preferred flow paths for groundwater and contaminants. Attempts to better define the stratigraphy and its effects on groundwater flow are described in the next section of this report.

The primary source of water to the aquifer is rainfall recharge. This is supplemented to some extent by wastewater discharge, primarily through on-site septic systems. Water leaves the system primarily through groundwater discharge at coastal wetlands and estuaries.

SECTION 4

MODEL DESIGN AND DEVELOPMENT

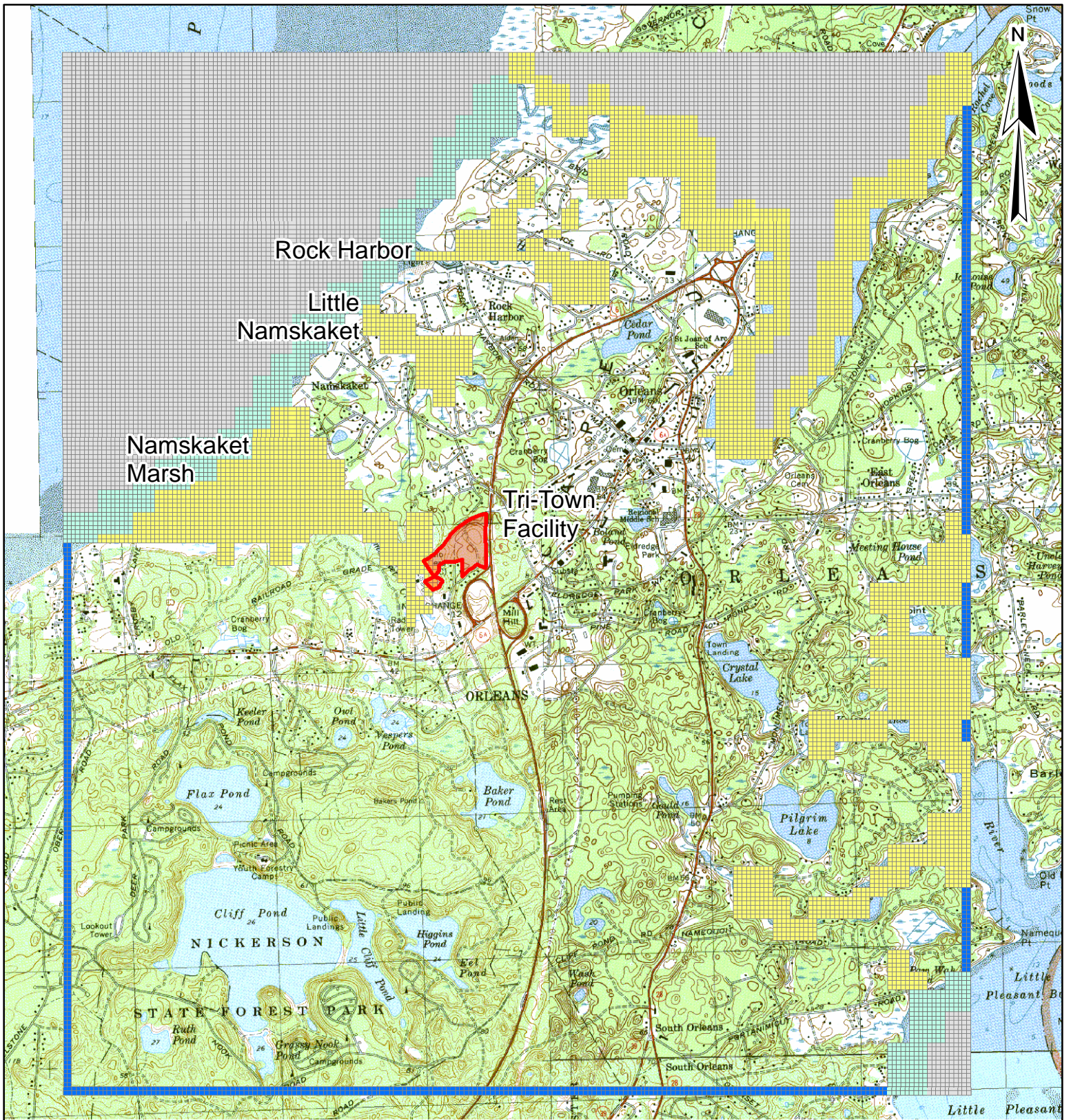
4.1 MODEL DESIGN AND DEVELOPMENT

The development of the regional USGS model is described in Walter and Whealan (2004). The only changes to this original model were the development of a sub-regional model as described above and site-specific changes to specific parameters as described below.

The extent of the Orleans sub-regional groundwater model (herein referred to as the Orleans Model) is shown in Figure 2 and 3. The model area consists primarily of the Town of Orleans but includes portions of Brewster to the west and Eastham to the north. The model extends to Cape Cod Bay, Eastham and Town Cove in the north, Pleasant Bay in the east, South Orleans in the south and the Town of Brewster in the west. The area of the model is approximately 17 square miles (21,000 by 24,000 feet). The model grid consists of 236 rows, 206 columns and 15 layers. The upper five layers of the regional model were eliminated because these layers were not saturated within the Orleans Model domain. The model nodes are a uniform 100 by 100 feet throughout the model domain.

The boundary conditions for the Orleans Model are shown in Figure 3. The primary difference in boundary conditions between the regional USGS Monomoy model and the Orleans Model is in the western and southern portion of the Orleans model where upgradient groundwater flowing into the model domain is simulated using constant head nodes. The head values for these constant head nodes were obtained directly from the calibrated regional model.

The coastal wetlands and creeks are simulated as drain nodes and the discharge of groundwater into Cape Cod Bay is simulated as a general head boundary. The drains in the Orleans model have been modified to better reflect the geometry and elevation of these wetlands and creeks. In addition, wetland drains have been added to include some of the smaller tributaries to Namskaket, Little Namskaket and Rock Harbor Creeks that were not included in the USGS regional model.



Legend

- Tri-Town Property Boundary
- Constant Head
- Drain
- General Head
- No Flow

SOURCE: Orthophoto
obtained from MassGIS.

Orleans CWMP
Site Investigations
Site 241
Model Grid and
Boundary Conditions

PROJ NO: 10645E DATE: April 2008

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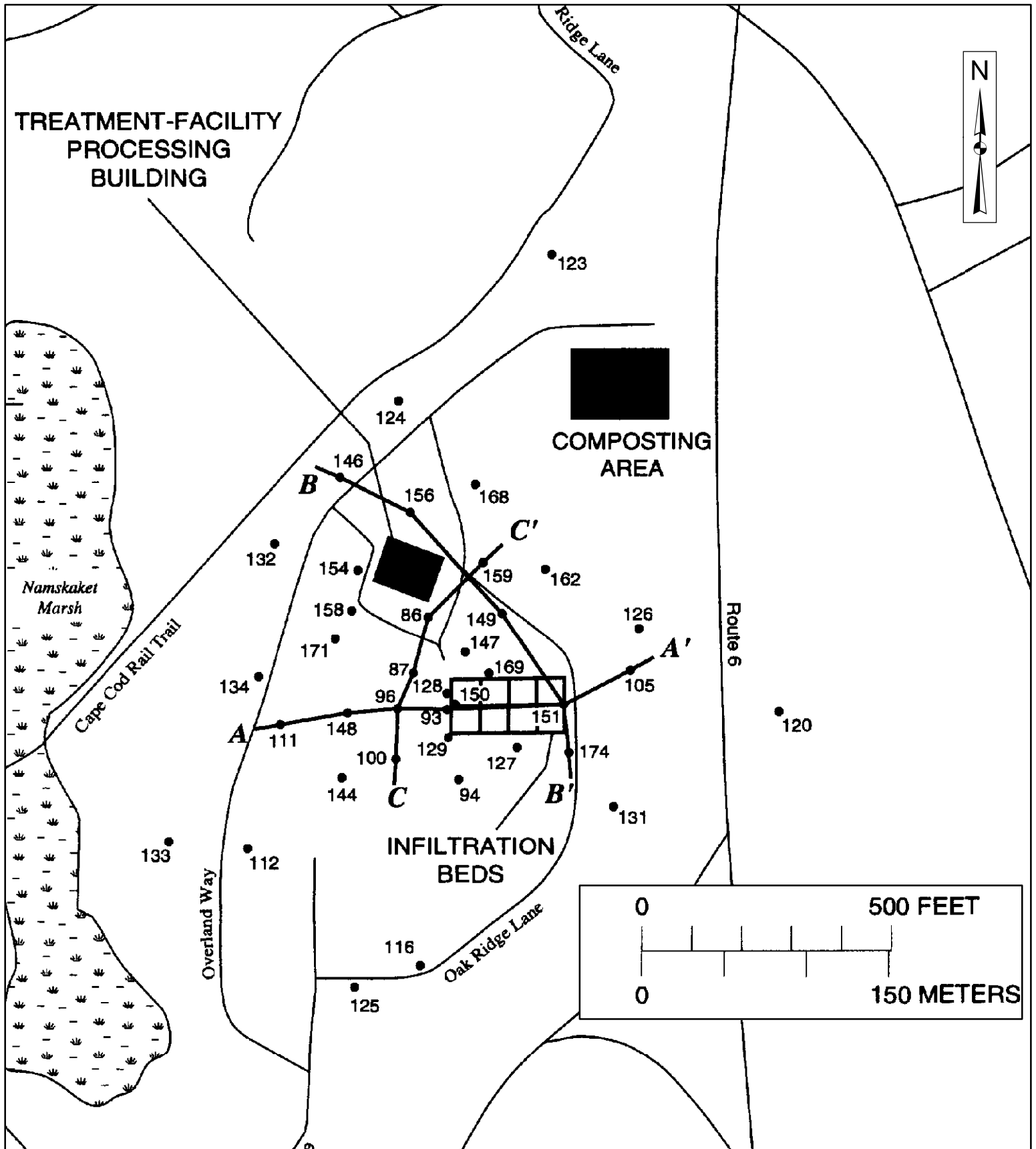
FIGURE:

3

Changes were made to the hydraulic conductivity (K) values in the model in order to take into account site-specific data that were not included in the regional model and to provide a better model calibration. In most cases, the revisions have resulted in lower K values than the regional model.

The majority of the changes in K value are in the area between the Tri-Town site and Cape Cod Bay. The changes were made on the basis of more detailed data from boring logs, mostly from USGS files, and from a detailed hydrogeological analysis provided in a USGS report on the Tri-Town site conducted in the early 1990's (DeSimone and others, 1996). Numerous borings were installed by USGS in the vicinity of the Tri-Town site and the hydrogeological conditions are described. The subsurface conditions are illustrated in a series of cross sections. The lines of cross sections are shown in Figure 4. The cross sections themselves are reproduced in Figures 5 through 7. It should be borne in mind that the stratigraphy of the individual borings is rather complex and that these cross sections are somewhat generalized. The authors of the USGS work identified four stratigraphic units that we have attempted to maintain in our conceptual model, at least within the vicinity of the Tri-Town site. The four units are: 1) an upper fine-grained unit (very fine or silty sand), 2) an intermediate coarse-grained unit (medium to very coarse sand with gravel), 3) a lower fine-grained unit (very fine to medium sand with silt or clay) and 4) a lower coarse-grained unit (medium to coarse sand). It was not always possible to identify all four units in each of the deep borings.

In the Orleans Model, the fine-grained units were assigned horizontal K values ranging from 10 to 30 ft/day. A horizontal-to-vertical K ratio of 10 to 1 was also assumed. The coarse-grained units were assigned K values ranging from 100 to 150 ft/day with horizontal to vertical K ratios ranging from 10-to-1 to 3-to-1. These are in accordance with values reported in DeSimone and others (1996) and with values used in the regional model. Table 1 provides a summary of the changes in K values between the regional model and the Orleans sub-regional model. The only significant changes were made in the upper six layers of the model (the portion of the aquifer from the water table to an elevation of -40 feet NGVD). There were three primary bases for changing K values: data from DeSimone and others (1996), boring log data (primarily from



Legend

A — A' LINE OF HYDROGEOLOGIC SECTION--

● 118

WELL CLUSTER SITE--Site of one or more observation wells completed at different depths.

SOURCE: USGS Open-File Report 95-290

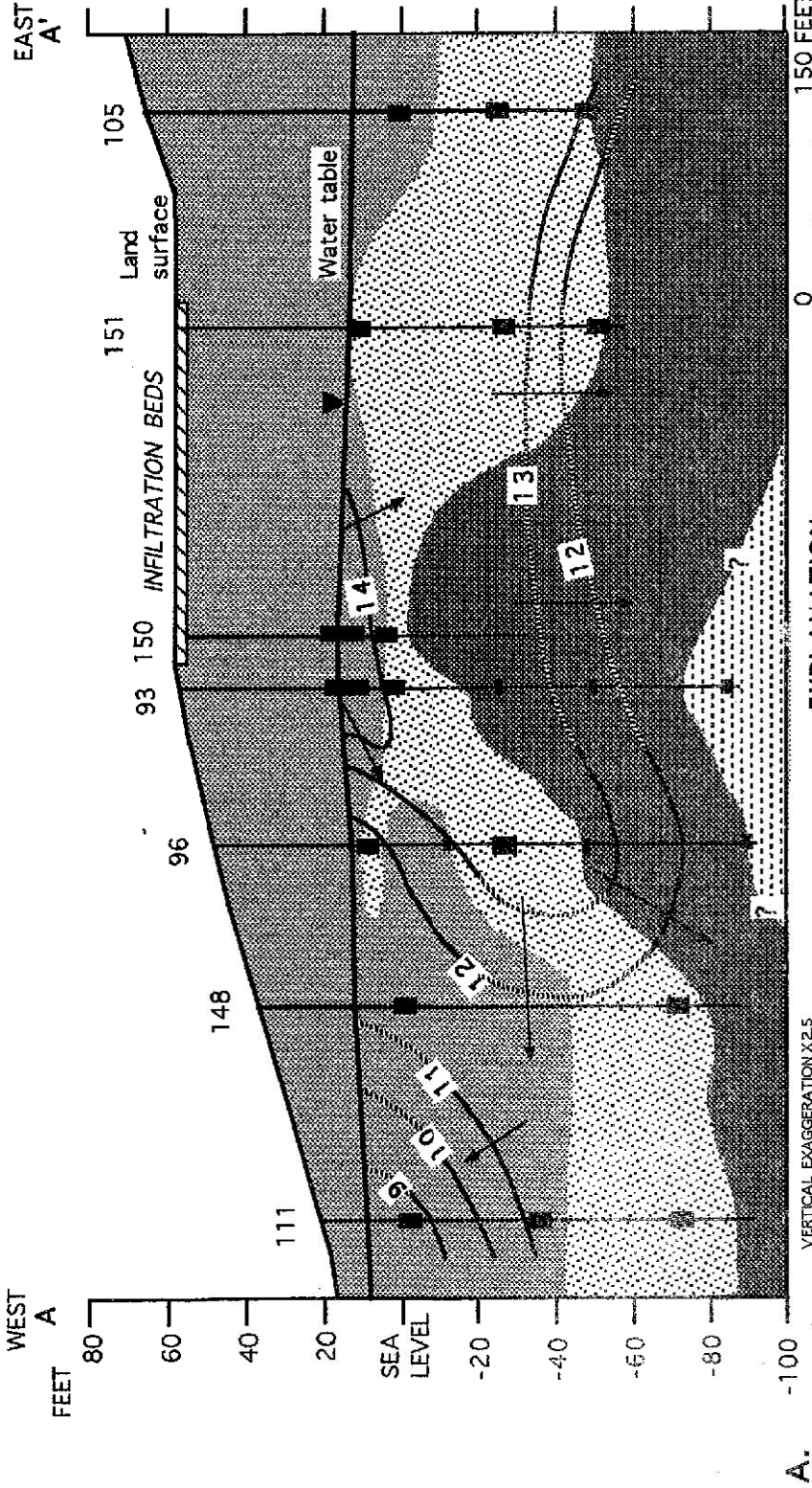
Orleans CWMP
 Site Investigations
 Site 241
 Base Map with Lines of
 Geologic Cross Section

PROJ NO: 10645E | DATE: April 2008

FIGURE:

WRIGHT-PIERCE
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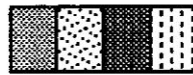
4



A. VERTICAL EXAGGERATION X2.5

EXPLANATION

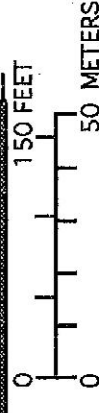
- LITHOLOGIC UNITS--Boundaries between lithologic units queried where uncertain
- UPPER FINE-GRAINED UNIT--Fine to very fine or fine to medium sand, with silt
- INTERMEDIATE COARSE-GRAINED UNIT--Medium to very coarse sand, with gravel
- LOWER FINE-GRAINED UNIT--Fine to very fine or medium to fine sand, with silt
- LOWER COARSE-GRAINED UNIT--Medium to coarse sand



—12..... POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells. Dashed where approximately located. Contour interval, 1 foot. Datum is sea level

→ GENERAL DIRECTION OF GROUND-WATER FLOW

■ WELL CLUSTER SITE IDENTIFIER AND SCREENED INTERVAL OF OBSERVATION WELL-- Site of one or more observation wells completed at different depths. Length of screened interval is variable interval of well



Orleans CWMIP
 Site Investigations
 Site 241
 Geologic Cross Section
 A-A'

NORTHWEST

FEET
80
60
40
20
SEA LEVEL
-20
-40
-60
-80

146 Overland Way

156

Land surface

149

INFILTRATION BEDS

151

174

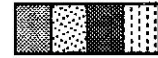
SOUTHEAST

B'

VERTICAL EXAGGERATION X2.5

EXPLANATION

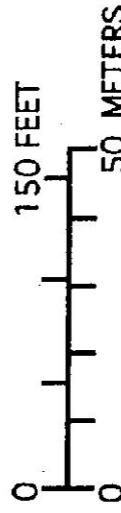
- LITHOLOGIC UNITS--Boundaries between lithologic units queried where uncertain
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—12..... POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells. Dashed where approximately located. Contour interval, 1 foot. Datum is sea level

