APPENDIX F

HYDROGEOLOGIC MODELING AT SITE 241

ORLEANS COMPREHENSIVE WASTEWATER MANAGEMENT PLAN

DRAFT

PHASE 6 -- SITE INVESTIGATIONS HYDROGEOLOGIC MODELING AT SITE 241

May 2008

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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.

0 3,000 Feet

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Site Investigations
Site 241
Locus Map

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10645E	April 2008	1

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SECTION 2

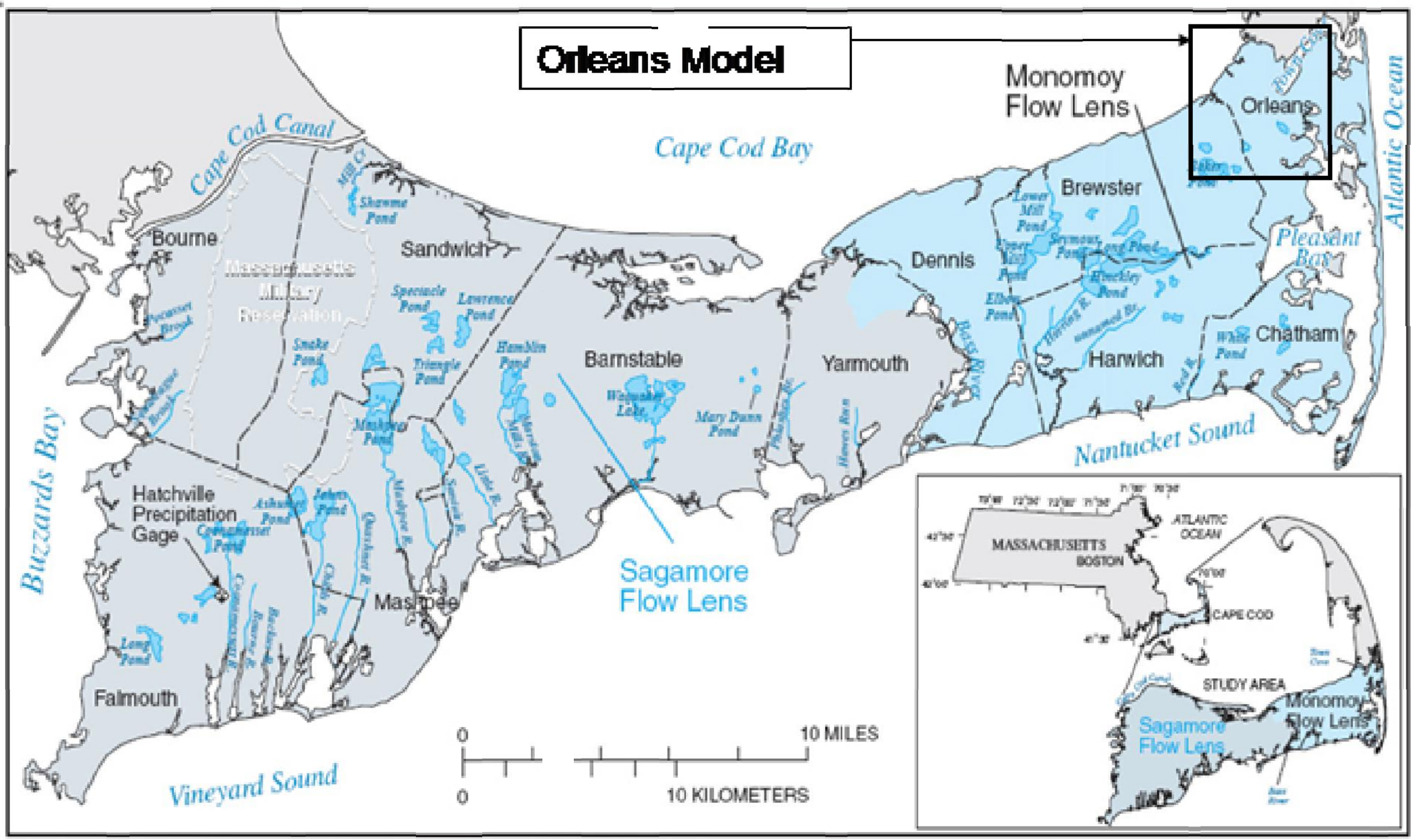
MODELING METHOD

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.



Base from U.S. Geological Survey topographic quadrangles, Chatham, Cotuit, Dennis, Falmouth, Harwich, Hyannis, Onset, 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

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Model Extents

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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.

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Site 241
Model Grid and
Boundary Conditions

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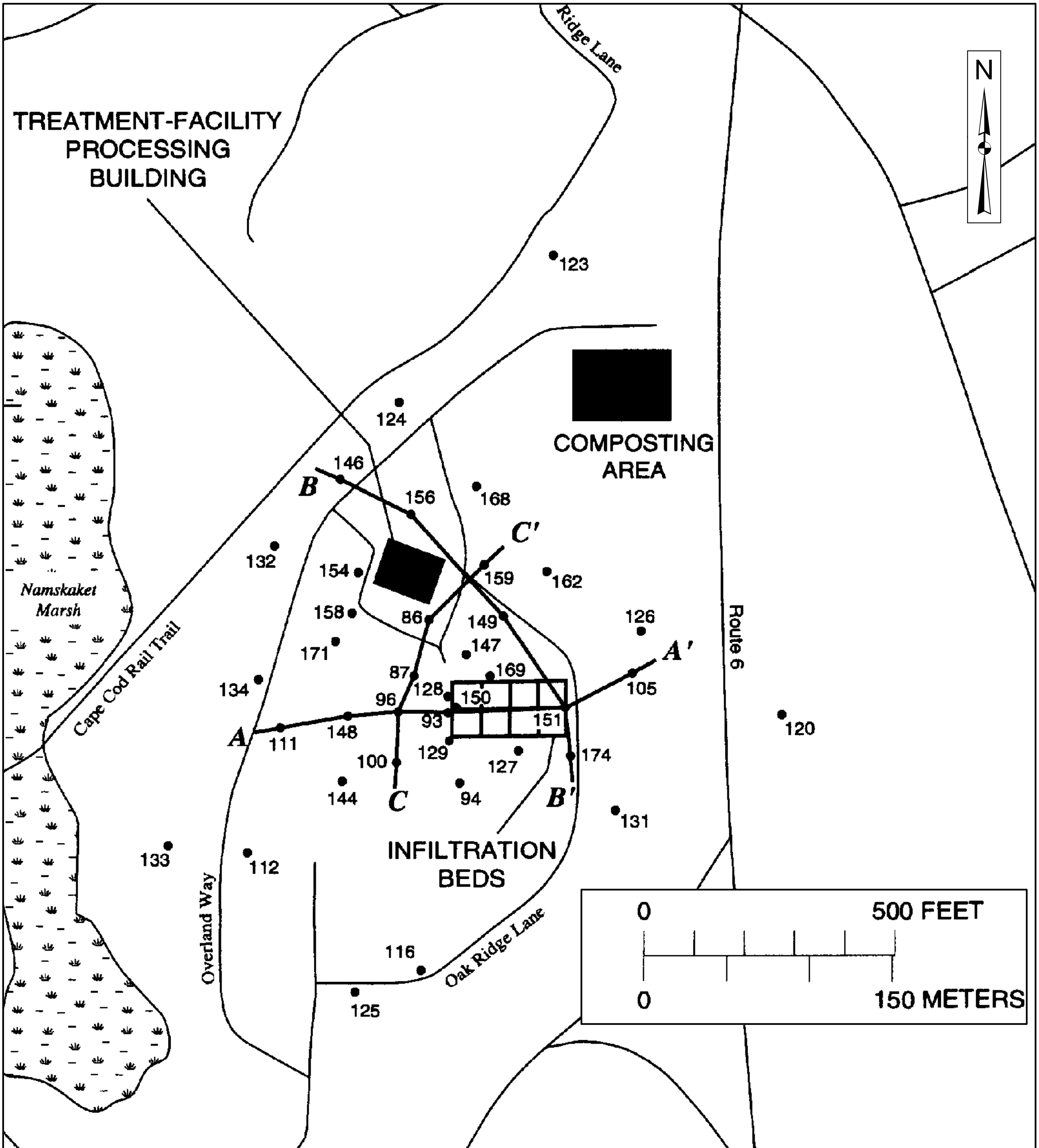
Changes were made to the hydraulic conductivity (K) values in the model in order to take into account site-specific data that were not included in the regional model and to provide a better model calibration. In most cases, the revisions have resulted in lower K values than the regional model.

