Environmental Partners GROUP
A partnership for engineering solutions

July 31, 2019

Mr. Robert Whritenour
Town Administrator
Town Hall
56 School Street
Oak Bluffs, MA 02557

RE: Proposed Eversource Energy Storage Site (ESS) - Technical Support Groundwater Modeling Report 8-31-2019

Dear Mr. Whritenour:

Eversource is in the process of permitting a 14.9 mw Energy Storage Site (ESS) at the Eversource Oak Bluffs Service Center, 208 Edgartown-Vineyard Haven Road (the "Site") in the Town of Oak Bluffs (the Town). Environmental Partners Group, Inc. (EP) with McLane Environmental, LLC (McLane) evaluated potential impacts to the Lagoon Pond Wellfield from a release at the proposed ESS facility. Attached is the modeling report summarizing the scope, methodology and results of the groundwater model.

Background

The ESS facility primary structure consists of a two-story building that will house the battery system; power conversion system ("PCS"); control and protection system; and other system components. The following components would be located outside the primary structure: heating, ventilation and air conditioning ("HVAC") chillers; step-up transformers; and distribution switchgear. The Eversource Information Request Responses states, "A drawback to the building approach is that in the extremely unlikely case that a significant event was to occur within the building, the event could impact all equipment located within the building." Hence, a catastrophic event at the ESS Site could impact all ancillary outside equipment associated with the ESS facility, as well as the nearby diesel generators. It is not known at this time whether Eversource will continue to maintain the onsite diesel generators and the quantity of diesel storage associated with each of the three generators.

The proposed Eversource ESS would be located approximately 1,500 feet south, and upgradient of the Town's Lagoon Pond water supply wells; and approximately 3,000 to 3,500 feet north and downgradient of the Town's State Forest and the John H. Randolph water supply wells. Subsurface geology in the area is composed of permeable interbedded sand and gravel glacial outwash deposits overlying till. Because of this lithology, there is a concern over whether a catastrophic release of oil or hazardous materials from the ESS Site could have long-term detrimental effects on the Town's water supply system.

In 2018 and 2019 EP with McLane developed a site specific hydrogeologic model for the Town's Lagoon Pond Wellfield, to evaluate potential effects to the Wellfield from climate change. The Model was constructed and calibrated using the groundwater modeling software AnAqSim, which is capable of representing groundwater flow, advective particle flow, and the freshwater-saltwater interface present in coastal aquifers. The model encompasses Martha's Vineyard with refinements and calibration focused around the Lagoon Pond wellfield.

This model was updated and refined to include the Eversource ESS site.

The model was used to evaluate (a) if groundwater from the proposed ESS facility could be captured by the Lagoon Pond wells under pumping conditions; and (b) if so, how long would it take for groundwater from the ESS site to reach the Lagoon Pond wells. Analyses were performed using three potential pumping rates as follows.

156 gallons per minute (gpm) – the current average annual pumping rate of the Wellfield;

349 gpm – the operating capacity of the Wellfield; and

552 gpm – the maximum authorized pumping rate for the Wellfield.

The model was run under steady state conditions at each pumping rate and particles were tracked forward from the ESS site until they discharged at a model boundary. The amount of time required for particles to reach model boundaries were then determined.

Results

Based on a preliminary assessment of readily available information and the results of the preliminary groundwater flow modeling, several potential environmental concerns are identified, as presented below. A catastrophic release of oil and/or hazardous materials (OHM) from the ESS Site could potentially contaminate the nearby Lagoon Pond Wellfield to the degree that the water is no longer potable.

The groundwater modeling results indicate that operation of the Lagoon Pond wellfield at higher pumping rates results in groundwater or surface water originating from the ESS site being captured by the Lagoon Pond wells. In summary,

(a) If the wellfield is pumping at its current pumping rate of 156 gpm (Figure 1), then all particle pathlines from the ESS site discharge to Lower Lagoon Pond and are not captured by the wellfield.

(b) If the wellfield is pumping at its current operating capacity of 349 gpm (Figure 2), then a few particle pathlines reach Upper Lagoon Pond in 3.5 years. Particles that discharge to Upper Lagoon Pond can then be captured by the wellfield.

(c) If the wellfield is pumping at its maximum authorized pumping rate of 552 gpm (Figure 3), then some groundwater particles from the ESS site would reach the wellfield in 5 to 6 years. In addition, particles from the ESS site are also discharged to Upper Lagoon Pond in 3 - 5 years. Particles that discharge to Upper Lagoon Pond can then be captured by the wellfield.