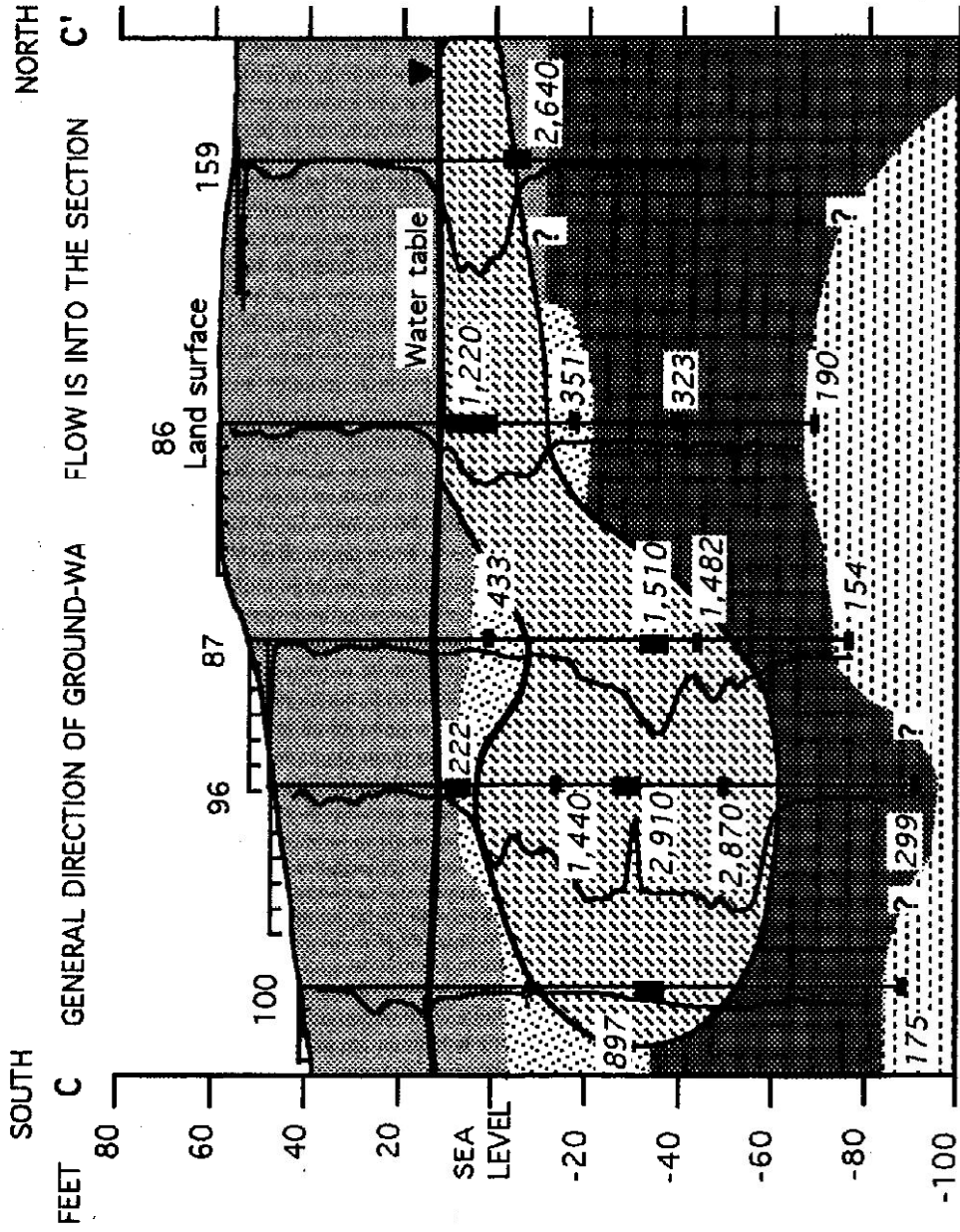
→ GENERAL DIRECTION OF GROUND-WATER FLOW

WELL CLUSTER SITE IDENTIFIER AND SCREENED INTERVAL OF OBSERVATION WELL-- Site of one or more observation wells completed at different depths. Length of screened interval is variable
 screened interval of well

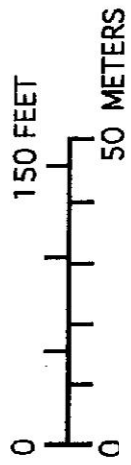


Orleans CWMIP
 Site Investigations
 Site 241
 Geologic Cross Section
 B-B'

PROJ NO 10645E | DATE April 2008 | FIGURE: 6
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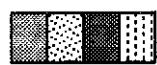


VERTICAL EXAGGERATION X2.5



EXPLANATION

- LITHOLOGIC UNITS--Boundaries between lithologic units queried where uncertain
- UPPER FINE-GRAINED UNIT--Fine to very fine or fine to medium sand, with silt
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- 12..... POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells. Dashed where approximately located. Contour interval, 1 foot. Datum is sea level

→ GENERAL DIRECTION OF GROUND-WATER FLOW

■ WELL CLUSTER SITE IDENTIFIER AND SCREENED INTERVAL OF OBSERVATION WELL-- Site of one or more observation wells completed at different depths. Length of screened interval is variable screened interval of well

Orleans CWMIP
Site Investigations
Site 241
Geologic Cross Section
C-C'

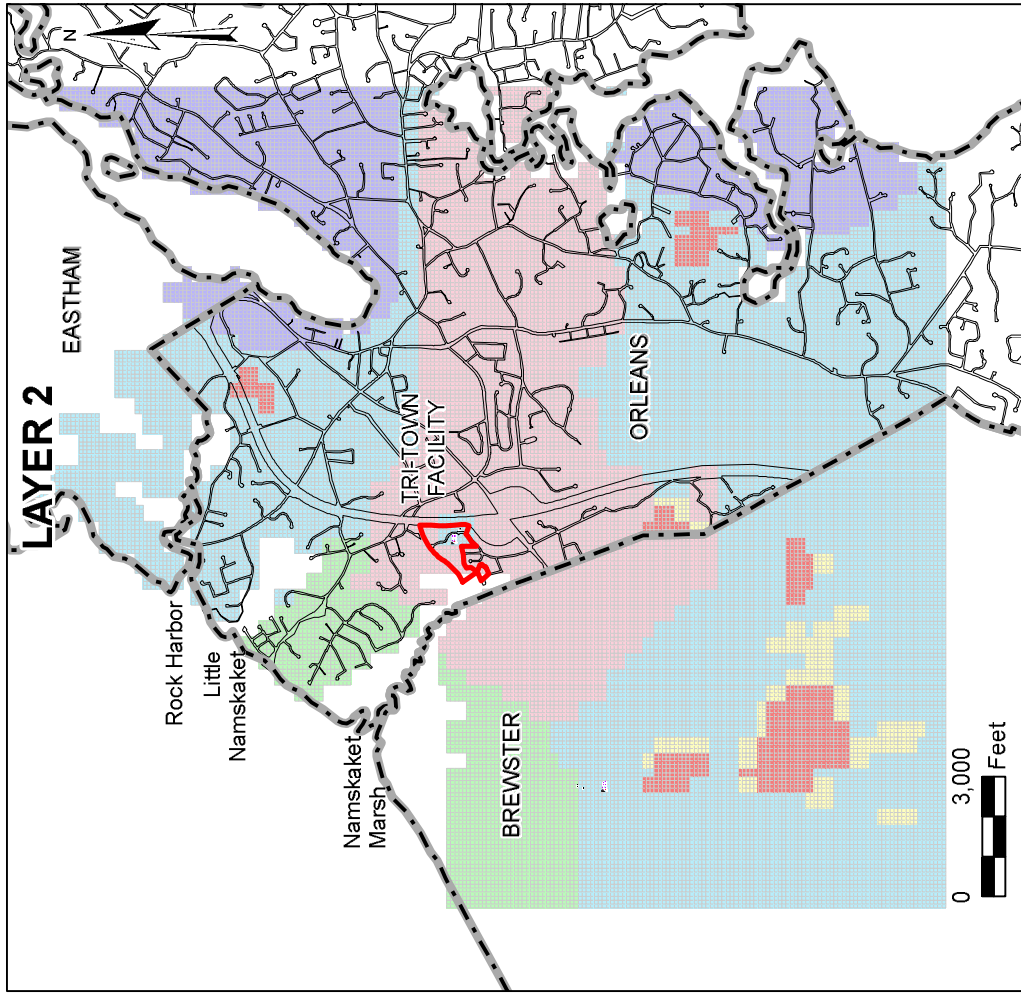
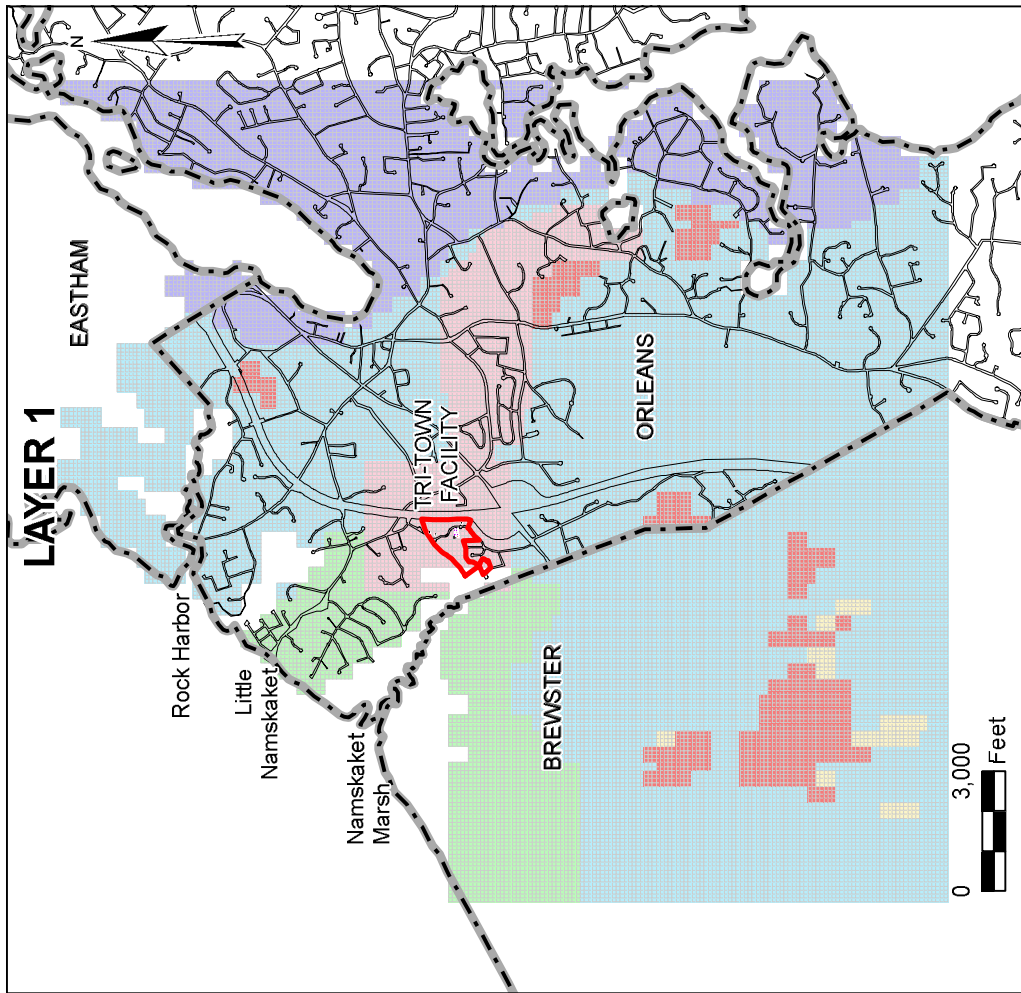
USGS files) and assumed K values that resulted in a better calibration. The final distribution of K values for the upper six layers of the Orleans Model is shown in Figures 8 through 10.

**TABLE 1
SUMMARY OF MAJOR K CHANGES BETWEEN ORLEANS
AND MONOMOY MODELS**

Area	Regional Model		Orleans Model		Basis
	Layer(s)	K (ft/day)	Layer(s)	K (ft/day)	
Tri-Town east to Crystal Lake	6	150	1	50	DeSimone and others, calibration
Most of model domain	6,7,8	150	1,2,3	100	calibration
Tri-Town Property	7,10	30	2,5	100	DeSimone and others
Tri-Town east to Crystal Lake	8	30	3	10	DeSimone and others
Tri-Town Property	9	30	4	100	DeSimone and others
Namskaket Creek	9,10	70	4,5	35	Boring data ¹
Namskaket Creek	11	100	6	50	Boring data ¹

1. Boring data obtained from USGS records.

In general, the Orleans Model has lower K values than the regional model, especially in the area between the Tri-Town site and Cape Cod Bay. As a result of these changes, the Orleans Model calibrated closer to observed long-term average conditions within the model domain than the regional model. Model calibration is discussed in the following section.

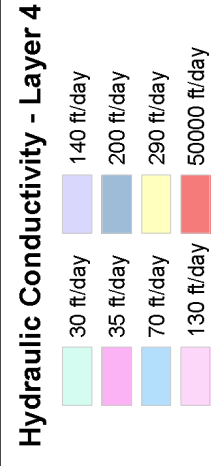
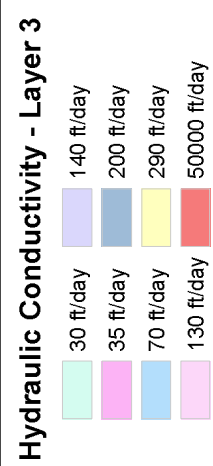
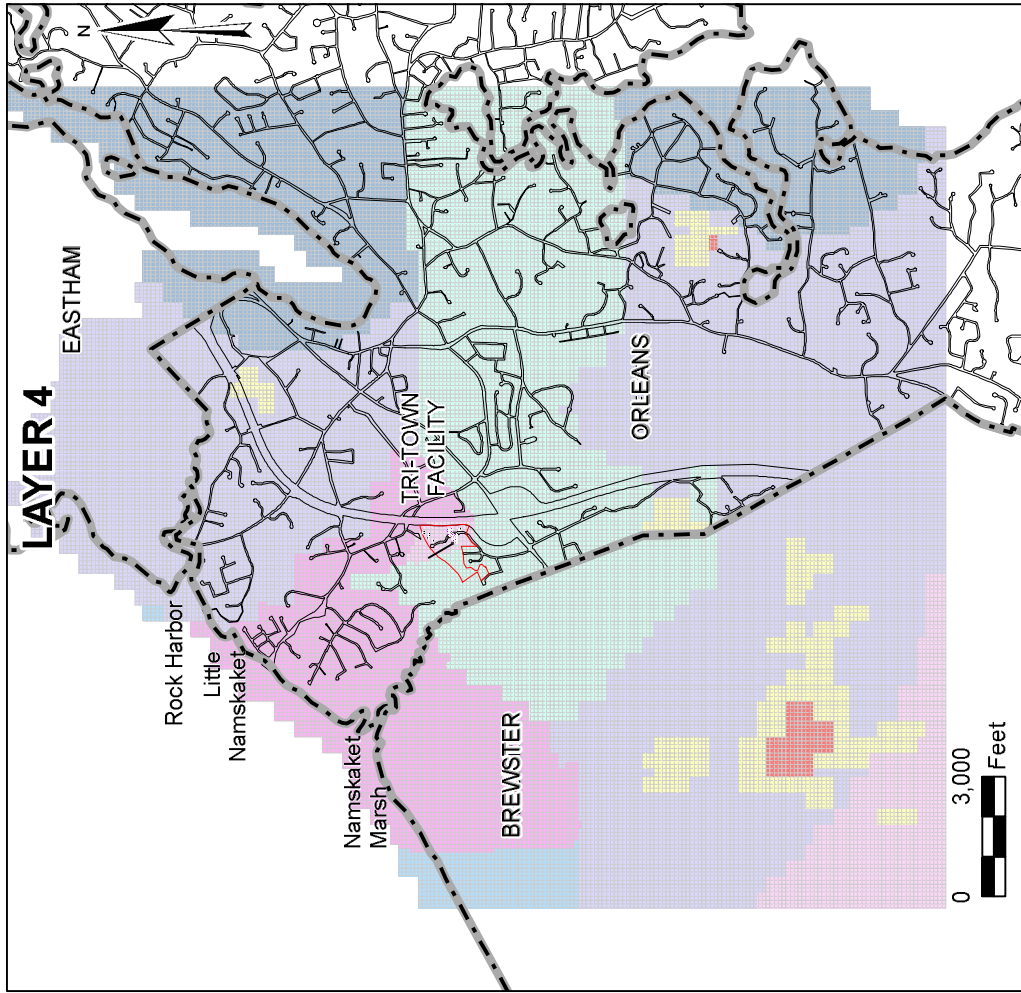
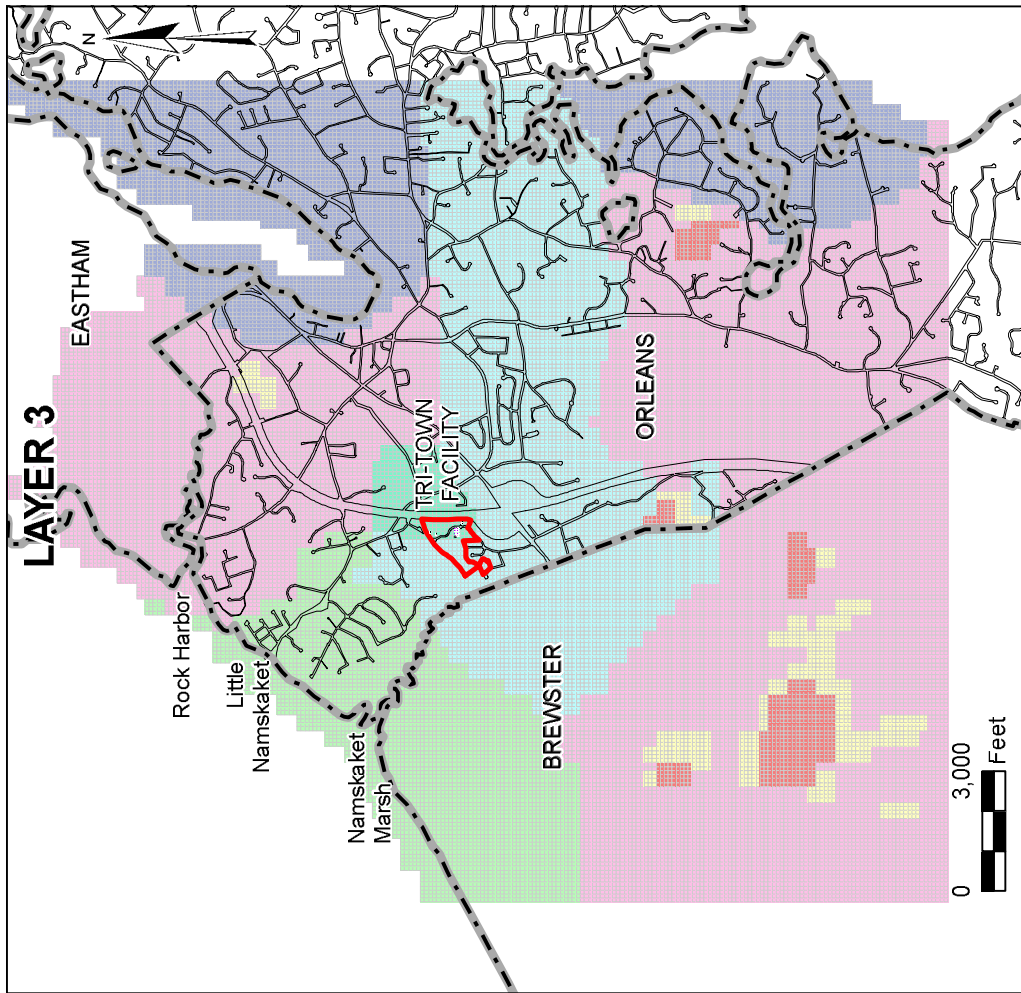