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

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

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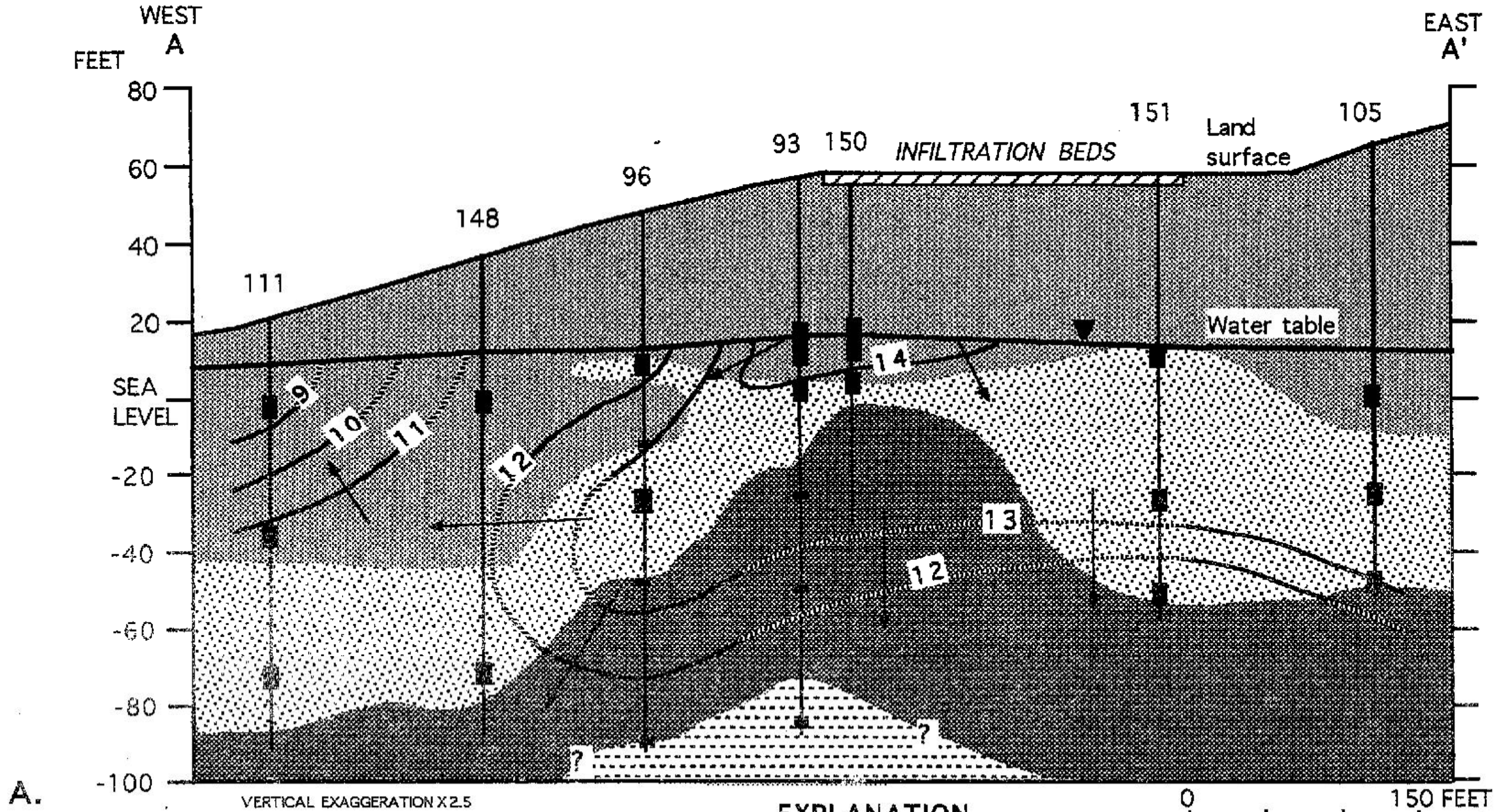

EXPLANATION

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

SOURCE: USGS Open-File Report 95-290

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Site 241
Geologic Cross Section
A-A'