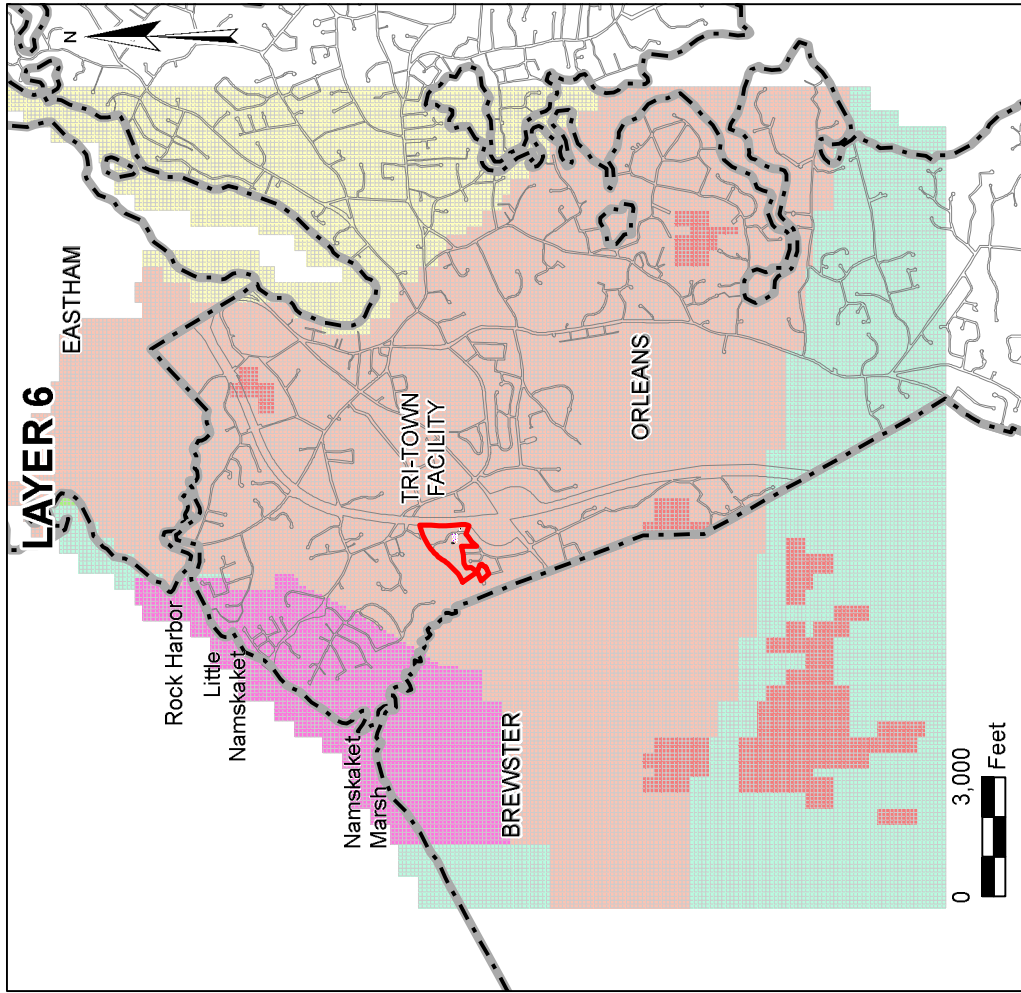
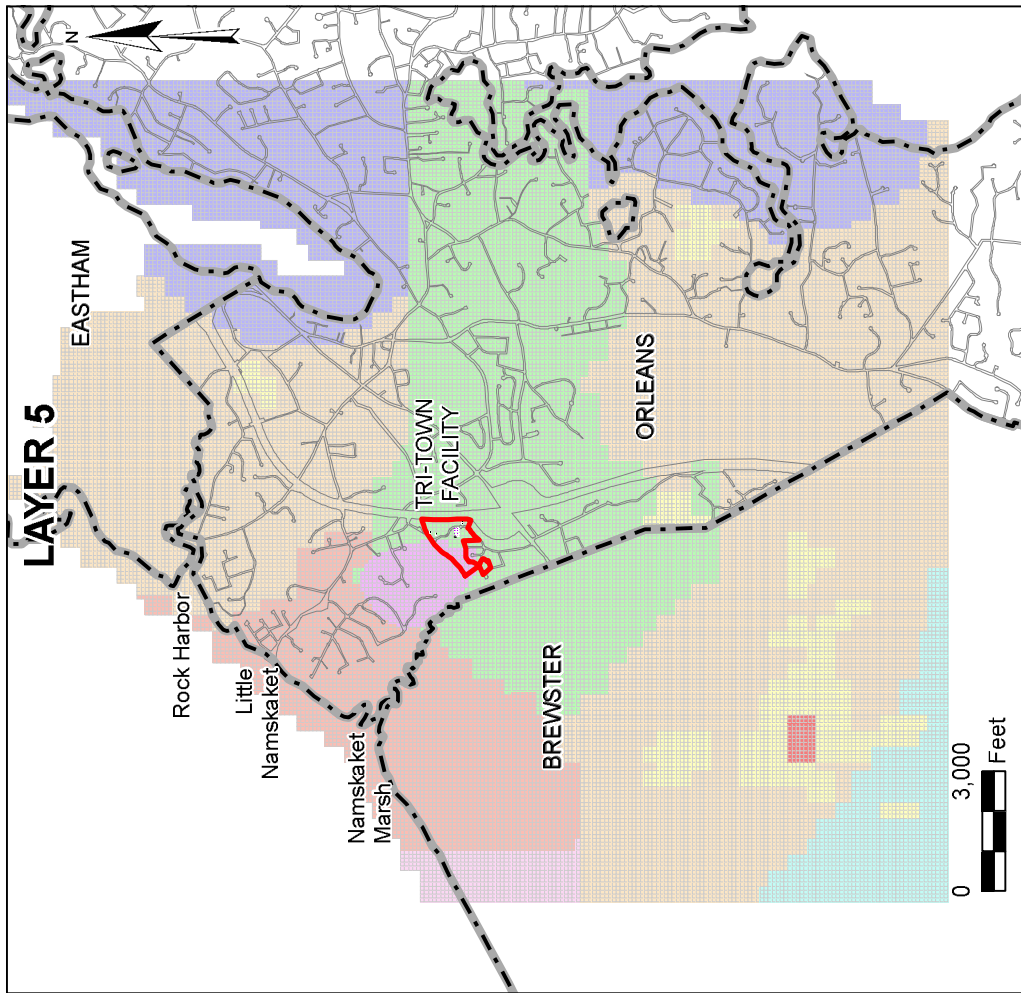
- Legend**
- Town Boundary
 - Tri-Town Property Boundary
 - Roads

- Hydraulic Conductivity - Layer 1**
- 50 ft/day
 - 100 ft/day
 - 105 ft/day
 - 230 ft/day
 - 300 ft/day
 - 50,000 ft/day

- Hydraulic Conductivity - Layer 2**
- 30 ft/day
 - 70 ft/day
 - 105 ft/day
 - 230 ft/day
 - 300 ft/day
 - 50,000 ft/day

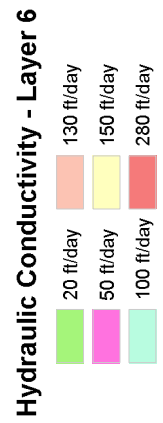
SOURCE: Basemap Obtained from MassGIS.





- Legend**
- Town Boundary
 - Tri-Town Property Boundary
 - Roads

SOURCE: Basemap Obtained from MassGIS.



Orleans CWMP
Site Investigations
Site 241
Hydraulic Conductivity
Layer 5 and 6

PROJ. NO.: 10645E DATE: April 2008

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FIGURE: **10**

SECTION 5

MODEL CALIBRATION

5.1 MODEL CALIBRATION

The original calibration of the USGS regional model included relatively few data points within the domain of the Orleans Model. There are long-term average water level data from five wells and four ponds. However, there does not appear to be any other suitable long-term average water data within the model domain with which to calibrate the model. There is a large quantity of water level data from various hydrogeologic reports in the area but none of these have been related to long-term average conditions. The available calibration targets are summarized in Table 2. The locations of these calibration targets are shown in Figure 11.

Recharge in the original USGS regional model was 27.25 inches per year over non-developed land. Additional recharge was added in developed areas to simulate the recharge attributed to on-site septic systems. The sub-regional Orleans Model calibrated best assuming a non-developed recharge rate of 28.5 inches per year.

Several statistical techniques are used to evaluate how well a model has been calibrated to observed conditions (Anderson & Woessner, 1992). One is to calculate the mean error, which is the mean of the residuals (the difference between observed and simulated groundwater elevations). Table 2 lists the residuals at the 9 calibration points. The mean of residuals was found to be 0.26 foot.

One drawback to using the mean residual to evaluate calibration is that positive and negative residuals tend to cancel each other out, making the calibration appear better than it might be. A better overall indication of error is the mean absolute residual. For this, the mean is taken of the absolute values of all the residuals. The mean absolute residual for the model calibration was 0.84 feet.

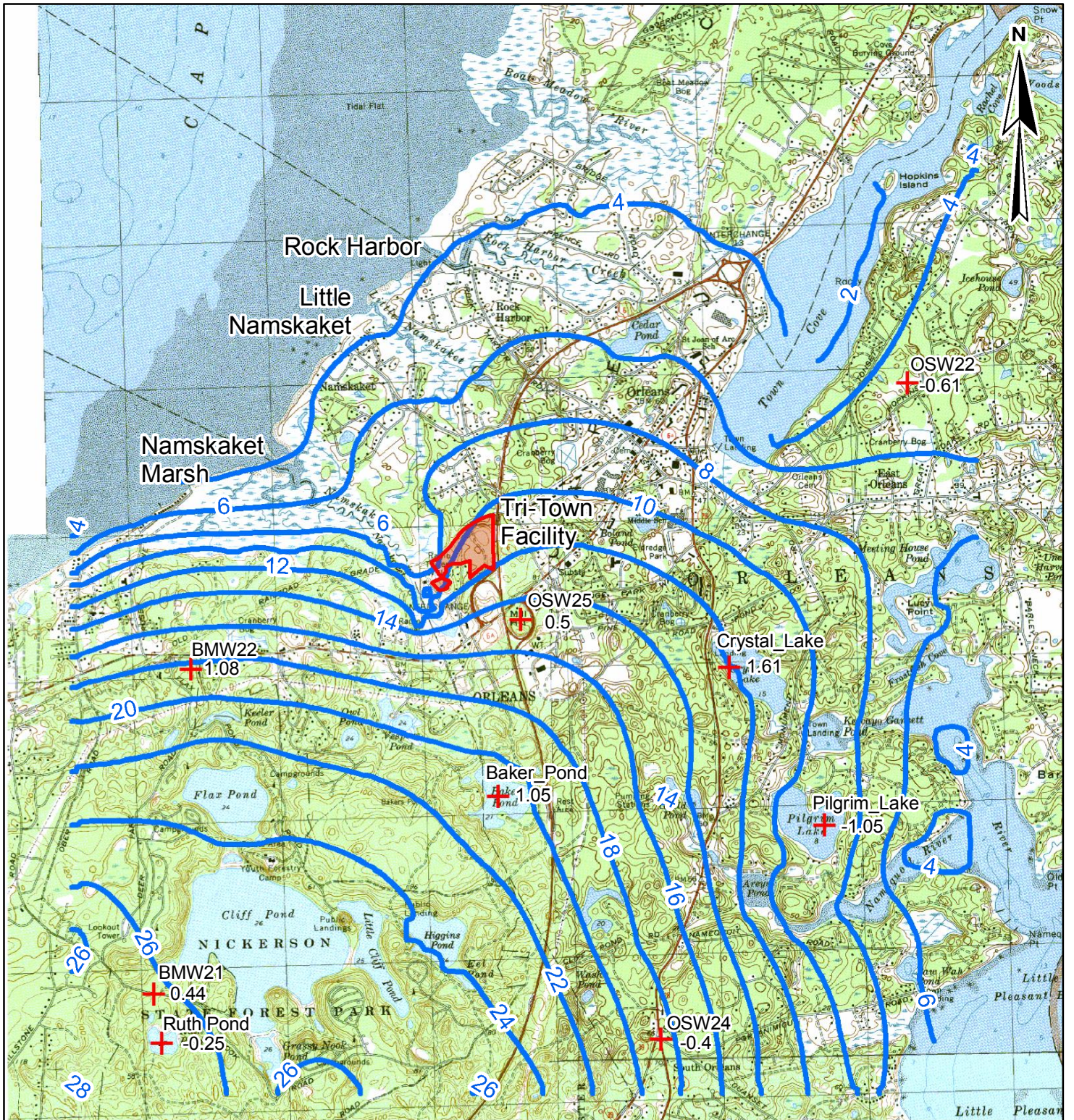
Another measure of the accuracy of a model calibration is the residual standard deviation divided by the range of head values. The residual standard deviation for the calibrated model was 0.84 ft.

The observed range in head was 22.48 ft. Therefore, the residual standard deviation divided by the range in head is 0.037 ft.

TABLE 2
SUMMARY OF MODEL CALIBRATION STATISTICS

Well Number	Observed Water Elevation (ft)	Simulated Water Elevation (ft)	Residual (ft)
OSW 22	4.29	4.89	-0.61
OSW 24	18.21	18.61	-0.23
OSW 25	15.37	26.29	0.40
BMW 21	26.76	26.32	0.44
BMW 22	19.46	18.38	1.08
Ruth Pond	26.42	26.67	-0.25
Pilgrim Lake	8.34	9.39	-1.05
Baker Pond	21.40	20.35	1.05
Crystal Lake	13.68	12.07	1.61
		Residual Mean	0.26
		Res. Std Dev.	0.84
		Sum of Squares	7.00
		Abs. Res. Mean	0.78
		Min Residual	-1.05
		Max Residual	1.61
		Range in Target Values	22.48
		Std Dev./Range	0.037

By all of these measures, the model calibration is considered to be quite good for the scale and head difference within the model. The calibrated average groundwater levels for the Orleans sub-regional model are shown in Figure 11.



0 3,000
 Feet

Legend

Tri-Town Property Boundary

Steady State Groundwater Contour (ft msl)

Calibration Target with Residual

SOURCE: USGS Quad maps obtained from MassGIS.