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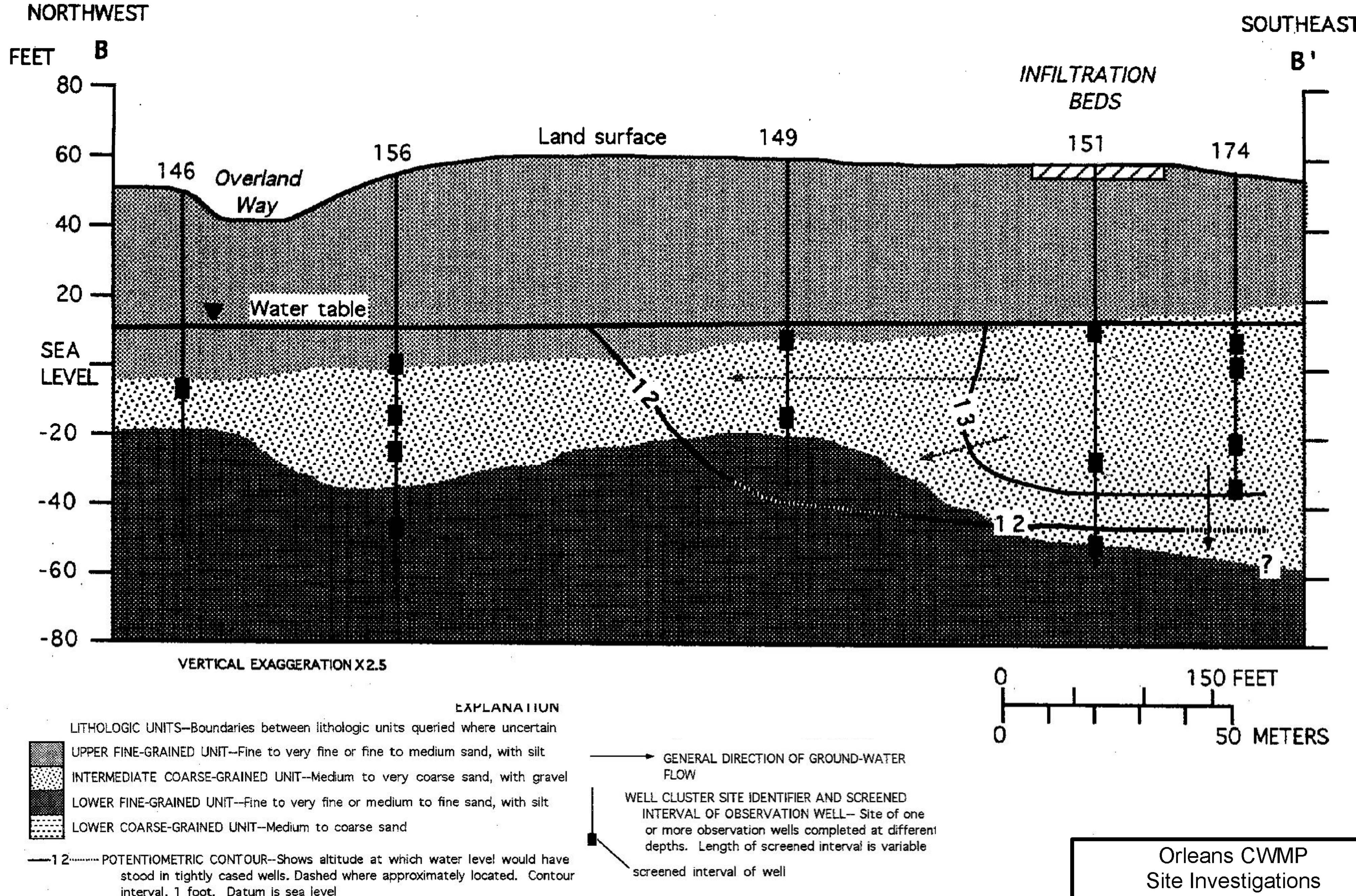

SOURCE: USGS Open-File Report 95-290

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Site Investigations
Site 241
Geologic Cross Section
B-B'

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FIGURE: 6

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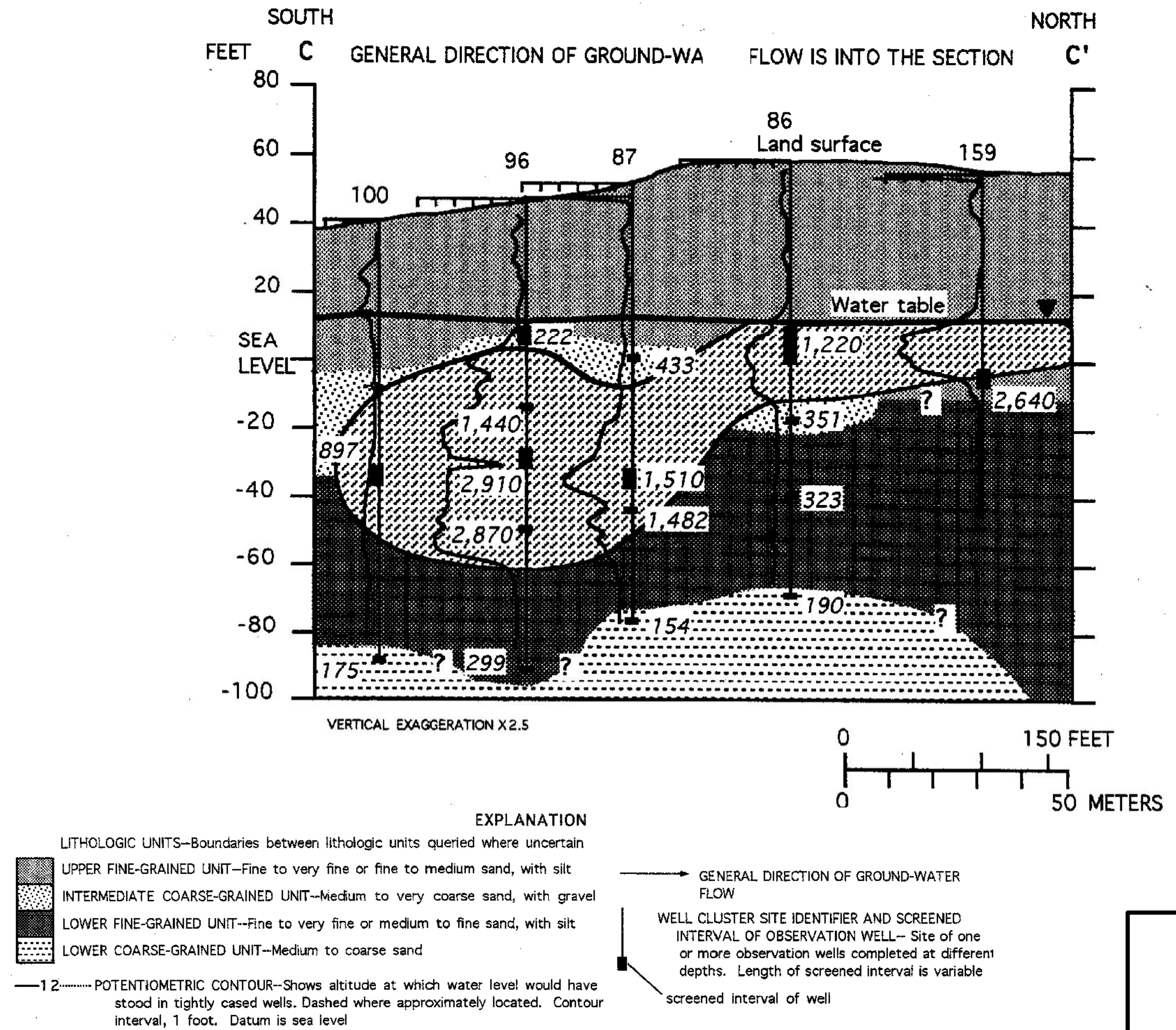

SOURCE: USGS Open-File Report 95-290

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Site Investigations
Site 241
Geologic Cross Section
C-C'

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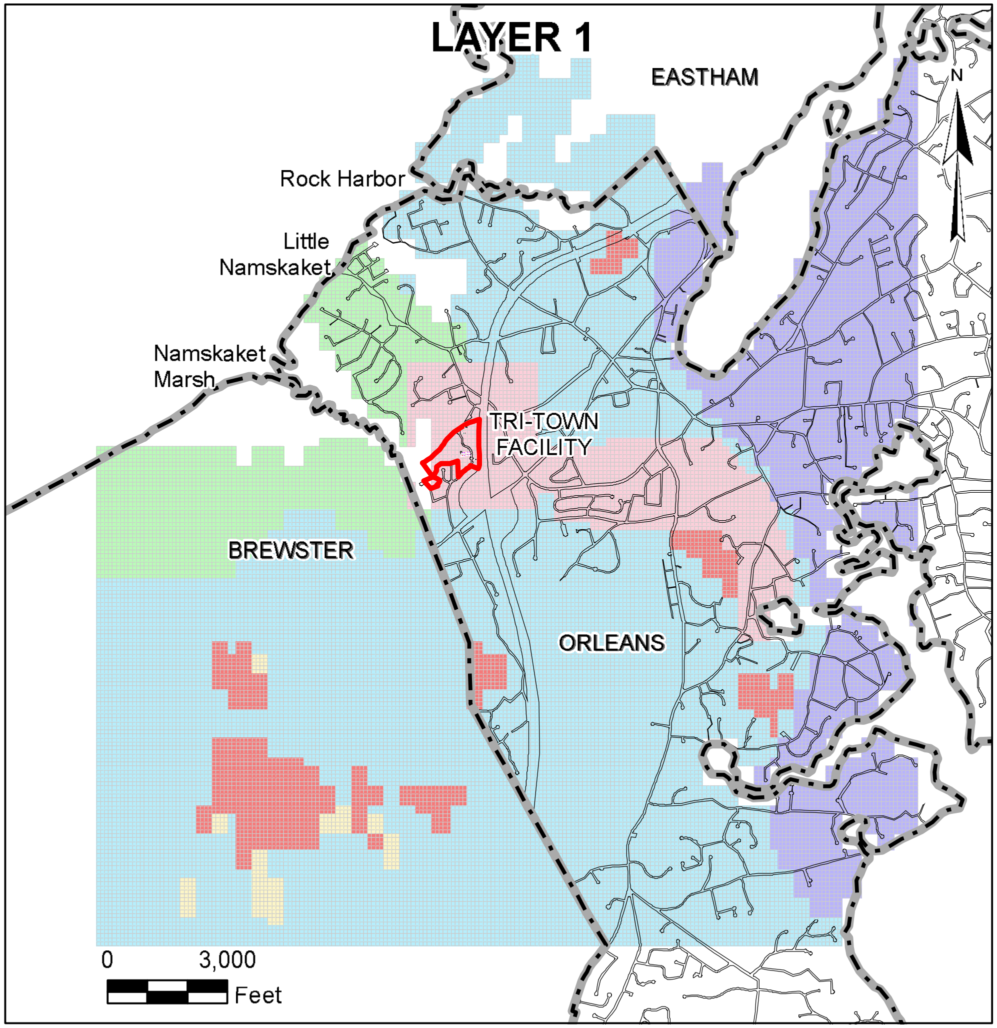
USGS files) and assumed K values that resulted in a better calibration. The final distribution of K values for the upper six layers of the Orleans Model is shown in Figures 8 through 10.

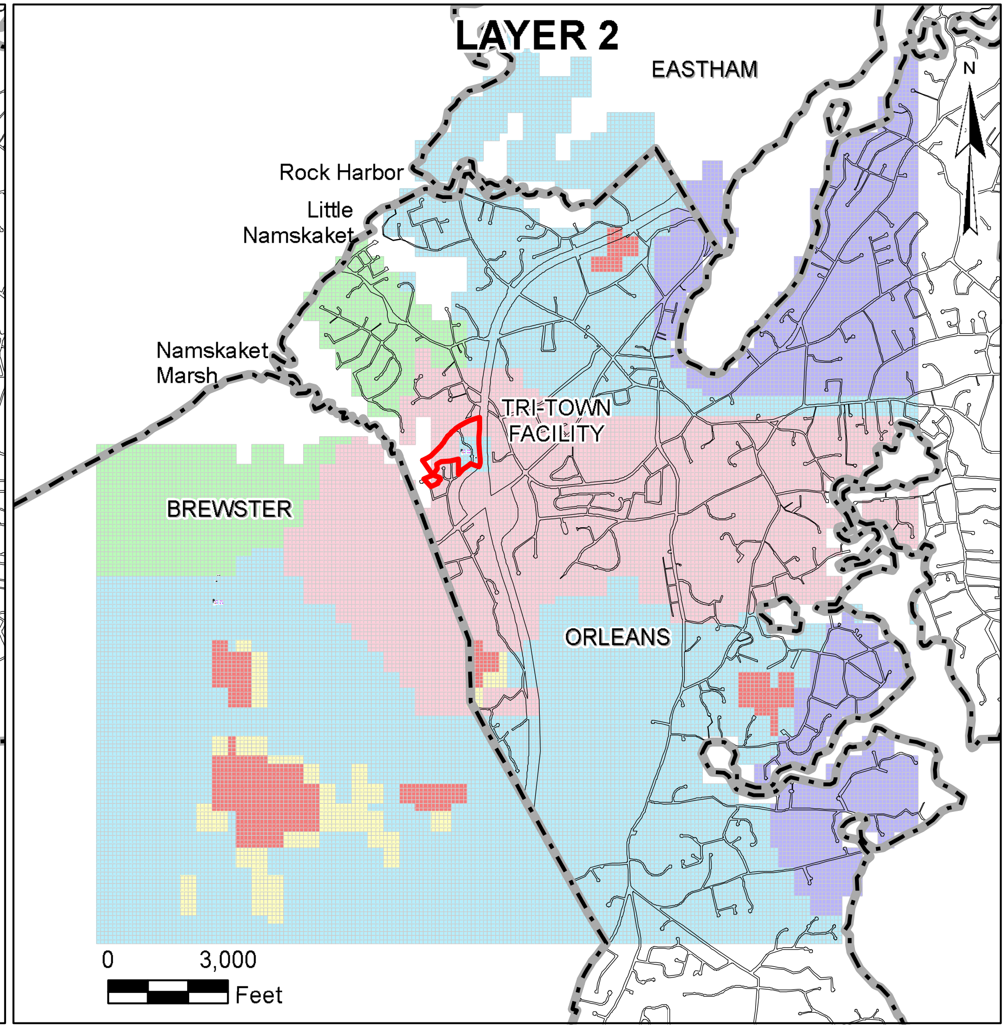
TABLE 1
SUMMARY OF MAJOR K CHANGES BETWEEN ORLEANS AND MONOMOY MODELS

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

SOURCE: Basemap Obtained from MassGIS.