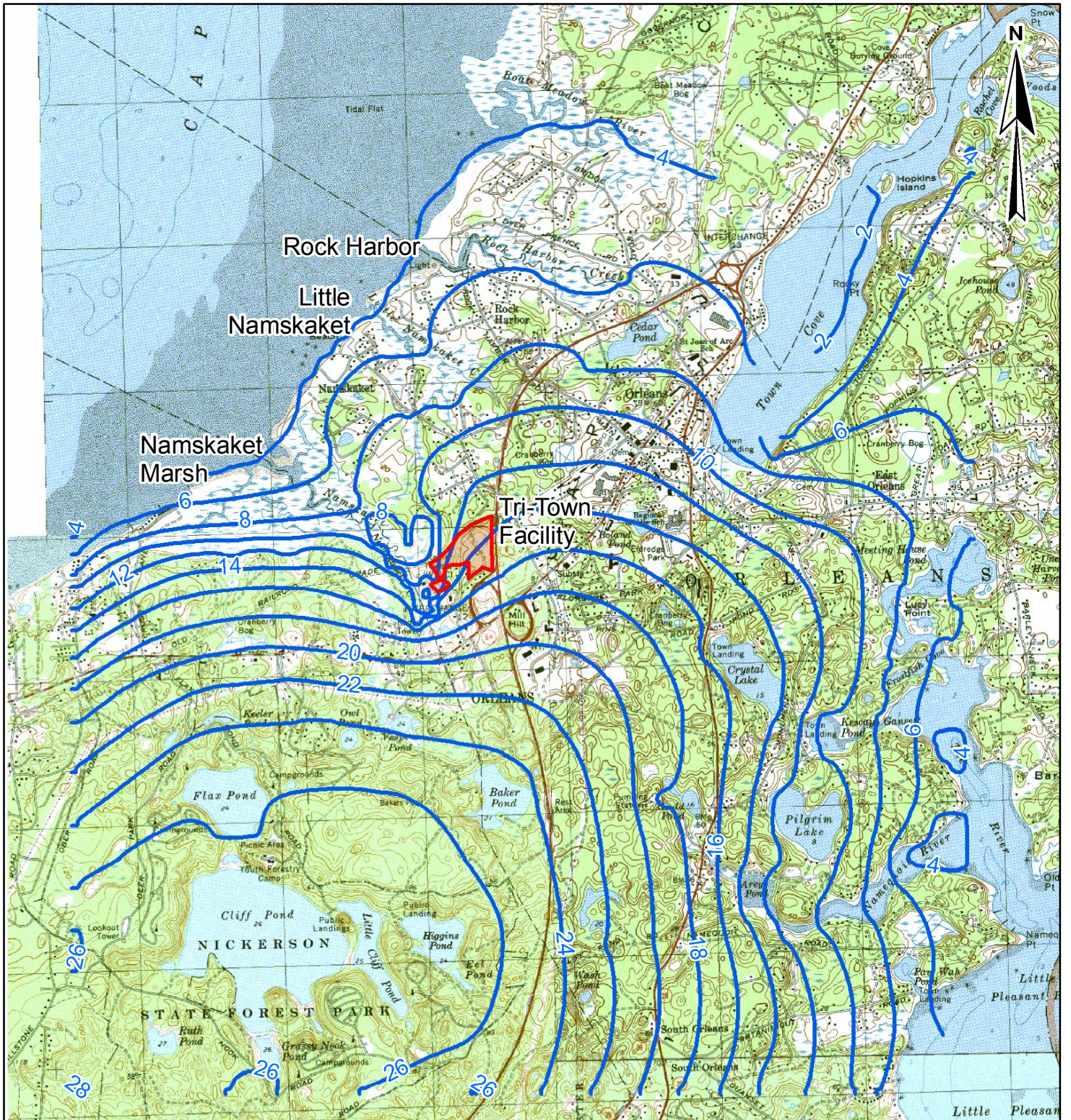
Orleans CWMP Site Investigations Site 241 Steady State Groundwater Contours and Target Residuals		
PROJ NO: 10645E	DATE: April 2008	FIGURE: 11
 Engineering a Better Environment		

SECTION 6

SIMULATED HIGH GROUNDWATER CONDITIONS

6.1 SIMULATED HIGH GROUNDWATER CONDITIONS

One of the primary purposes of the groundwater model is to predict the groundwater mounding that would occur at the proposed discharge site under maximum discharge conditions and high ambient groundwater levels. For each of the mounding model runs, the base condition was assumed to be high groundwater conditions. High groundwater levels were estimated using long-term water level data from the closest USGS well to the Tri-Town site with a long-term record – well BMW-22. The well is located approximately 3,000 feet west of the Tri-Town site. Water level records at this well date back to 1962. Statistics from the USGS Groundwater watch web site (www.groundwaterwatch.usgs.gov) indicate that the highest groundwater level at this well typically occurs in June and mean high water level for that month is 20.67 feet NGVD. Using this water level as a target, the rate of recharge was increased until the best fit was found. This corresponded to an average annualized recharge rate of 48 inches per year. The model simulated high groundwater conditions are shown in Figure 12.



Legend

- Tri-Town Property Boundary
- Model Simulated High Groundwater Contour (ft msl)

SOURCE: USGS Quad maps obtained from MassGIS.

<p>Orleans CWMP Site Investigations Site 241 Model-Simulated High Groundwater Contours</p>		
PROJ NO: 10645E	DATE: April 2008	FIGURE:
<p>WRIGHT-PIERCE </p> <p style="font-size: small; text-align: center;">Engineering a Better Environment</p>		12

SECTION 7

MODEL SIMULATIONS

7.1 MODEL SIMULATIONS

Discharged wastewater was simulated as additional recharge over the area of the proposed infiltration beds. Several different scenarios of discharge rate and discharge bed configuration were simulated. There were essentially two types of model runs: 1) maximum monthly discharge runs for determining the highest potential groundwater mound and 2) annual average discharge runs for determining the ultimate fate of effluent-impacted groundwater. The scenarios are summarized in Table 3.

**TABLE 3
MODEL-SIMULATED DISCHARGE SCENARIOS**

Scenario	Description	Annual Average Discharge (gpd)	Maximum Month Discharge (gpd)
1	Current Flow Conditions	30,000	NA
2	Maximum Surficial Site Capacity	740,000	1,480,000
3	Plan 2 at Planning Horizon Flows	504,000	1,010,000
4	Plan 2 at Current Flows	370,000	740,000
5	Town-wide and Eastham Flows	1,035,000	2,070,000

Three maximum monthly discharge rates were simulated corresponding to: 1) the estimated maximum potential capacity of the rapid infiltration beds; 2) the maximum estimated discharge for Plan 2 at 2030, the end of the planning horizon; and 3) the maximum estimated discharge for Plan 2 at current flows. These maximum monthly rates were estimated to be 1.48, 1.01 and 0.74 million gallons per day (mgd), respectively. The proposed discharge was distributed over an area of 260,000 square feet. This is a conservatively small area; although the proposed beds themselves have a combined bottom area of 230,000 square feet, there is space between the beds. The total discharge area including the spaces between the beds is closer to 320,000 square feet. The predicted groundwater mound under high groundwater conditions for the highest discharge scenario (1.48 mgd) is presented in Table 4, and groundwater contours are presented in

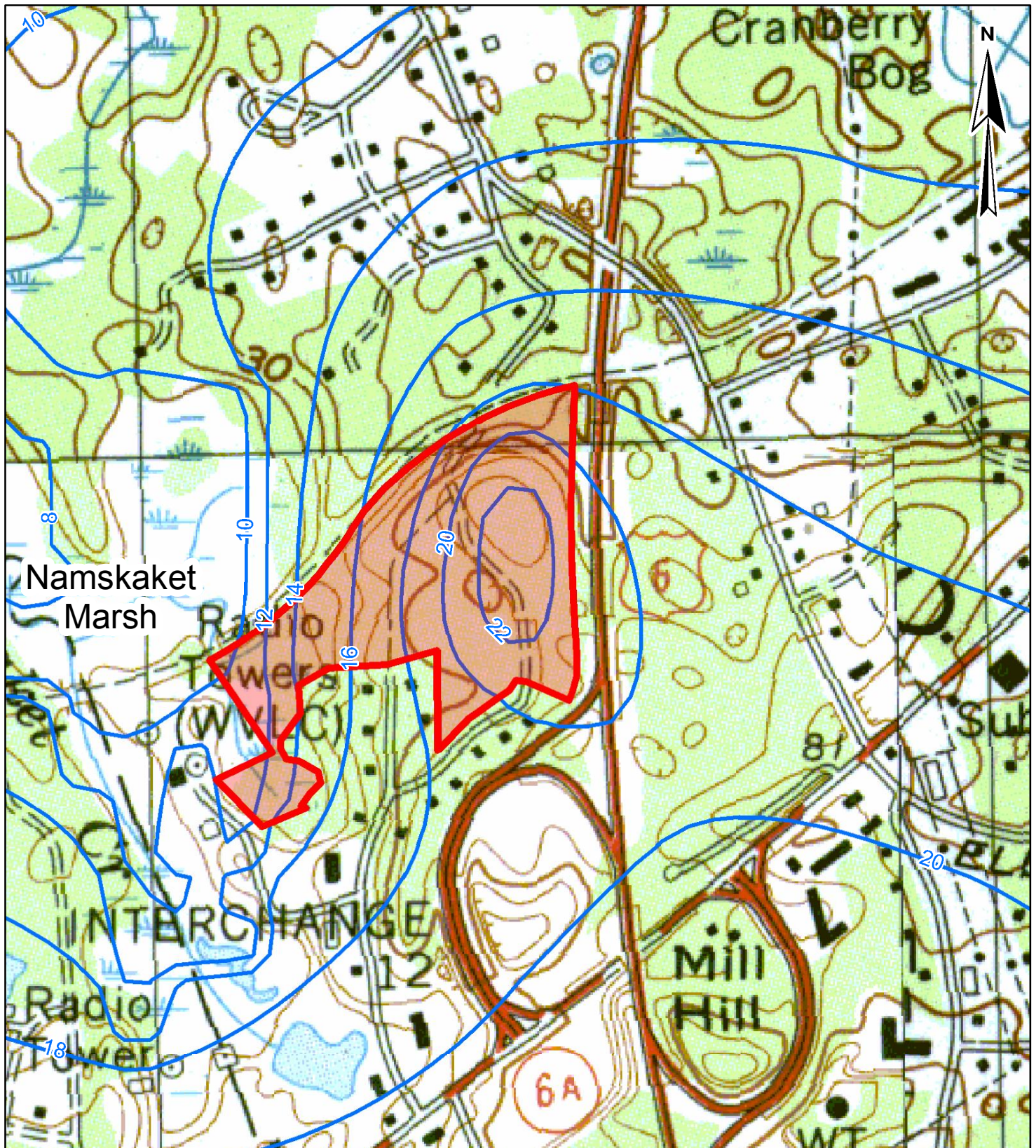
Figure 13. Under this highest discharge scenario, the simulated groundwater mounds remained greater than four feet below the bottom of the proposed discharge beds. The highest projected groundwater mound (approximately 11 feet under the maximum potential discharge rate) is at an elevation of approximately 25 feet and the lowest ground surface at the Tri-Town site is approximately 50 feet. The highest mound does not result in any groundwater levels at or near the surface of the ground in the region surrounding the Tri-Town site. The highest predicted groundwater level is also more than 10 feet below the ground surface at the homes to the north of the Tri-Town Site. Based on the results of these model runs it appears that increased water levels, even under seasonal high groundwater conditions and the highest projected discharge rate, will not result in any negative impacts at or near the site. The projected groundwater mounds under discharge rates of 1.01 and 0.74 mgd were 8.2 and 5.7 feet, respectively.

**TABLE 4
GROUNDWATER MOUNDING SIMULATION
AT MAXIMUM-MONTH FLOWS**

Scenario #	Maximum Month Discharge (mgd)	Seasonal High Water Table (ft)	Mound Height (ft)	Water Table Elevation w/ Discharge (ft)	Ground Surface Separation (ft)
2	1,480,000	14	11	25	25
3	1,010,000	14	8	22	28
4	740,000	14	6	20	30
5	2,070,000	14	16	30	20

The potential movement of effluent-impacted groundwater through the aquifer was evaluated by means of a particle tracking analysis. The particle tracking program MODPATH (Pollock, 1994) was used for this purpose. Particles were initiated at the water table beneath the potential effluent discharge beds. Nine particles were initiated at each of the 100-ft by 100-ft nodes representing the discharge beds. The particles were tracked through the steady state flow field for a maximum of 270 years.

The particles trace analysis was conducting on the basis of projected average annual flows for each of the three scenarios described above – the maximum potential, Phase 2 at the planning horizon and Phase 2 with current flows. The respective estimated average annual discharges for



Legend

- ▭ Tri-Town Property Boundary
- Model Simulated High Mound Contour (ft msl) at 1.48 mgd Discharge Scenario



SOURCE: USGS Quad maps obtained from MassGIS.

Orleans CWMP
 Site Investigations
 Site 241
 Model-Simulated High
 Mound Contours

PROJ NO: 10645E DATE: April 2008

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**FIGURE:
 13**

these three scenarios are 0.74, 0.504 and 0.37 mgd. The particle tracks for each of these scenarios is illustrated in Figures 14 through 16. In each scenario, the largest number of particles are discharged to Namskaket Creek. Discharges also occurred to Little Namskaket Creek. The particle trace analysis also indicates that a significant percent of the effluent-impacted groundwater will flow beneath the coastal wetlands and estuaries and emerges in Cape Cod Bay. No effluent-impacted water was predicted to flow to Rock Harbor. A summary of the ultimate fate of the wastewater discharge for each of the scenarios is presented in Table 5.

**TABLE 5
MODEL-PREDICTED FATE OF WASTEWATER DISCHARGES**

Scenario #	Application Volume mgd	Percentage of Total Discharge by Watershed			
		Namskaket %	Little Namskaket %	Cape Cod Bay %	Rock Harbor %
2	0.740	65	10	25	0
3	0.504	68	8	24	0
4	0.370	71	3	26	0
1	0.030	100	0	0	0

There is a significant difference in groundwater travel times associated with the discharges or ultimate fate of nitrogen-enriched groundwaters. Travel times to the upper portion of Namskaket Creek, particularly to the wetlands located approximately one thousand feet to the west of the Tri-Town site, will be on the order of months or years. Groundwater travel times to the remainder of the Namskaket Creek system and Little Namskaket Creek would be on the order of decades. Groundwater travel times to Cape Cod Bay are greater than 50 years and can be as long as 300 years. This is because these groundwater flow paths go deep into the aquifer. Because the model does not account for saltwater, it is not possible to accurately predict these flows. However, because the flows are deep within the aquifer, the discharges will not occur at the Cape Cod Bay beaches. Those near-shore discharges are derived from much more shallow groundwater and water quality at the beaches is impacted by stormwater discharges.

In addition to the first four scenarios summarized in Table 5, an additional simulation (Scenario 5) was conducted to determine the potential impacts associated with a theoretical planning horizon (year 2030) maximum wastewater discharge. Scenario 5 considers an annual average



Legend

 Tri-Town Property Boundary

 Particle Track



SOURCE: USGS Quad maps obtained from MassGIS.

Orleans CWMP
 Site Investigations
 Site 241
 Particle Tracks
 Scenario 2

PROJ NO: 10645E DATE: April 2008

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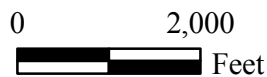
FIGURE:
14



Legend

 Tri-Town Property Boundary

 Particle Track



Orleans CWMP
 Site Investigations
 Site 241
 Particle Tracks
 Scenario 3

PROJ NO: 10645E DATE: April 2008

FIGURE:

SOURCE: USGS Quad maps
 obtained from MassGIS.

WRIGHT-PIERCE
 Engineering a Better Environment

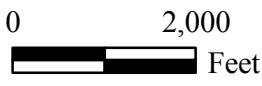
15



Legend

 Tri-Town Property Boundary

 Particle Track



Orleans CWMP
 Site Investigations
 Site 241
 Particle Tracks
 Scenario 4

PROJ NO: 10645E DATE: April 2008

FIGURE:

SOURCE: USGS Quad maps
 obtained from MassGIS.



16

flow of 1.035 mgd and a maximum-month flow of 2.07 mgd. These flows are the aggregation of Orleans' town-wide wastewater generation in addition to contributions from the Eastham portion of Rock Harbor and Town Cove. At the maximum monthly rate, the groundwater mound was calculated to be approximately 16 feet. This still provides greater than four feet of unsaturated soils beneath the proposed discharge structures. The model also predicts that even at this high discharge rate there would be no discharge to areas that do not already have groundwater discharges and there would be no flow of effluent-impacted groundwater to Rock Harbor.

SECTION 8

SUMMARY AND CONCLUSIONS

8.1 SUMMARY AND CONCLUSIONS

Based on the calibration criteria, the groundwater flow model simulates existing and potential groundwater conditions at the site reasonably well. Due to the complex stratigraphy in the region of the model between the Tri-Town Site and Cape Cod Bay and the limited amount of subsurface data, there is some uncertainty with respect to potential preferential pathways of groundwater flow. However, it is clear that the primary control of groundwater flow in this region of the model is the presence of discharge areas – wetlands, coastal estuaries and Cape Cod Bay. The model uncertainty is not expected to have a significant impact on the predicted groundwater mounding or on the potential for effluent-impacted groundwater to reach Rock Harbor.

The groundwater mounding analysis conducted under high groundwater conditions indicate that even under the highest expected discharge rates, groundwater mounding beneath the site: 1) will be lower than four feet from the bottom of the discharge bed; 2) will not impact nearby basements or septic systems; and 3) will not result in any new locations of groundwater discharge. The results of the particle tracking analysis indicate that the ultimate fate of the effluent impacted groundwater is not radically different from previous analyses conducted by the USGS although there have been changes in the predicted percentages of effluent impacted groundwater reaching the major discharge locations. Of most significance is our finding that effluent-impacted groundwater will emerge in the Namskaket and Little Namskaket marsh systems (whose current nitrogen loads are less than threshold values) and not in the Rock Harbor system (where current nitrogen loads exceed threshold values).

SECTION 9

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ORLEANS COMPREHENSIVE WASTEWATER MANAGEMENT PLAN

PHASE 8 -- SUPPLEMENTAL SITE INVESTIGATIONS AT SITE 241

May 2009

ORLEANS COMPREHENSIVE WASTEWATER MANAGEMENT PLAN

PHASE 8 -- SUPPLEMENTAL SITE INVESTIGATIONS AT SITE 241

1.0 INTRODUCTION

The Town of Orleans Draft Comprehensive Wastewater Management Plan (CWMP) sets forth a recommended plan to construct a new wastewater treatment facility (WWTF) at Site 241, the existing Tri-Town site. Numerous previous studies have been completed on-site, including work by GZA in 1981 to 1984, USGS in 1995 and Wright-Pierce in 2007 to 2009. Wright-Pierce efforts are documented in the reports entitled: *Phase 6 - Hydrogeologic Investigation at Site 241* (February 2008) and *Phase 6 - Hydrogeologic Modeling at Site 241* (January 2009). The previous efforts included reviewing existing subsurface investigations as well as completing test pits, soil borings, monitoring wells, percolation testing, a large-scale hydraulic loading test and computerized groundwater modeling.