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

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Site Investigations
Site 241
Hydraulic Conductivity
Layer 1 and 2

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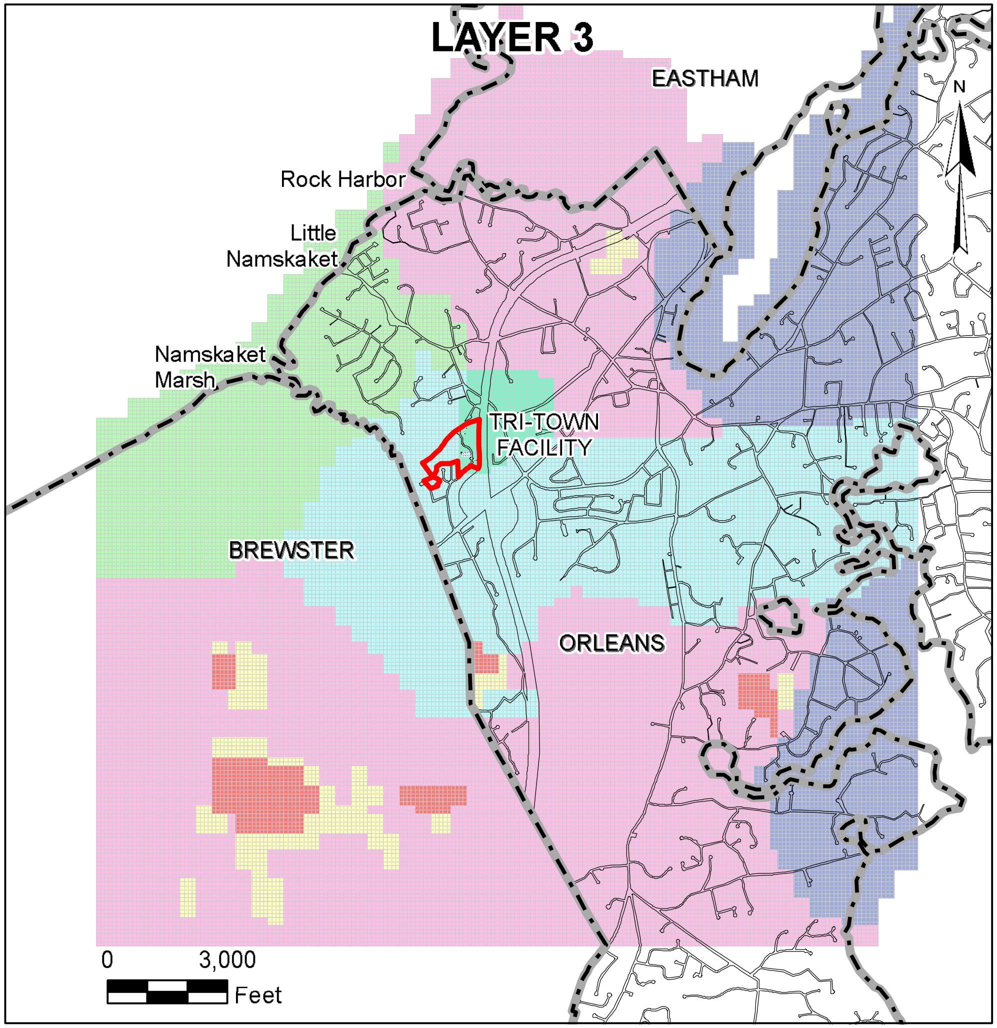

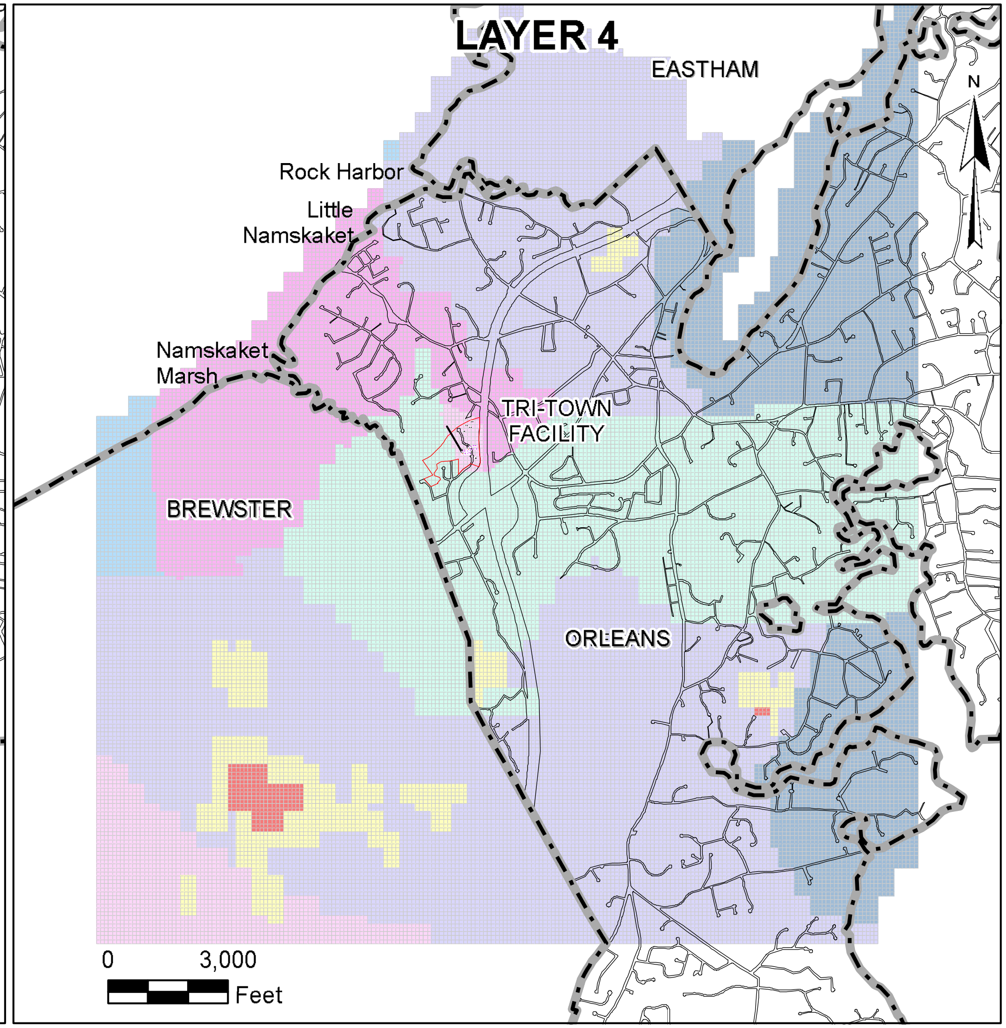

Legend

- Town Boundary
- Tri-town Property Boundary
- Roads

Hydraulic Conductivity - Layer 3

30 ft/day	140 ft/day
35 ft/day	200 ft/day
70 ft/day	290 ft/day
130 ft/day	50000 ft/day

Hydraulic Conductivity - Layer 4

30 ft/day	140 ft/day
35 ft/day	200 ft/day
70 ft/day	290 ft/day
130 ft/day	50000 ft/day

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Site 241
Hydraulic Conductivity
Layer 3 and 4