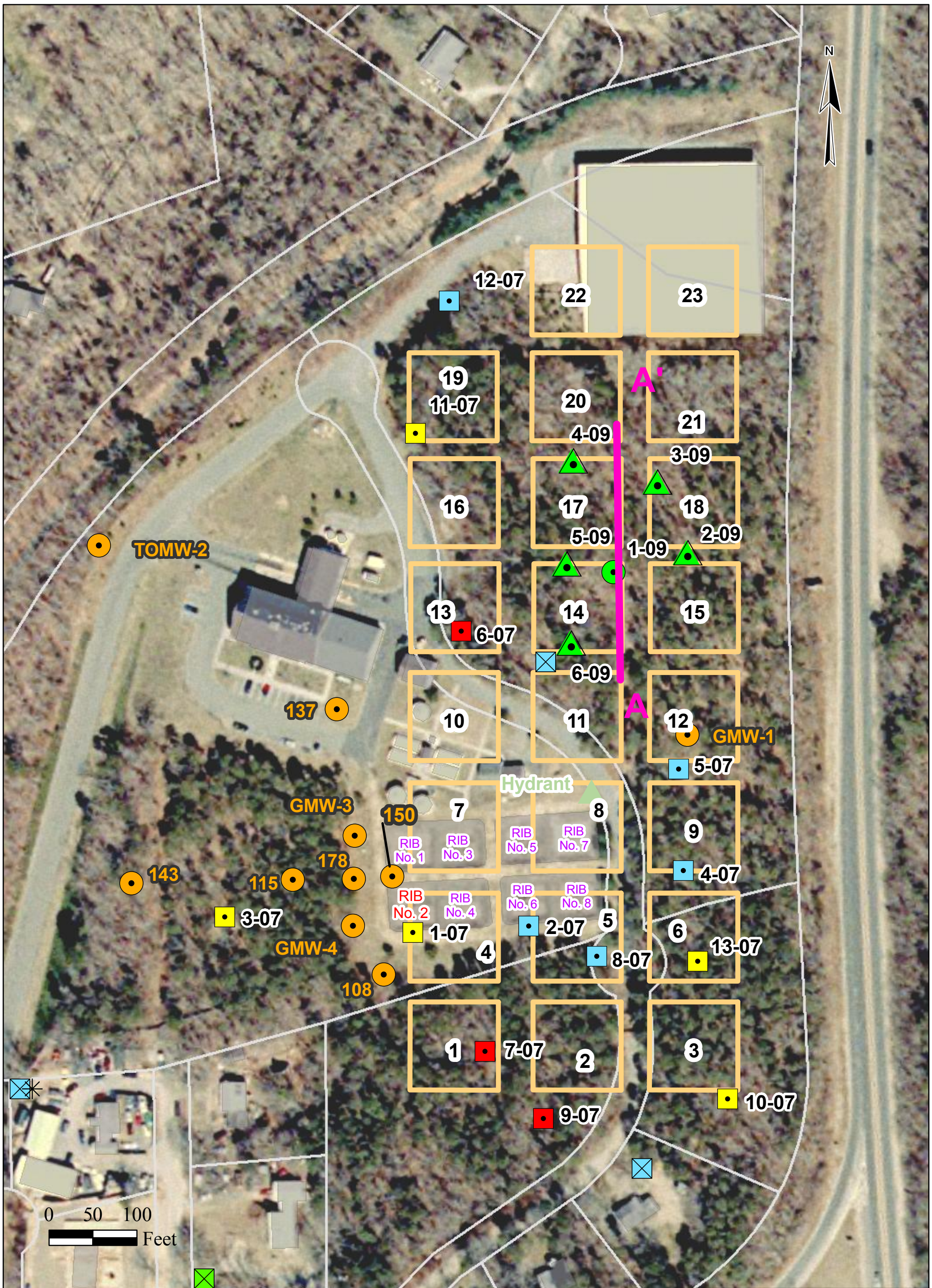
One area of the site which has not been well explored to date is the hill northeast of the treatment buildings and south of the Compost Shed. This is primarily due to the fact that the top of the hill is approximately 20 feet higher than the anticipated bottom elevation of the future rapid infiltration basins. The primary purpose of this supplemental evaluation is to determine whether the anticipated application rates for this area of the site are better, worse or the same as previously assumed.

2.0 SUBSURFACE EXPLORATIONS

A program of test boring investigations was developed and implemented for the site. A total of six test borings (numbered 1-09 through 6-09) were advanced at the site between April 7 and April 9, 2009. The drilling was performed with a track-mounted drill rig utilizing the drive-and-wash method with 3.25-inch hollow stem augers. Monitoring wells were constructed with 3-inch diameter flush joint casing. The locations of the test borings are shown on Figure 1. The boring logs are provided in Attachment A.

In general, the soil borings indicate that an upper silty fine sand layer overlays a clean medium sand layer ranging in thickness from approximately 22 to 50 feet at elevations ranging from 26.5 to 54 feet above mean sea level (ft msl). The medium sand was encountered in each of the borings except 5-09 in which fine sand was found. The clean medium sand layer in the remainder of the borings extends down to elevations ranging from 8 to 20 ft msl. At most of the borings the medium sand was underlain by fine or silty sand. An intermediate fine sand layer was observed within the clean medium sand layer on the northern portion of the knoll (test borings 2-09, 3-09, 4-09, and 5-09) ranging in thickness from 2 to 6 feet at elevations ranging from 24 to 39 feet msl. Many "stringers" of very thin 1/8" to 2" layers of dense silty fine sand were observed through out the borings. These stringers likely pinch out and are discontinuous. A generalized cross-section of the site is included as Figure 2.

A summary of the monitoring wells on-site, including the newest monitoring well, is provided in Table 1.



Legend		Test Pits 2007	Test Pits by Others
Monitoring Well April 2009	Hydrant	<2 min/inch	<2 min/in
Test Boring April 2009	Parcels	>5 min/inch	2-5 min/in
Monitoring Wells (USGS)	Conceptual Basins	None	>5 min/in
Line of Geologic Cross Section			Estimated based on Soil Logs

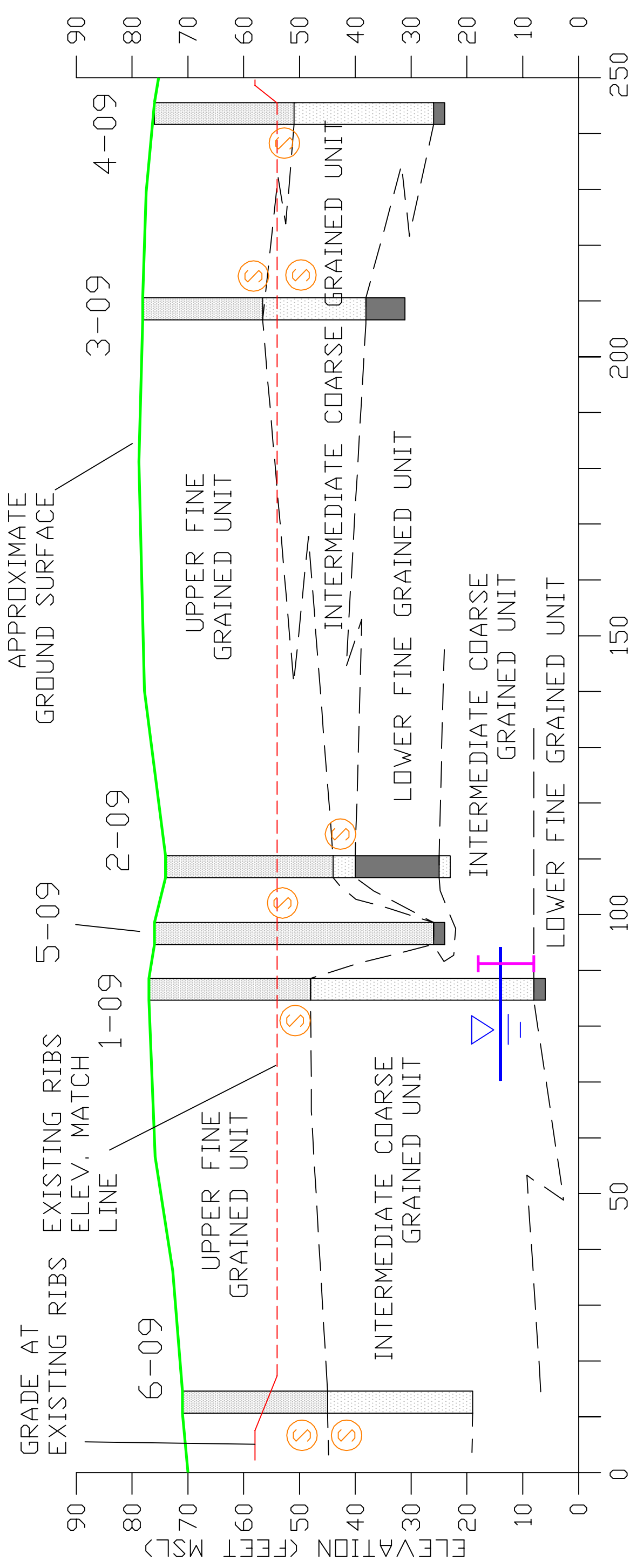
Orleans CWMP
Site Investigations
Site 241
Test Borings April 2009

PROJ NO: May 2009	WRIGHT-PIERCE Engineering a Better Environment	FIGURE: 1
DATE:		
SCALE: AS SHOWN		

SOURCE: Well Cluster Sites and Test Pits created by Wright-Pierce. All other data obtained from Town of Orleans and MassGIS.

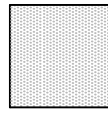
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NORTH



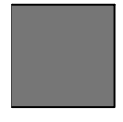
VERTICAL TO HORIZONTAL RATIO 1:1
DASHED WHERE INFERRED

LEGEND



UPPER FINE GRAINED UNIT (FINE SAND)

UPPER COARSE GRAINED UNIT (MEDIUM SAND)



LOWER FINE GRAINED UNIT (SILT AND FINE SAND)

LOWER FINE GRAINED UNIT (SILT AND FINE SAND)

WELL SCREEN



SIEVE ANALYSIS SOIL SAMPLE LOCATION

GEOLOGIC CROSS SECTION A-A		ORLEANS, MA	FIGURE: 2
PROJ NO: 10645G	DATE: MAY 2009		
SCALE: SEE DRAWING		WRIGHT-PIERCE Engineering a Better Environment	

Table 1
Monitoring Well Summary

Monitoring Well I.D. (Figure 1)	Associated USGS Well Cluster Site	Screened Interval ft msl^{1,2}
115	99	-12 to -13
108	94	6 to -1
137	86	10 to -0.5
143	148	1.5 to -3.5
150	150	3.5 to -1.5
178	93	3.5 to -1.5
GMW-1	126	17 to -2.5
GMW-3	128	20 to 0.0
GMW-4	129	20 to 0.0
TOMW-2	132	11 to -9
TOMW-3	133	10 to -10
BMW-22	NA	1.5 to -1.5
1-09	NA	16 to 6

1. Source: USGS Open File Report 95-439
2. Wright-Pierce, April 2009.

Test boring 1-09 was drilled from a grade elevation of approximately 77 ft msl to a depth of 71 feet below ground surface (ft bgs). The soils observed consisted of brown fine to medium sand, little coarse sand, from the ground surface to a depth of 10 ft bgs; varved gray fine sand and silt, from 10 to 24 ft bgs; light brown fine sand, some medium sand, trace silt, from 24 to 29 ft bgs; brown fine to medium sand, little coarse sand, from 29 to 34 ft bgs; clean brown medium sand little fine and coarse sand, some fine sand, trace silt, from 34 to 39 ft bgs; clean brown fine to medium sand, some coarse sand trace silt and fine gravel, from 39 to 66 ft bgs; and varved gray fine sand and silt with orange fine to medium sand, from 66 to 71 ft bgs. Ten feet of 10 slot PVC screen was set in test boring 1-09 from 60 to 70 ft bgs. The static water level was measured at approximately 62.8 ft bgs.

Test boring 2-09 was drilled from a grade elevation of approximately 74 ft msl to a depth of 51 feet below ground surface (ft bgs). The soils observed consisted of gray light brown fine sand and silt, from the ground surface to a depth of 4 ft bgs; light brown fine sand, from 4 to 9 ft bgs; orange brown fine sand, from 9 to 14 ft bgs; gray silt and fine sand, from 14 to 30 ft bgs; clean brown medium sand little fine and coarse sand, from 30 to 34 ft bgs; clean brown fine sand, from 34 to 46 ft bgs; and clean brown/orange medium sand, little fine and coarse sand from 46 to 51 ft bgs. Perched water was observed at 14 to 20 ft bgs.

Test boring 3-09 was drilled from a grade elevation of approximately 76.5 ft msl to a depth of 47 feet below ground surface (ft bgs). The soils observed consisted of gray light brown fine sand and silt, from the ground surface to a depth of 5 ft bgs; brown silty fine to medium sand, from 5 to 10 ft bgs; light brown fine sand, some medium sand, from 10 to 21.5 ft bgs; orange brown medium sand, trace fine and coarse sand, from 21.5 to 40 ft bgs; clean white fine sand, from 40 to 41 ft bgs; and gray brown fine sand and silt from 41 to 47 ft bgs.

Test boring 4-09 was drilled from a grade elevation of approximately 75 ft msl to a depth of 52 feet below ground surface (ft bgs). The soils observed consisted of gray light brown fine sand and silt, from the ground surface to a depth of 5 ft bgs; brown silty fine to medium sand, from 5 to 10 ft bgs; light brown fine sand, some medium sand, from 10 to 20 ft bgs; gray brown silt and fine sand, from 20 to 26 ft bgs; clean brown gray fine to medium sand, from 26 to 46 ft bgs; and gray brown fine sand, little medium sand, from 46 to 52 ft bgs.

Test boring 5-09 was drilled from a grade elevation of approximately 76.5 ft msl to a depth of 52 feet below ground surface (ft bgs). The soils observed consisted of gray light brown fine sand and silt, from the ground surface to a depth of 5 ft bgs; brown silty fine to medium sand, from 5 to 10 ft bgs; light brown fine sand, some medium sand, from 10 to 20 ft bgs; light brown/orange fine sand, some medium sand, from 20 to 21 ft bgs; and clean brown/white loose fine sand, from 21 to 2 ft bgs.

Test boring 6-09 was drilled from a grade elevation of approximately 72 ft msl to a depth of 52 feet below ground surface (ft bgs). The soils observed consisted of gray light brown fine sand and silt, from the ground surface to a depth of 5 ft bgs; brown silty fine to medium sand, from 5 to 10 ft bgs; light brown fine sand, some medium sand, from 10 to 20 ft bgs; clean brown/orange medium, trace of fine & coarse sand, from 20 to 41 ft bgs; Brown dense fine sand, from 41 to 50 ft bgs; and clean orange brown medium sand, little fine and coarse sand, from 50 to 52 ft bgs.

3.0 LABORATORY TESTING

Eight soil samples collected during the test boring program were submitted for laboratory particle size analysis. Particle size analysis reports are included as Attachment B. The particle size analyses were used to calculate the hydraulic conductivity of the soils via the Hazen method per Freeze and Cherry (1979), Vukovic and Soro (1992) and Fetter (2001). A summary of the hydraulic conductivity results is provided in Table 2. Hydraulic conductivity values ranged from less than 0.2 feet per day to 6 feet per day for the silty fine sand and from 47 feet per day to 189 feet per day for the sand. Average values were 2 to 3 feet per day for the silty fine sand and 84 to 120 feet per day for the sand.

TABLE 2
HYDRAULIC CONDUCTIVITY VALUES COMPUTED FROM SIEVE ANALYSIS
TRI-TOWN SEPTAGE TREATMENT FACILITY
ORLEANS, MA

Sample ID	Matrix	d ₁₀ (mm)	C _u	Hydraulic Conductivity Via the Hazen Method				
				Validation Criteria: 0.1mm<d10 <0.6mm (Cu<5)				
				ft/day ^A	ft/day ^B	ft/day ^C	Median (ft/day)	Avg (ft/day)
1-09 24-26 ft ^D	Moist, yellowish brown silty sand	0.04	3.753	4	5	6	5	5
2-09 29-31 ft	Moist, yellowish brown sand	0.14	3.245	47	58	79	60	61
3-09 20-22 ft	Moist, yellowish brown sand	0.26	4.619	151	189	187	175	176
3-09 25-27 ft	Moist, yellowish brown sand with silt	0.14	5.827	47	58	61	55	55
4-09 25-27 ft	Moist, yellowish brown sand	0.17	2.821	66	82	106	83	85
5-09 20-22 ft ^D	Moist, olive yellow silty sand	0.03	7.372	3	3	3	3	3
6-09 20-22 ft ^D	Moist, light yellowish brown silty sand	0.01	1036	0.3	0.4	0.2	0.3	0.3
6-09 25-27 ft	Moist, yellowish brown sand	0.22	3.377	108	135	164	134	136
			Site Median (ft/day)	75	94	110	for Sand	
			Site Avg (ft/day)	84	105	120	for Sand	
			Silty Sand Median (ft/day)	1	2	2		
			Silty Sand Avg (ft/day)	2	3	3		

^A (Fetter, 2001)

^B (Freeze and Cherry, 1979)

^C (MVASK; Vukovic and Soro, 1992)

^D Not within validation criteria. Values omitted from site median and average values.

4.0 INTERPRETATION AND ANALYSIS

Overall, the test boring investigation and particle size analyses indicate that permeable soils exist at or below the approximate elevation of the proposed RIBs. However, these permeable soils are underlain and overlain by less permeable material and there are numerous and unpredictable "stringers" of less permeable material which may control the flow of the discharge. The presence of heterogenous fine grained soils is consistent with previous investigations conducted by Wright-Pierce, GZA, USGS on-site. Accordingly, the results of these investigations do not change the previous modeling results with regard to mound height or ultimate disposition of nitrogen.

The site soils are very heterogeneous and are not well suited to broad generalizations. This is illustrated by the fact that some of the existing RIBs have very well drained soils, while some others do not. This is also illustrated by the perched groundwater in GMW-3 during the large-scale loading test conducted in December 2007 (i.e., indicative of pockets of low permeability soils in the soil column).

Given that the anticipated bottom surface of the future RIBs is at approximate elevation 53 ft msl, the upper silty fine sand layer will be removed during construction to expose the more permeable layers below. In some areas, "over-excavation" (i.e., below the desired bed depth) may be required to remove pockets of undesirable materials which may exist below the desired rapid infiltration basin application elevation. Based on the generalized cross-section, the target elevation of the proposed RIBs should range between approximately 40 to 54 feet msl. Additional investigations, including hydraulic loading test(s), will need to be conducted in this area to determine the ultimate capacity of the soils underlying this portion of the site. This testing could be done prior to construction or after the first phase of construction is completed.

The February 2008 Hydrogeologic Report included a preliminary rapid infiltration bed layout (23 beds, each 100 feet by 100 feet) as shown in Figure 1. This layout was subsequently utilized in the January 2009 Hydrogeologic Modeling Report to predict ground water mounding. The capacity range for each of these 23 beds was estimated based on the field work conducted at that time. This table has been replicated herein as Table 3. The explorations completed as a part of the April 2009 field work were intended to provide additional subsurface information for the 11 beds located in the central and northern portions of the site (Numbered 13 through 23).