PROJ NO: 10645E | DATE: April 2008 | FIGURE: 9

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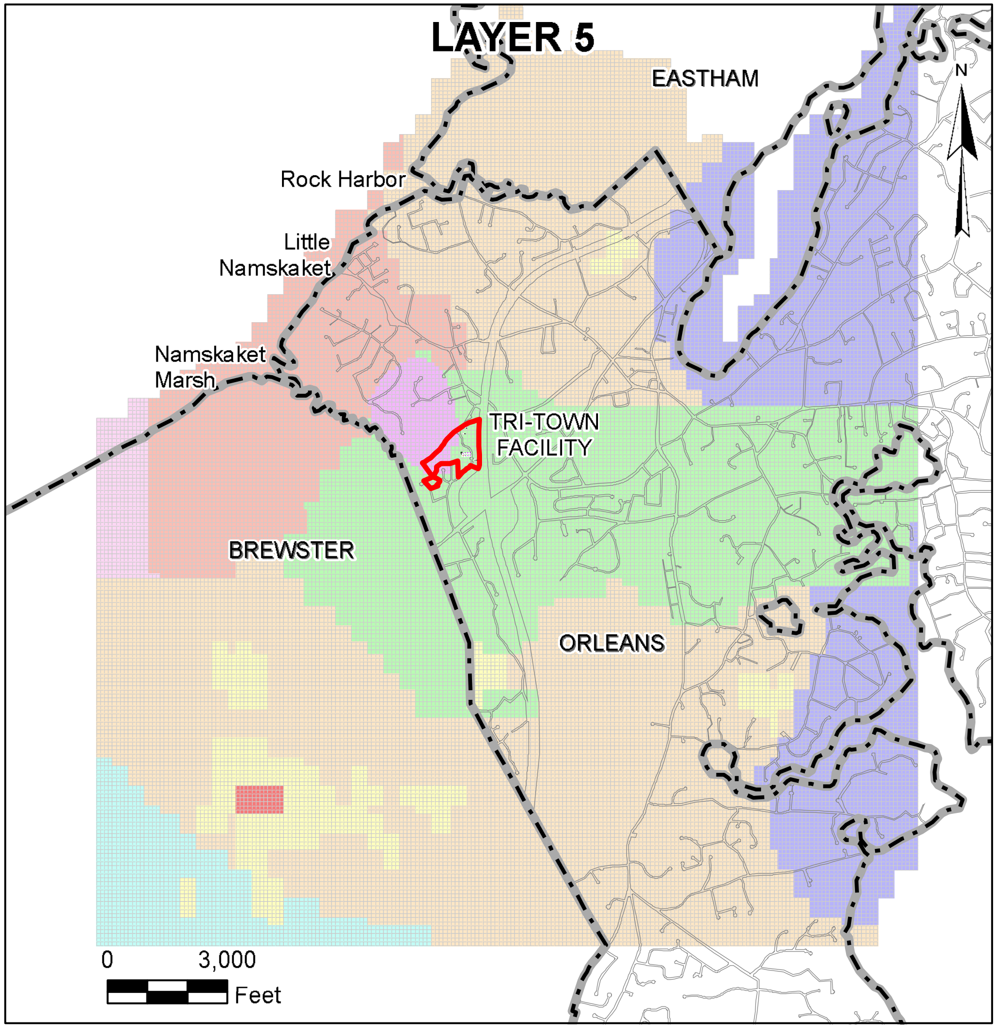

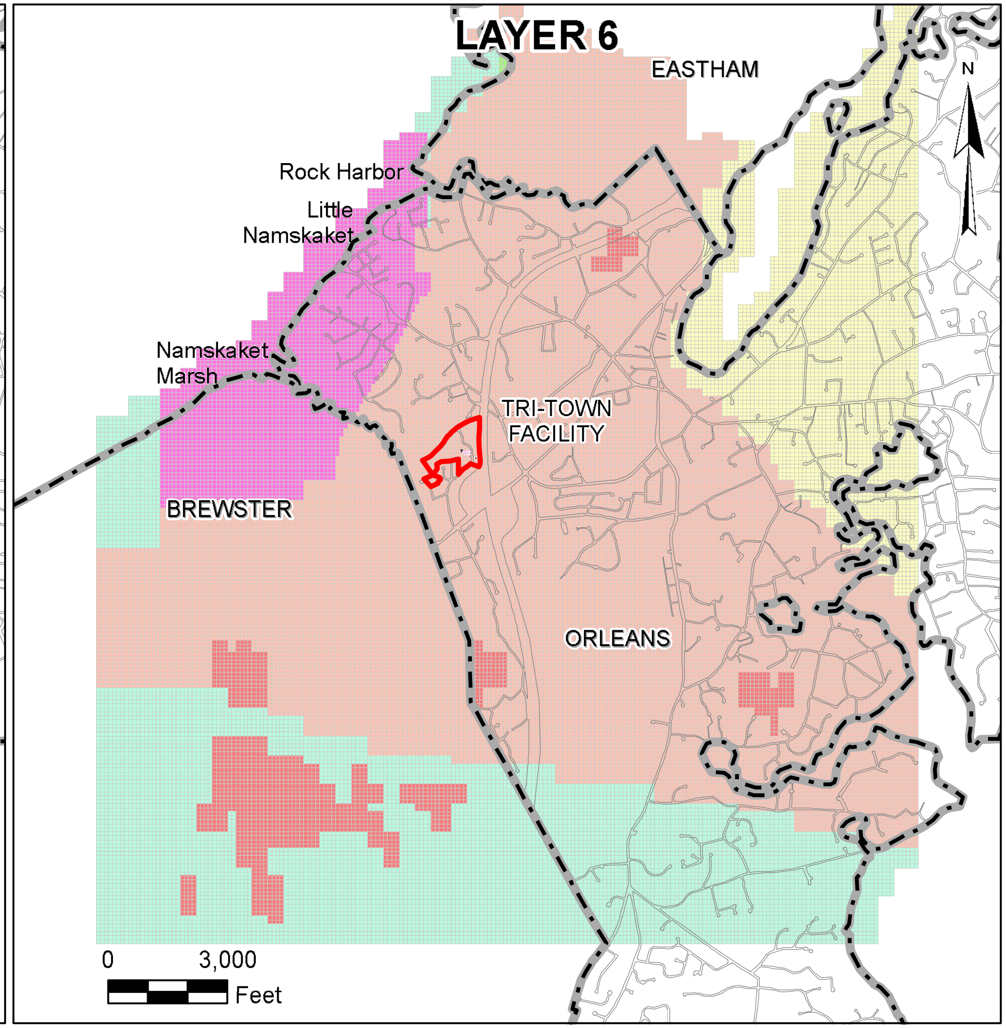

Legend

- Town Boundary
- Tri-Town Property Boundary
- Roads

SOURCE: Basemap Obtained from MassGIS.

Hydraulic Conductivity - Layer 5

- 30 ft/day
- 35 ft/day
- 70 ft/day
- 104 ft/day
- 130 ft/day
- 140 ft/day
- 150 ft/day
- 280 ft/day
- 50000 ft/day

Hydraulic Conductivity - Layer 6

- 20 ft/day
- 50 ft/day
- 100 ft/day
- 130 ft/day
- 150 ft/day
- 280 ft/day

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Site 241
Hydraulic Conductivity
Layer 5 and 6

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FIGURE: 10

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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.