5.0 CONCLUSIONS AND RECOMMENDATIONS

As noted above, one of the primary goals of this evaluation is to address the question of whether the site capacity is better, worse or the same as previously assumed. Given the heterogeneous nature of the site soils, it is prudent to characterize the site capacity as roughly the same as previously assumed. Permeable soils do exist at or below the approximate elevation of the proposed rapid infiltration basins. However, these permeable soils are underlain and overlain by less permeable silty material which may restrict the infiltration rate. While large scale infiltration testing at the central portion of the site showed that the silty layers do not pose significant limitations on effluent disposal, the impact of the silty layers at the northern portion of the site can not be quantified at this time.

As was concluded in earlier investigations, the ability of the surficial soils to accept the effluent will govern the capacity of this site but will not change the previous conclusions from the modeling efforts (i.e., mound height and general location, ultimate disposition of nitrogen, etc.). Accordingly, the aggregate recommended disposal capacity remains at 7.7 gpd/sf (based on a maximum month flow) and indicates a site capacity range of 1.78 mgd, including the area currently occupied by the Compost Shed, and approximately 1.40 mgd, excluding the area currently occupied by the Compost Shed. The ultimate capacity of the site will be determined when treated effluent is applied to the soils and may be somewhat less than that estimated herein if the silty soils can not be cost-effectively removed.

The heterogeneous geomorphology of the site is due to its location at the head of the glacial outwash (i.e. the transition zone between relatively coarse materials washed out of the glacier and the relatively fine materials deposited from glacial lakes). The heterogeneous nature of the site will result in a higher cost per gallon of disposal capacity to construct than a similar capacity would cost on a more homogeneous medium sand site (e.g., Chatham). The additional costs will be related to additional design aspects (e.g., additional field explorations and modeling to substantiate loading rates in the permit application) to additional construction aspects (e.g. over-excavation of unsuitable silty sands to create a conduit to higher permeability soils below).

**Table 3
Recommended Loading Rates**

Basin No.	Basin Area	Loading Rates Based on Percolation Tests		Loading Rates Based on All Tests	
		Rate	Total Application	Rate	Total Application
		gpd/sf	gpd	gpd/sf	gpd
1	10,000	4	40,000	4	40,000
2	10,000	4	40,000	4	40,000
3	10,000	4	40,000	4	40,000
4	10,000	5	50,000	14	140,000
5	10,000	5	50,000	14	140,000
6	10,000	5	50,000	14	140,000
7	10,000	5	50,000	14	140,000
8	10,000	5	50,000	14	140,000
9	10,000	5	50,000	14	140,000
10	10,000	5	50,000	14	140,000
11	10,000	5	50,000	14	140,000
12	10,000	5	50,000	14	140,000
13	10,000	4	40,000	10	100,000
14	10,000	5	50,000	10	100,000
15	10,000	5	50,000	10	100,000
16	10,000	4	40,000	10	100,000
17	10,000	5	50,000	10	100,000
18	10,000	5	50,000	10	100,000
19	10,000	5	50,000	10	100,000
20	10,000	5	50,000	10	100,000
21	10,000	5	50,000	10	100,000
22	10,000	5	50,000	10	100,000
23	10,000	5	50,000	10	100,000
Total, gpd		23 beds	1,100,000	23 beds	2,480,000
		18 beds	850,000	18 beds	1,780,000
Total, gpd/sf		23 beds	4.8		10.8
		18 beds	4.7		9.9
		Composite			7.7

The subsurface conditions in the northerly portions of the Tri-Town site appear to be better suited than those found in the southerly areas of the site. From disposal capacity and setback perspectives, the soils in the northern portion of the site are more advantageous than those in the southern portion of the site. That said, a cost effectiveness analysis of shifting the Phase 1 RIBs to the northerly areas of the site should be completed in Preliminary Design. The analysis would need to balance the costs of removing the hill versus the costs of lower disposal capacity.

Based on these investigations, we estimate the site capacity to be approximately 1.78 mgd based on the maximum monthly flow, including the area currently occupied by the Compost Shed. This represents 163% of the Core Plan (1.09 mgd maximum month flow) and approximately 88% of the Extended Plan (2.01 mgd maximum month flow). Based on the rapid infiltration basin layouts included in the Draft CWMP, we estimate the site capacity to be 1.40 mgd based on maximum monthly flow, excluding the area currently occupied by the Compost Shed. This represents 128% of the Core Plan (1.09 mgd maximum month flow) and approximately 70% of the Extended Plan (2.01 mgd maximum month flow)

The Town should apply for a Groundwater Discharge Permit based on the flows documented in the Draft CWMP for the Core Plan, specifically those associated with a 1.09 mgd maximum month flow. A Groundwater Discharge Permit should be readily obtainable with the three existing hydrogeologic reports (including this report) and perhaps some limited additional information. The Groundwater Discharge Permit Application could state the Town's intention to request an increased flow rate in the future based on large-scale testing of constructed rapid infiltration basins (reference Section 11.9.2 of the Draft CWMP), if implementation of a regional plan or the Extended Plan are contemplated.

Consistent with the Draft CWMP, it is also recommended that the Town secure rights to future development of effluent disposal sites in the vicinity of the proposed WWTF, if the Extended Plan or Regionalization is expected or desired.

6.0 REFERENCES

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Vukovic, M. and Soro, A., 1992, "Determination of Hydraulic Conductivity of Porous Media From Grain Size Composition," Water Resources Publications, Littleton, CO.

Wright-Pierce, 2005, "Tri-Town Septage Treatment Facility Evaluation."

Wright-Pierce, 2008, "Orleans Comprehensive Wastewater Management Plan -- Phase 6 Site Investigations, Hydrogeological Investigation at Site 241."

Wright-Pierce, 2009, "Orleans Comprehensive Wastewater Management Plan -- Phase 6 Site Investigations, Hydrogeologic Modeling at Site 241."

Wright-Pierce, 2009, "Orleans Comprehensive Wastewater Management Plan."

**ATTACHMENT A
SOIL BORING LOGS**

PROJECT: Orleans, MA - TriTown Follow-on Planning				JOB NO. 10645G	
CLIENT: Orleans, MA				DATE STARTED: 4/7/09	
BORING CONTRACTOR: NH Boring				DATE FINISHED: 4/8/09	
CAS.	SAMP.	CORE	TUBE	ELEVATION (ground):	
Steel	Wash/SS	-	-	ELEVATION (PVC):	
DIAMETER	3"	-	-	GROUNDWATER (ft bgs): 62.8	
WEIGHT	300 lbs	-	-	DRILLER: Jay	
FALL	30"	-	-	INSPECTOR: Peter Wilson	

DEPTH (ft)	WELL CONSTRUCTION	FORMATION CLASSIFICATION	SAMPLE				NOTES
			NO.	INTER. (ft)	REC. (in)	BLOWS/24"	
0	<p>Native Backfill</p> <p>Screen: 5' of 2" Sch 40 PVC 10- slot screen set at 60-70' Riser: 2" PVC</p> <p>4" steel protective</p> <p>Bentonite</p> <p>No 1 Sand Pack</p>	Brown fine to medium SAND, little coarse sand		0-10	NA		Wash sample
5		Gray fine SAND & SILT. Varved.		10-20	NA		Wash sample
10		Gray fine SAND & SILT. Varved.		19-21	24	41	3 inch Split Spoon
15		Light Brown FINE SAND, some medium sand, trace silt.		24-26	12	34	3 inch Split Spoon
20		Brown fine to medium SAND, little coarse SAND		29-31	13	38	3 inch Split Spoon
25		Clean brown medium to coarse SAND, some fine sand, trace silt		34-36	9	45	3 inch Split Spoon
30		Brown fine to medium SAND, some coarse sand, trace silt & fine gravel		39-41	8	70	3 inch Split Spoon
35		Same as above		44-46	0	71	3 inch Split Spoon
40		Same as above		49-51	9	95	3 inch Split Spoon
45		Same as above		54-56	8	123	3 inch Split Spoon
50		SAA to 60.5' then 2" layer of gray FINE SAND & SILT, varved, then brown medium to fine SAND, little coarse sand.		59-61	13	91	3 inch Split Spoon
55		Brown fine to medium SAND, stringer (0.5") of gray FINE SAND & SILT		64-66	11	102	
60		Gray SILT & FINE SAND. Varved lenses of orange stained fine to medium sand.		69-71	24	98	3 inch Split Spoon End of boring

PROJECT: Orleans, MA - TriTown Follow-on Planning				JOB NO. 10645G	
CLIENT: Orleans, MA				DATE STARTED: 4/8/09	
BORING CONTRACTOR: NH Boring				DATE FINISHED: 4/8/09	
	CAS.	SAMP.	CORE	TUBE	ELEVATION (ground):
TYPE	Auger		-	-	ELEVATION (PVC):
DIAMETER	2.5" ID		-	-	GROUNDWATER (ft bgs): Not Encountered
WEIGHT	180 lbs	2 ' Split Spoon	-	-	DRILLER: Jay
FALL	30"		-	-	INSPECTOR: Peter Wilson

DEPTH (ft)	WELL CONSTRUCTION	FORMATION CLASSIFICATION	SAMPLE				NOTES
			NO.	INTER. (ft)	REC. (in)	BLOWS/24"	
0	Test Boring - No Well Installed	Gray/light brown FINE SAND & SILT		0-4			Off augers
5		Light brown FINE SAND		4-9			Off augers
10		Orange brown FINE SAND		9-14			Off augers
15		upper 5" Orange brown medium SAND lower 5" Gray SILT & FINE SAND with 1/8" layers of orange medium sand.		14-16	10	75	Begin Split Spoon
20		Same as above		19-21	14	30	Wet -Perched water
25		Same as above		24-26	16	21	
30		Same as above to 30' then Clean brown medium SAND, little fine & coarse sand.		29-31	12	26	
35		Gray SILT & FINE SAND with 1/8" layers of orange medium sand.		34-36	18	23	
40		Clean Brown FINE SAND. Gray Fine SAND at soon tip.		39-41	6	32	
45		Light brown Fine SAND, dense		44-46	8	28	
50	Clean brown/orange medium SAND, little fine & coarse sand		49-51	10	27	End of boring	
55							
60							
65							
70							

PROJECT: Orleans, MA - TriTown Follow-on Planning				JOB NO. 10645G	
CLIENT: Orleans, MA				DATE STARTED: 4/8/09	
BORING CONTRACTOR: NH Boring				DATE FINISHED: 4/8/09	
	CAS.	SAMP.	CORE	TUBE	ELEVATION (ground):
TYPE	Auger		-	-	ELEVATION (PVC):
DIAMETER	2.5" ID		-	-	GROUNDWATER (ft bgs): Not Encountered
WEIGHT	180 lbs	2 ' Split Spoon	-	-	DRILLER: Jay
FALL	30"		-	-	INSPECTOR: Peter Wilson

DEPTH (ft)	WELL CONSTRUCTION	FORMATION CLASSIFICATION	SAMPLE				NOTES
			NO.	INTER. (ft)	REC. (in)	BLOWS/24"	
0	Test Boring - No Well Installed	Gray/light brown FINE SAND & SILT		0-5			Off augers
5		Brown Silty fine to medium SAND.		5-10			Off augers
10		Light brown FINE SAND, some medium sand		10-20			Off augers
20		Same as above to 21.5' then Clean orange brown medium SAND, trace fine & coarse sand		20-22	8	10	Begin split spoon
25		Same as above		25-27	10	26	1/2 stone in spoon
30		Same as above		30-32	8	29	
35		Upper 4": gray fine SAND & SILT Lower 7" Clean orange brown medium SAND, trace fine & coarse		35-37	11	12	
40	Upper 3" White Clean brown FINE SAND, some very fine sand Lower 10" Gray brown Fine SAND & SILT		40-42	13	19		
45	Same as above.		45-47			End of boring	
50							
55							
60							
65							
70							

PROJECT: Orleans, MA - TriTown Follow-on Planning				JOB NO. 10645G	
CLIENT: Orleans, MA				DATE STARTED: 4/9/09	
BORING CONTRACTOR: NH Boring				DATE FINISHED: 4/9/09	
	CAS.	SAMP.	CORE	TUBE	ELEVATION (ground):
TYPE	Auger		-	-	ELEVATION (PVC):
DIAMETER	2.5" ID		-	-	GROUNDWATER (ft bgs): Not Encountered
WEIGHT	180 lbs	2 ' Split Spoon	-	-	DRILLER: Jay
FALL	30"		-	-	INSPECTOR: Peter Wilson

DEPTH (ft)	WELL CONSTRUCTION	FORMATION CLASSIFICATION	SAMPLE				NOTES
			NO.	INTER. (ft)	REC. (in)	BLOWS/24"	
0	Test Boring - No Well Installed	Gray/light brown FINE SAND & SILT		0-5			Off augers
5		Brown Silty fine to medium SAND.		5-10			Off augers
10		Light brown FINE SAND, some medium sand		10-20			Off augers
20		Gray/brown FINE SAND & SILT		20-22	18	20	Begin split spoon
25		Upper 6" Same as above Lower 10" brown/gray fine to medium SAND, clean.		25-27	16	10	1/2 stone in spoon
30		Brown/orange fine to medium SAND, clean.		30-32	8	29	
35		Upper 5" Same as above Lower 5" brown white VF-FINE SAND, some medium sand, clean.		35-37	10	30	
40		Alternating layers (1") brown fine to medium SAND/ Brown FINE SAND/Dense Brown FINE		40-42	10	15	
45		Upper 9" Orange brown fine to medium SAND, clean Lower 8" Gray brown FINE SAND, little medium sand.		45-47	16	21	
50		Alternating layers (1.5') of clean medium SAND/Gray brown FINE SAND, little medium sand.		50-52	10	28	End of boring
55							
60							
65							
70							

PROJECT: Orleans, MA - TriTown Follow-on Planning				JOB NO. 10645G	
CLIENT: Orleans, MA				DATE STARTED: 4/9/09	
BORING CONTRACTOR: NH Boring				DATE FINISHED: 4/9/09	
	CAS.	SAMP.	CORE	TUBE	ELEVATION (ground):
TYPE	Auger		-	-	ELEVATION (PVC):
DIAMETER	2.5" ID		-	-	GROUNDWATER (ft bgs): Not Encountered
WEIGHT	180 lbs	2 ' Split Spoon	-	-	DRILLER: Jay
FALL	30"		-	-	INSPECTOR: Peter Wilson

DEPTH (ft)	WELL CONSTRUCTION	FORMATION CLASSIFICATION	SAMPLE				NOTES
			NO.	INTER. (ft)	REC. (in)	BLOWS/24"	
0	Test Boring - No Well Installed	Gray/light brown FINE SAND & SILT		0-5			Off augers
5		Brown Silty fine to medium SAND.		5-10			Off augers
10		Light brown FINE SAND, some medium sand		10-20			Off augers
20		Light brown/white/orange FINE SAND, little medium sand, Clean. 1/8" thick layer of gray/brown FINE SAND		20-22	12	23	Begin split spoon
25		Clean Brown/White FINE SAND, loose		25-27	24	34	
30		Same as above		30-32	18	30	
35		Same as above with 0.5" gray FINE SAND & SILT		35-37	10	30	
40		Same as above		40-42	13	50	
45		Same as above		45-47	16	21	
50		Same as above with Gray dense FINE SAND AND SILT at spoon tip		50-52	10	28	End of boring
55							
60							
65							
70							

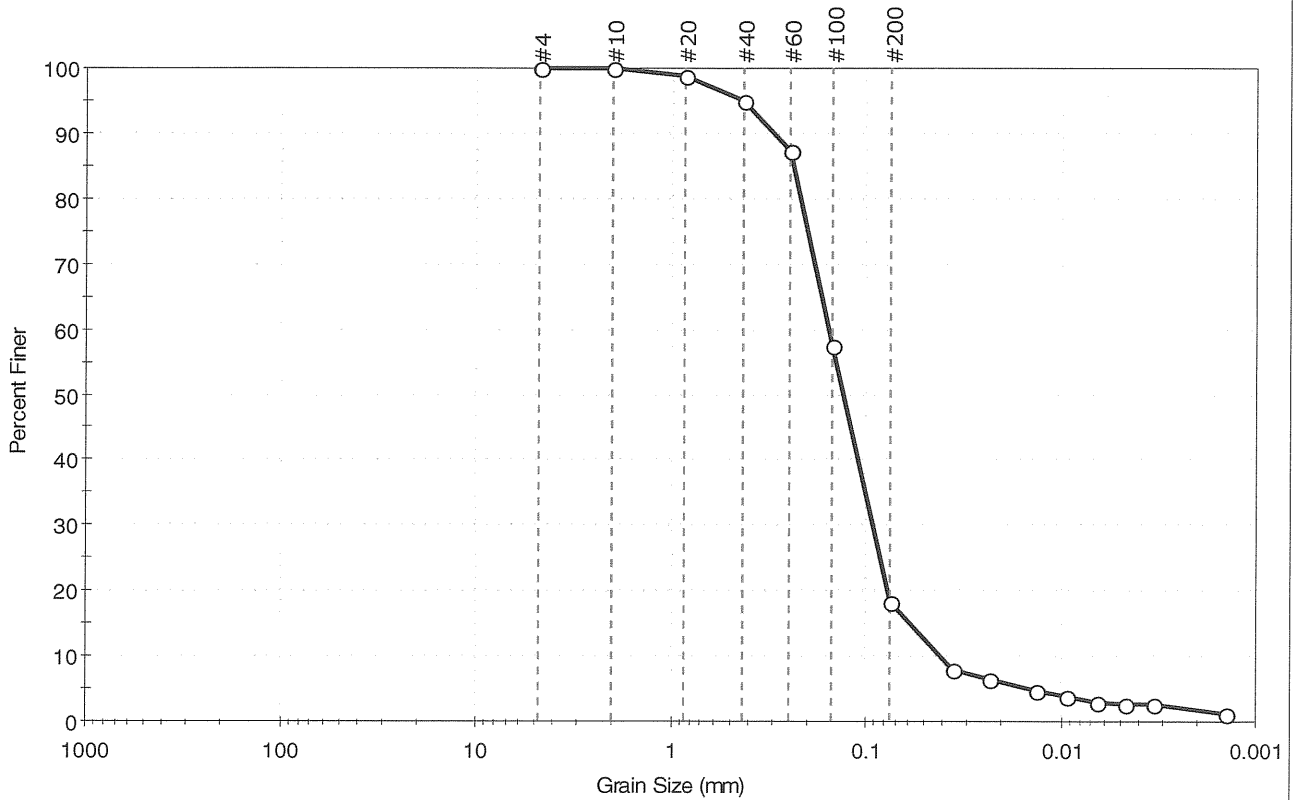
PROJECT: Orleans, MA - TriTown Follow-on Planning				JOB NO. 10645G	
CLIENT: Orleans, MA				DATE STARTED: 4/9/09	
BORING CONTRACTOR: NH Boring				DATE FINISHED: 4/9/09	
	CAS.	SAMP.	CORE	TUBE	ELEVATION (ground):
TYPE	Auger		-	-	ELEVATION (PVC):
DIAMETER	2.5" ID		-	-	GROUNDWATER (ft bgs): Not Encountered
WEIGHT	180 lbs	2 'Split Spoon	-	-	DRILLER: Jay
FALL	30"		-	-	INSPECTOR: Peter Wilson

DEPTH (ft)	WELL CONSTRUCTION	FORMATION CLASSIFICATION	SAMPLE				NOTES
			NO.	INTER. (ft)	REC. (in)	BLOWS/24"	
0	Test Boring - No Well Installed	Gray/light brown FINE SAND & SILT		0-5			Off augers
5		Brown Silty fine to medium SAND.		5-10			Off augers
10		Light brown FINE SAND, some medium sand		10-20			Off augers
15							
20		Light brown FINE SAND & SILT		20-22	10	15	Begin split spoon
25		Same as above to 26' change to Clean brown orange medium SAND, trace fine & coarse sand.		25-27	24	34	
30		Same as above		30-32	14	10	
35		Same as above. Yellowish brown		35-37	10	30	
40		Upper 8" same as above. Lower 8" Brown FINE SAND, loose. Stringer (1/4") of dense FINE SAND & SILT at spoon tip.		40-42	16	27	
45		Brown orange silty medium to fine SAND.		45-47	18	16	
50		Clean orange brown medium SAND, little fine to coarse sand.		50-52	10	20	End of boring
55							
60							
65							
70							

**ATTACHMENT B
PARTICLE SIZE ANALYSES**

Client: Wright-Pierce	Project: Tri-Town	Location: Orleans, MA	Project No: GTX-8978
Boring ID: ---	Sample Type: bag	Tested By: jbr	Checked By: jdt
Sample ID:1-09	Test Date: 04/28/09	Test Id: 151610	
Depth : 24-26 ft			
Test Comment: ---			
Sample Description: Moist, yellowish brown silty sand			
Sample Comment: ---			

Particle Size Analysis - ASTM D 422-63 (reapproved 2002)



% Cobble	% Gravel	% Sand	% Silt & Clay Size
---	0.0	81.8	18.2

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	100		
#20	0.85	99		
#40	0.42	95		
#60	0.25	87		
#100	0.15	58		
#200	0.075	18		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0362	8		
---	0.0235	6		
---	0.0135	5		
---	0.0095	4		
---	0.0067	3		
---	0.0047	3		
---	0.0034	3		
---	0.0014	1		

Coefficients

D ₈₅ = 0.2408 mm	D ₃₀ = 0.0924 mm
D ₆₀ = 0.1565 mm	D ₁₅ = 0.0597 mm
D ₅₀ = 0.1314 mm	D ₁₀ = 0.0417 mm
C _u = N/A	C _c = N/A

Classification

ASTM N/A

AASHTO Silty Gravel and Sand (A-2-4 (0))

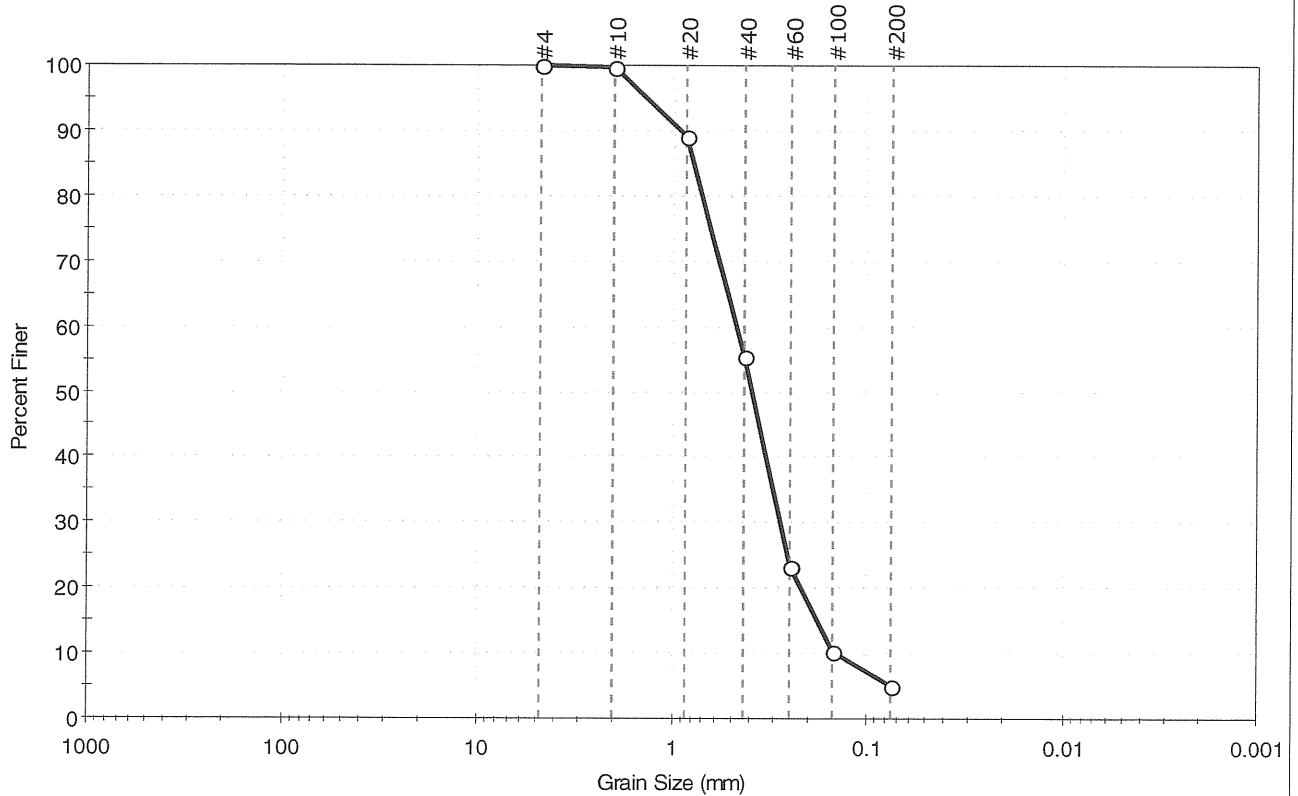
Sample/Test Description

Sand/Gravel Particle Shape : ---

Sand/Gravel Hardness : ---

Client: Wright-Pierce	Project No: GTX-8978
Project: Tri-Town	Tested By: jbr
Location: Orleans, MA	Checked By: jdt
Boring ID: ---	Sample Type: bag
Sample ID: 2-09	Test Date: 04/27/09
Depth : 29-31 ft	Test Id: 151605
Test Comment: ---	
Sample Description: Moist, yellowish brown sand with silt	
Sample Comment: ---	

Particle Size Analysis - ASTM D 422-63 (reapproved 2002)



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	—	94.9	5.1

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	100		
#20	0.85	89		
#40	0.42	56		
#60	0.25	23		
#100	0.15	10		
#200	0.075	5		

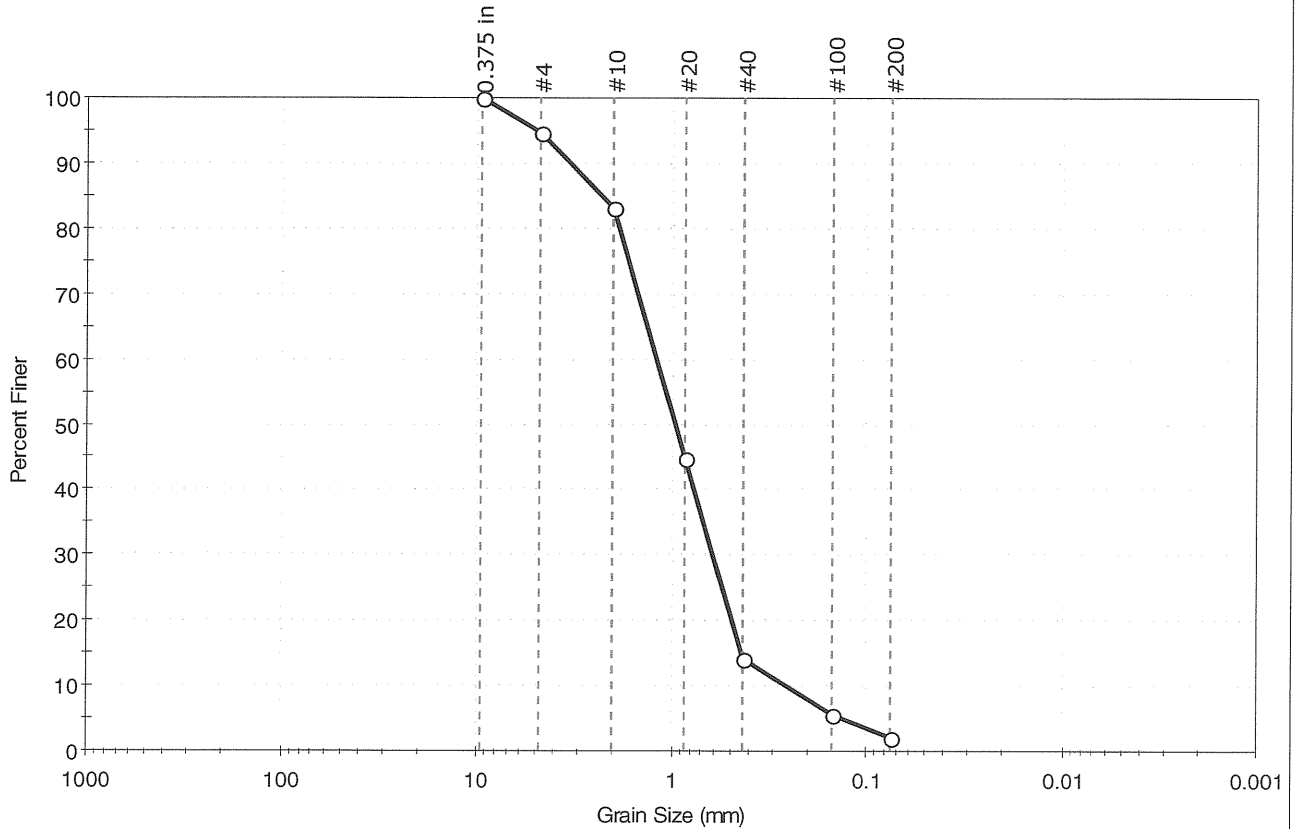
<u>Coefficients</u>	
D ₈₅ = 0.7798 mm	D ₃₀ = 0.2788 mm
D ₆₀ = 0.4657 mm	D ₁₅ = 0.1801 mm
D ₅₀ = 0.3877 mm	D ₁₀ = 0.1435 mm
C _u = 3.245	C _c = 1.163

<u>Classification</u>	
ASTM	N/A
AASHTO	Fine Sand (A-3 (0))

<u>Sample/Test Description</u>
Sand/Gravel Particle Shape : ---
Sand/Gravel Hardness : ---

Client: Wright-Pierce	Project: Tri-Town	Location: Orleans, MA	Project No: GTX-8978
Boring ID: ---	Sample Type: bag	Tested By: jbr	
Sample ID: 3-09	Test Date: 04/27/09	Checked By: jdt	
Depth: 20-22 ft	Test Id: 151606		
Test Comment: ---			
Sample Description: Moist, yellowish brown sand			
Sample Comment: ---			

Particle Size Analysis - ASTM D 422-63 (reapproved 2002)



%Cobble	%Gravel	%Sand	%Silt & Clay Size
—	5.3	92.6	2.1

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
0.375 in	9.50	100		
#4	4.75	95		
#10	2.00	83		
#20	0.85	45		
#40	0.42	14		
#100	0.15	6		
#200	0.075	2		

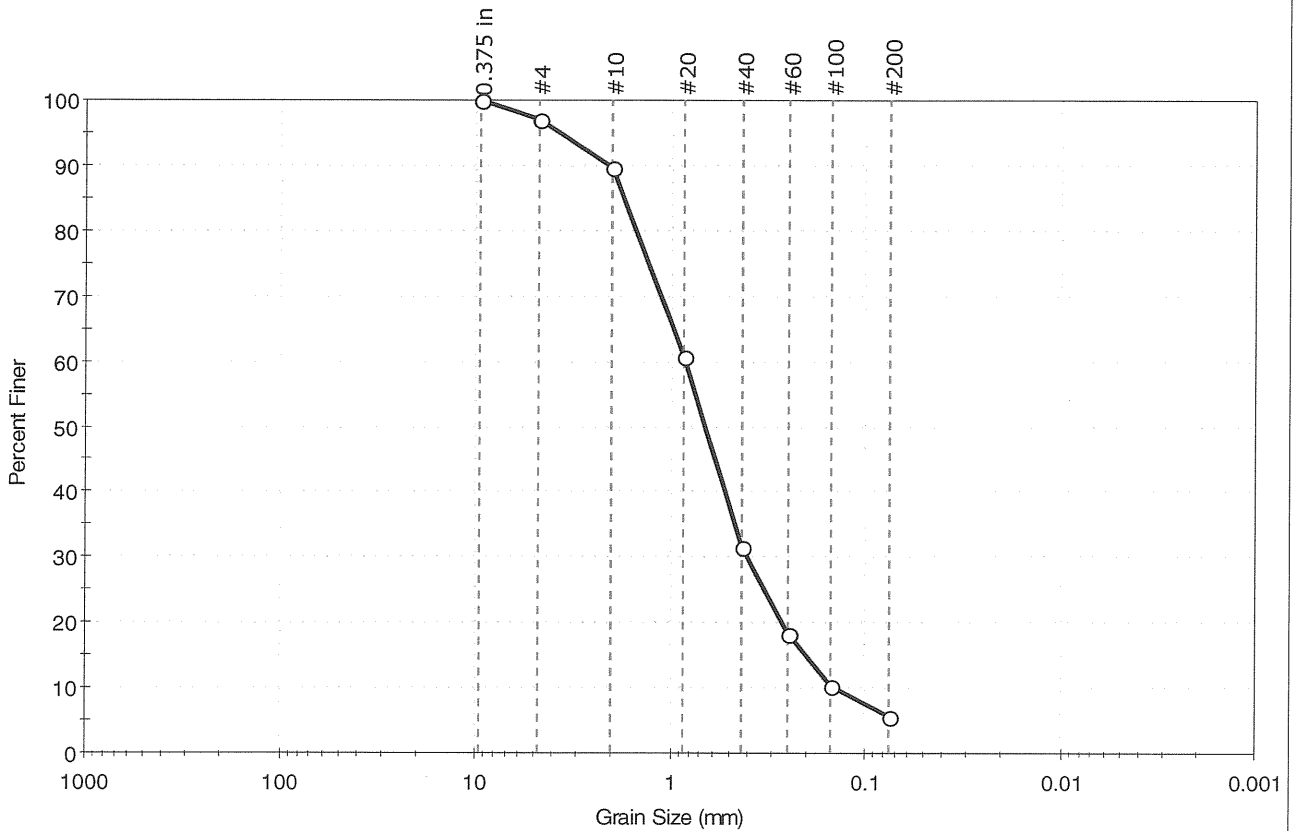
<u>Coefficients</u>	
D ₈₅ = 2.3035 mm	D ₃₀ = 0.6085 mm
D ₆₀ = 1.1931 mm	D ₁₅ = 0.4340 mm
D ₅₀ = 0.9540 mm	D ₁₀ = 0.2583 mm
C _u = 4.619	C _c = 1.201

<u>Classification</u>	
<u>ASTM</u>	Poorly graded sand (SP)
<u>AASHTO</u>	Stone Fragments, Gravel and Sand (A-1-b (0))

<u>Sample/Test Description</u>	
Sand/Gravel Particle Shape :	---
Sand/Gravel Hardness :	---

Client: Wright-Pierce	Project: Tri-Town	Location: Orleans, MA	Project No: GTX-8978
Boring ID: ---	Sample Type: bag	Tested By: jbr	Checked By: jdt
Sample ID:3-09	Test Date: 04/27/09	Test Id: 151607	
Depth : 25-27 ft			
Test Comment: ---	Sample Description: Moist, yellowish brown sand with silt		
Sample Comment: ---			

Particle Size Analysis - ASTM D 422-63 (reapproved 2002)



% Cobble	% Gravel	% Sand	% Silt & Clay Size
---	3.1	91.3	5.6

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
0.375 in	9.50	100		
#4	4.75	97		
#10	2.00	90		
#20	0.85	61		
#40	0.42	31		
#60	0.25	18		
#100	0.15	10		
#200	0.075	6		

Coefficients

D ₈₅ = 1.7428 mm	D ₃₀ = 0.4007 mm
D ₆₀ = 0.8356 mm	D ₁₅ = 0.2032 mm
D ₅₀ = 0.6593 mm	D ₁₀ = 0.1434 mm
C _u = 5.827	C _c = 1.340

Classification

ASTM N/A

AASHTO Stone Fragments, Gravel and Sand (A-1-b (0))