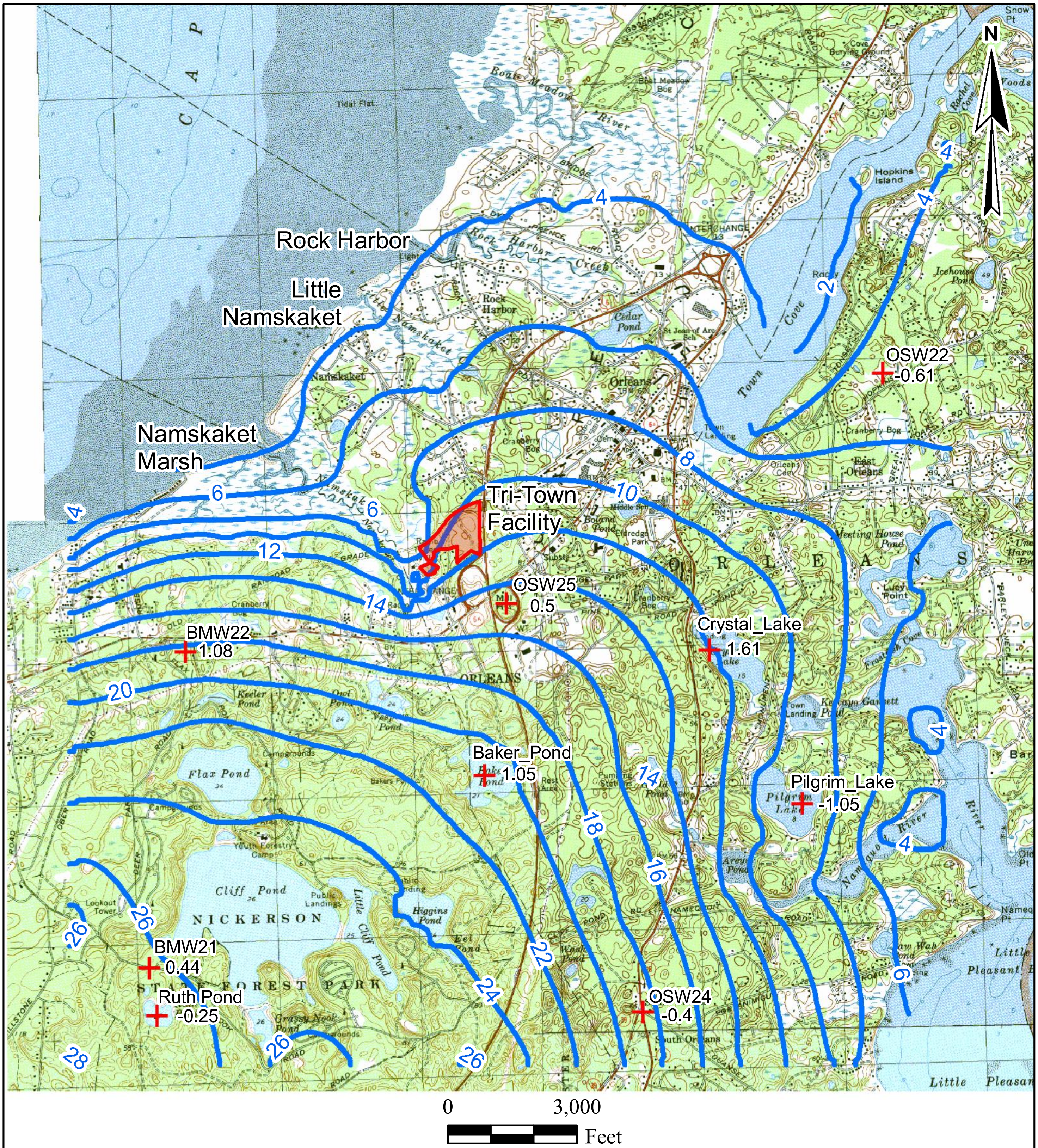
Another measure of the accuracy of a model calibration is the residual standard deviation divided by the range of head values. The residual standard deviation for the calibrated model was 0.84 ft.

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.



Legend

Tri-Town Property Boundary

Calibration Target with Residual

Steady State Groundwater Contour (ft msl)

SOURCE: USGS Quad maps obtained from MassGIS.

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Steady State Groundwater Contours and Target Residuals

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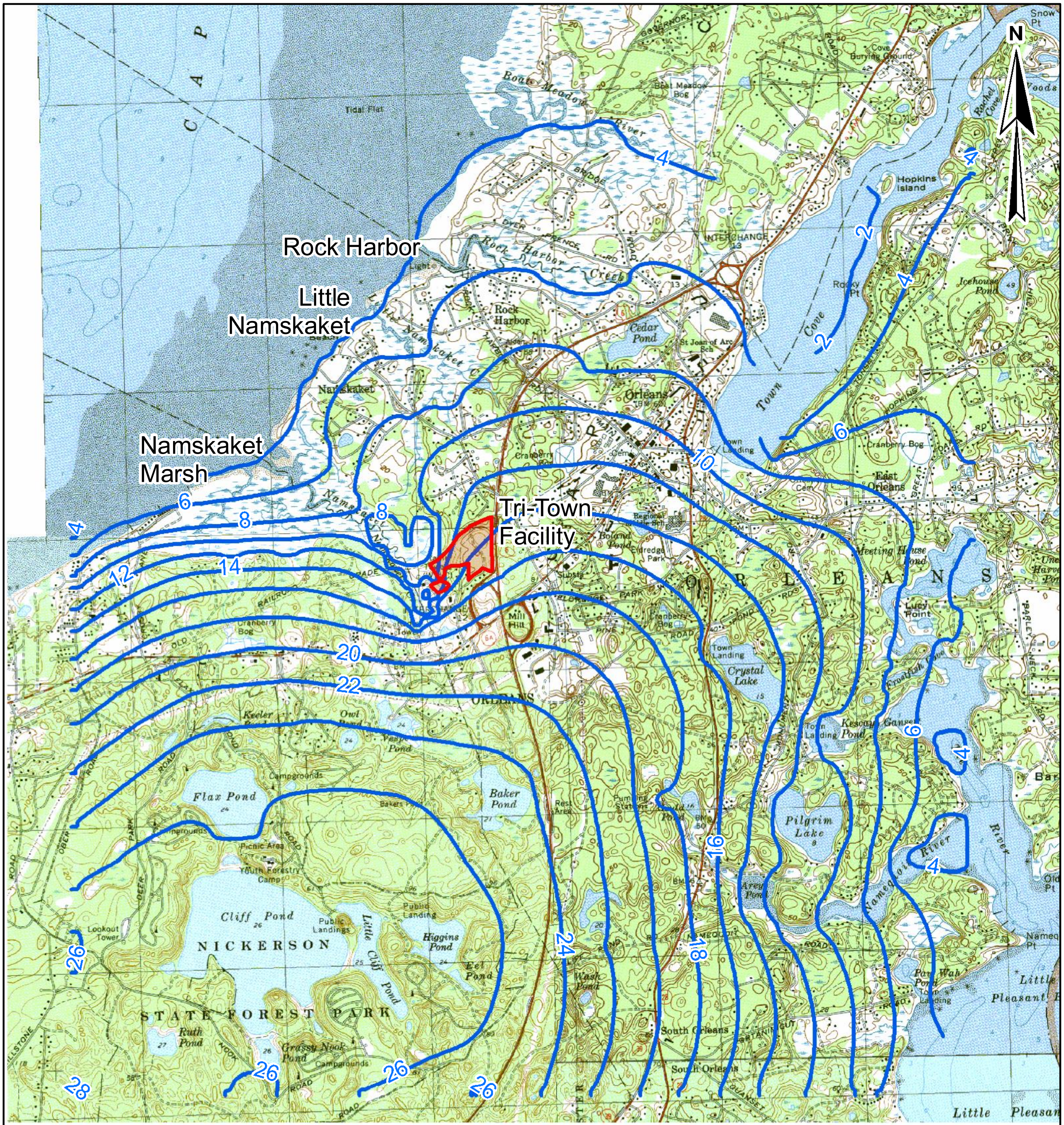
SECTION 6

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.



0 3,000 Feet

Legend

Tri-Town Property Boundary

Model Simulated High Groundwater Contour (ft msl)

SOURCE: USGS Quad maps obtained from MassGIS.

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Site 241
Model-Simulated High
Groundwater Contours

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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

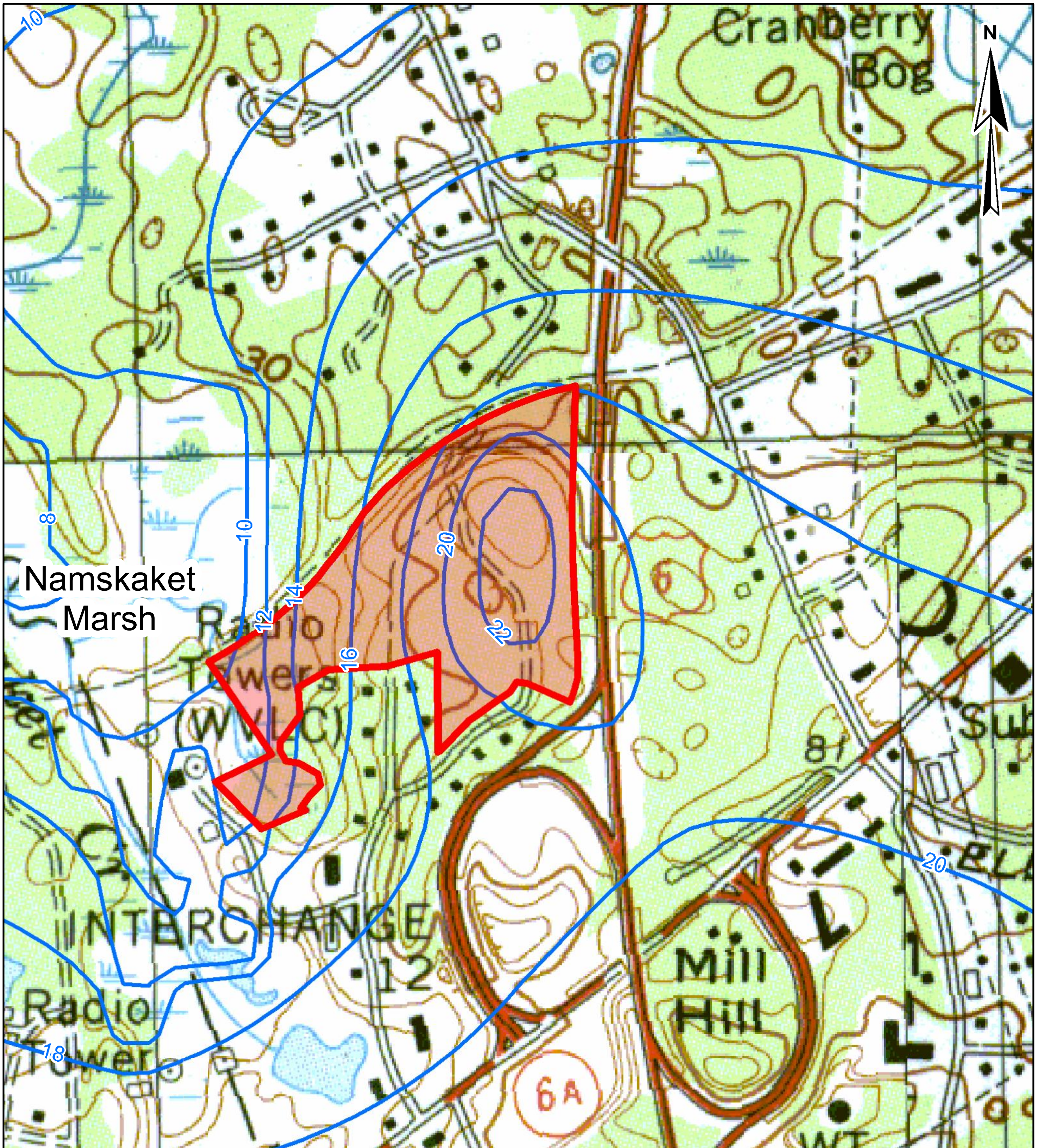
Figure 13. Under this highest discharge scenario, the simulated groundwater mounds remained greater than four feet below the bottom of the proposed discharge beds. The highest projected groundwater mound (approximately 11 feet under the maximum potential discharge rate) is at an elevation of approximately 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

0 500 Feet

SOURCE: USGS Quad maps obtained from MassGIS.

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Site 241
Model-Simulated High Mound Contours

PROJ NO: 10645E | DATE: April 2008 | FIGURE: 13

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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	Percentage of Total Discharge by Watershed			
		Namskaket	Little Namskaket	Cape Cod Bay	Rock Harbor
#	mgd	%	%	%	%
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

0 2,000 Feet

SOURCE: USGS Quad maps obtained from MassGIS.

Orleans CWMP
Site Investigations
Site 241
Particle Tracks
Scenario 2

PROJ NO: 10645E	DATE: April 2008	FIGURE: 14

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Legend

Tri-Town Property Boundary

Particle Track

0 2,000
Feet

SOURCE: USGS Quad maps obtained from MassGIS.

Orleans CWMP
Site Investigations
Site 241
Particle Tracks
Scenario 3

PROJ NO: 10645E | DATE: April 2008 | FIGURE: 15

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Legend

Tri-Town Property Boundary

Particle Track

0 2,000 Feet

SOURCE: USGS Quad maps obtained from MassGIS.

Orleans CWMP
Site Investigations
Site 241
Particle Tracks
Scenario 4

PROJ NO: 10645E	DATE: April 2008	FIGURE: 16

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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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