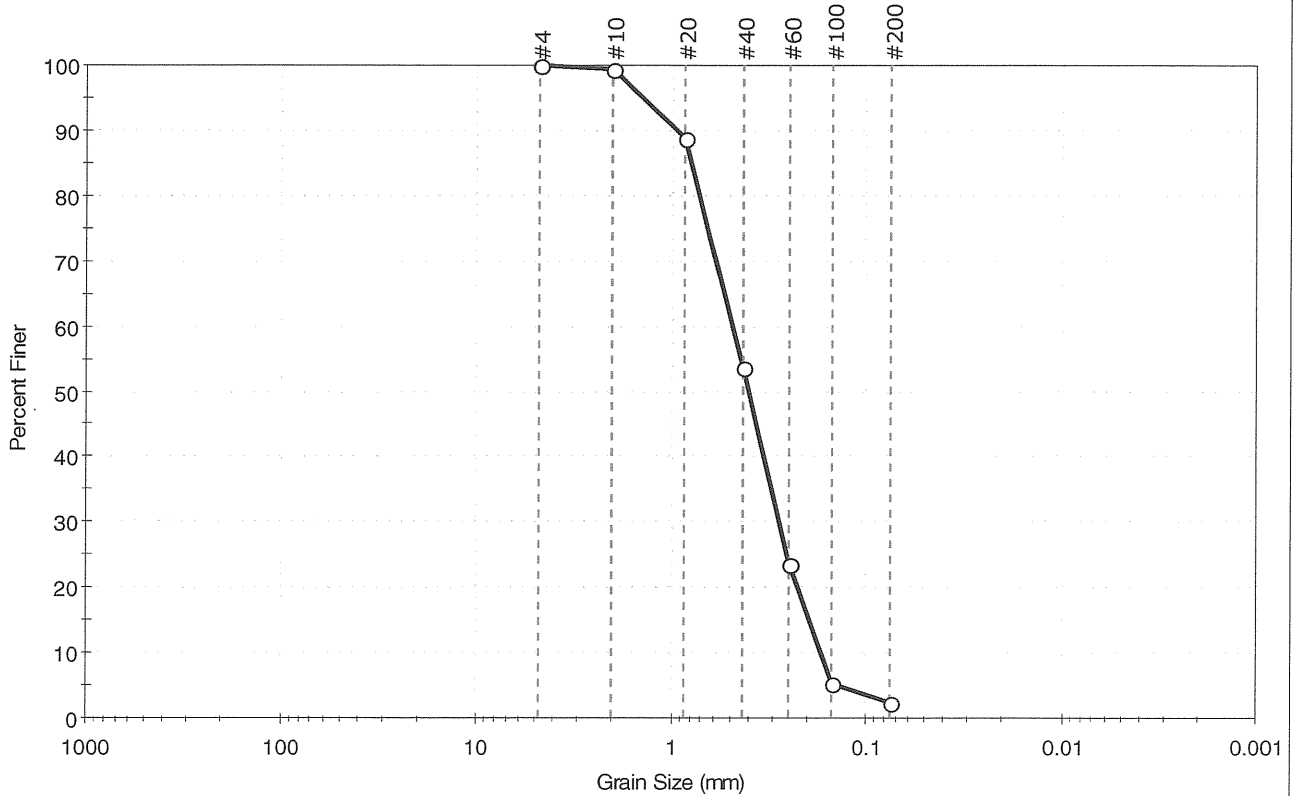
Sample/Test Description

Sand/Gravel Particle Shape : ---

Sand/Gravel Hardness : ---

Client: Wright-Pierce	Project No: GTX-8978
Project: Tri-Town	Tested By: jbr
Location: Orleans, MA	Checked By: jdt
Boring ID: ---	Sample Type: bag
Sample ID: 4-09	Test Date: 04/27/09
Depth : 25-27 ft	Test Id: 151608
Test Comment: ---	
Sample Description: Moist, light yellowish brown sand	
Sample Comment: ---	

Particle Size Analysis - ASTM D 422-63 (reapproved 2002)



% Cobble	% Gravel	% Sand	% Silt & Clay Size
---	---	97.7	2.3

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	99		
#20	0.85	89		
#40	0.42	54		
#60	0.25	24		
#100	0.15	5		
#200	0.075	2		

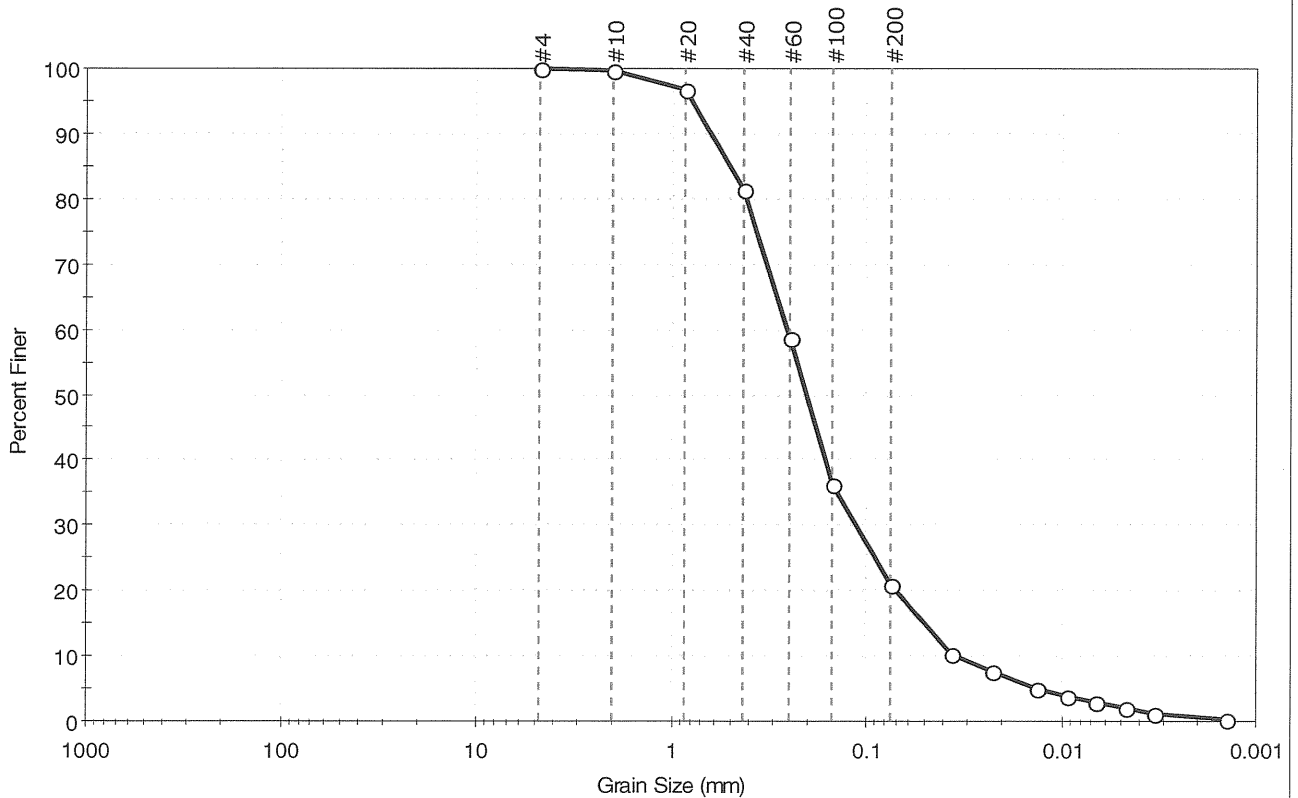
<u>Coefficients</u>	
D ₈₅ = 0.7888 mm	D ₃₀ = 0.2799 mm
D ₆₀ = 0.4813 mm	D ₁₅ = 0.1964 mm
D ₅₀ = 0.3982 mm	D ₁₀ = 0.1706 mm
C _u = 2.821	C _c = 0.954

<u>Classification</u>	
ASTM	Poorly graded sand (SP)
AASHTO	Fine Sand (A-3 (0))

<u>Sample/Test Description</u>
Sand/Gravel Particle Shape : ---
Sand/Gravel Hardness : ---

Client: Wright-Pierce	Project No: GTX-8978
Project: Tri-Town	Tested By: jbr
Location: Orleans, MA	Checked By: jdt
Boring ID: ---	Sample Type: bag
Sample ID:5-09	Test Date: 04/28/09
Depth : 20-22 ft	Test Id: 151611
Test Comment: ---	
Sample Description: Moist, olive yellow silty sand	
Sample Comment: ---	

Particle Size Analysis - ASTM D 422-63 (reapproved 2002)



% Cobble	% Gravel	% Sand	% Silt & Clay Size
---	0.0	79.1	20.9

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
#4	4.75	100		
#10	2.00	100		
#20	0.85	97		
#40	0.42	81		
#60	0.25	59		
#100	0.15	36		
#200	0.075	21		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0369	10		
---	0.0227	8		
---	0.0134	5		
---	0.0094	4		
---	0.0067	3		
---	0.0047	2		
---	0.0034	1		
---	0.0014	0		

Coefficients

D ₈₅ = 0.5021 mm	D ₃₀ = 0.1127 mm
D ₆₀ = 0.2573 mm	D ₁₅ = 0.0506 mm
D ₅₀ = 0.2046 mm	D ₁₀ = 0.0349 mm
C _u = N/A	C _c = N/A

Classification

ASTM N/A

AASHTO Silty Gravel and Sand (A-2-4 (0))

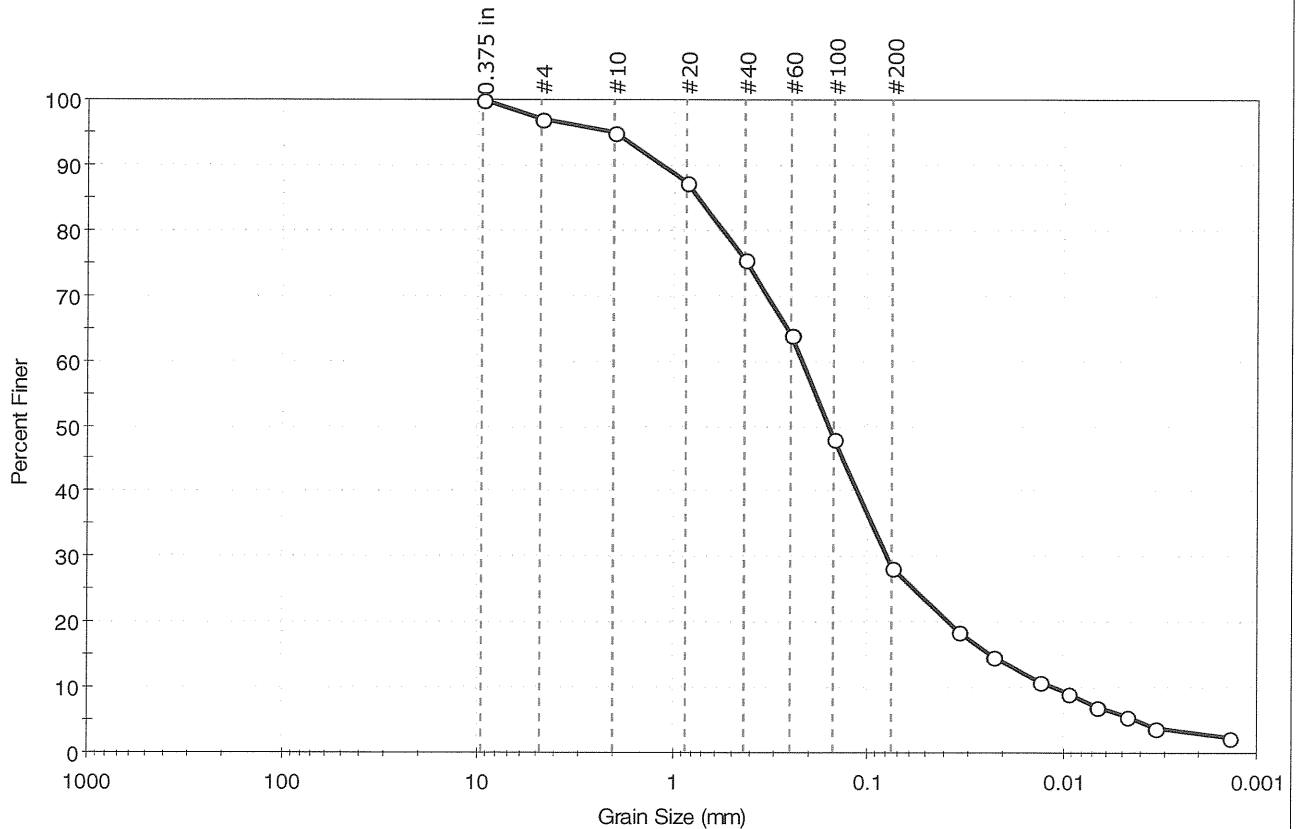
Sample/Test Description

Sand/Gravel Particle Shape : ---

Sand/Gravel Hardness : ---

Client: Wright-Pierce	Project No: GTX-8978
Project: Tri-Town	Tested By: jbr
Location: Orleans, MA	Checked By: jdt
Boring ID: ---	Sample Type: bag
Sample ID: 6-09	Test Date: 04/28/09
Depth: 20-22 ft	Test Id: 151612
Test Comment: ---	
Sample Description: Moist, light yellowish brown silty sand	
Sample Comment: ---	

Particle Size Analysis - ASTM D 422-63 (reapproved 2002)



% Cobble	% Gravel	% Sand	% Silt & Clay Size
---	2.8	68.8	28.4

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
0.375 in	9.50	100		
#4	4.75	97		
#10	2.00	95		
#20	0.85	87		
#40	0.42	76		
#60	0.25	64		
#100	0.15	48		
#200	0.075	28		
---	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0340	19		
---	0.0229	15		
---	0.0133	11		
---	0.0094	9		
---	0.0067	7		
---	0.0047	6		
---	0.0033	4		
---	0.0014	2		

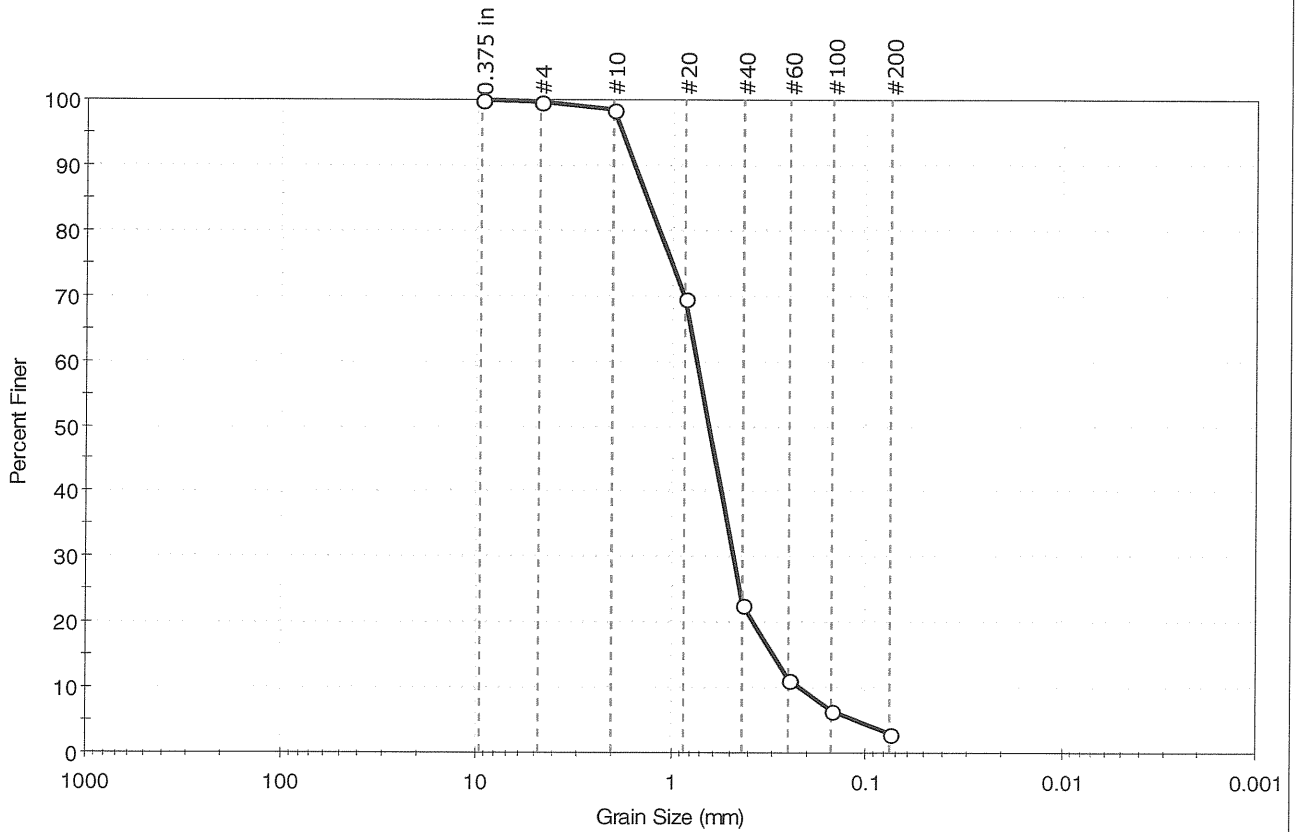
<u>Coefficients</u>	
D ₈₅ = 0.7384 mm	D ₃₀ = 0.0795 mm
D ₆₀ = 0.2193 mm	D ₁₅ = 0.0235 mm
D ₅₀ = 0.1600 mm	D ₁₀ = 0.0112 mm
C _u = N/A	C _c = N/A

<u>Classification</u>	
ASTM	N/A
AASHTO	Silty Gravel and Sand (A-2-4 (0))

<u>Sample/Test Description</u>
Sand/Gravel Particle Shape : ---
Sand/Gravel Hardness : ---

Client: Wright-Pierce	Project No: GTX-8978
Project: Tri-Town	
Location: Orleans, MA	
Boring ID: ---	Sample Type: bag
Sample ID:6-09	Tested By: jbr
Depth : 25-27 ft	Test Date: 04/27/09
	Checked By: jdt
Test Id: 151609	
Test Comment: ---	
Sample Description: Moist, light yellowish brown sand	
Sample Comment: ---	

Particle Size Analysis - ASTM D 422-63 (reapproved 2002)



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	0.2	96.8	3.0

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
0.375 in	9.50	100		
#4	4.75	100		
#10	2.00	99		
#20	0.85	70		
#40	0.42	23		
#60	0.25	11		
#100	0.15	7		
#200	0.075	3		

Coefficients

D ₈₅ = 1.3409 mm	D ₃₀ = 0.4727 mm
D ₆₀ = 0.7373 mm	D ₁₅ = 0.2970 mm
D ₅₀ = 0.6358 mm	D ₁₀ = 0.2183 mm
C _u = 3.377	C _c = 1.388

Classification

ASTM	Poorly graded sand (SP)
AASHTO	Stone Fragments, Gravel and Sand (A-1-b (0))

Sample/Test Description

Sand/Gravel Particle Shape : ---
Sand/Gravel Hardness : ---