The groundwater flow model was developed to evaluate conditions at the Lagoon Pond wellfield. Additional subsurface hydrogeologic data is needed at the ESS Site to refine and better calibrate the model in the vicinity of the proposed ESS facility. In addition, the modeling did not consider a release from the three diesel generators, which are located closer to the area of contribution for the Lagoon Pond wellfield than the ESS Site.

The Town should determine from Eversource whether the ancillary ESS equipment stored outside the building will have secondary containment. The goal should be complete containment and pre-discharge treatment assuming worst-case conditions.

A rapid response to a catastrophic condition is important to prevent or minimize the release of oil or hazardous materials from the ESS Site to groundwater. For this reason, Eversource should identify what the anticipated response time would be should a catastrophic event occur at the ESS facility, and whether the crew is located on Martha's Vineyard. This is especially important during periods of adverse weather conditions such as due to storms or during winter when access to the island can be delayed.

We appreciate the opportunity to assist you with this important project. Feel free to contact Mark White or Ann Marie Petricca if you have any questions or comments.

Sincerely,
Environmental Partners Group, Inc.

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Attachments: *Groundwater Travel Time Analysis, Eversource ESS Site, Oak Bluffs, Massachusetts*, McLane Environmental, LLC, July 31, 2019

cc: Michael A. Goldsmith - Reynolds, Rappaport, Kaplan & Hackney, LLC

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July 31, 2019

Ms. Ann Marie Petricca, C.P.G., Project Manager
Environmental Partners Group, Inc.
1900 Crown Colony Drive, Suite 402
Quincy, MA 02169

Re: Groundwater Travel Time Analysis
Eversource ESS Site
Oak Bluffs, Massachusetts

At the request of Environmental Partners Group, Inc. (Environmental Partners), who is working on behalf of the Town of Oak Bluffs, Massachusetts (the Town or the Client), McLane Environmental, LLC (McLane Environmental) has performed modeling analyses to provide the Town with hydrogeologic information to support an evaluation potential environmental impacts associated with the proposed Eversource Energy Storage System (ESS). The proposed ESS Site is located at 208 Edgartown-Vineyard Haven Road in Oak Bluffs, Massachusetts. The proposed site, which would include an energy storage system, composed of Lithium batteries that contain $Li(NiCoMn)O_2$, would be located approximately 1,500 ft west-southwest of the Lagoon Pond Wellfield located at Barnes Rd and Head of Pond Rd in Oak Bluffs, MA.

Modeling analyses were performed using the McLane Environmental AnAqSim Model of Martha's Vineyard (the Martha's Vineyard model), which was developed for the Oak Bluffs Water and Wastewater District in January 2019 to assess potential impacts associated with climate change at the Lagoon Pond Wellfield. Current analyses included running the model under current conditions using three different pumping rates:

1) 156 gpm (226,000 gpd), the present 2015 – 2017 average daily pumping rate,
2) 349 gpm (503,000 gpd), the operating capacity of the wellfield, and
3) 552 gpm (795,000 gpd), the maximum authorized pumping rate.

The following report presents a brief overview of the Martha's Vineyard model (Section 1), as well as a discussion of the modeling analyses (and associated results) performed under the current scope (Section 2).

1. Overview of Martha's Vineyard Groundwater Flow and Saltwater Interface Model

The Lagoon Pond Wellfield is located within the Eastern Moraine of the Martha's Vineyard aquifer, which is bounded on all sides by the Ocean. The model was developed using past modeling of Oak

Bluffs and Tisbury and hydrogeologic investigations conducted to permit the Lagoon Pond Wellfield. The model was calibrated to water level targets collected as part of the 1995 Whitman and Howard modeling and utilizing hydraulic conductivities that were derived from those used by Whitman and Howard (1995) and Earth Tech (1999).

Boundary conditions around the model were defined at the present coastline based on the mean highest high water (MHHW) of 0.98 ft NAVD88 and used a constant head boundary set to the present mean tide level of -0.33 ft NAVD88. Boundaries for Upper Lagoon Pond and Lower Lagoon Pond were finely discretized to their current MHHW boundaries and set as head dependent flow boundaries using average measured water levels in two staff gauges monitored by Environmental Partners between June 2018 and November 2018 (-0.16 ft NAVD88 for Lower Lagoon Pond and 2.0 ft NAVD88 for Upper Lagoon Pond).

A recharge rate of 22.5 inches/year was applied over the Central Plain and Eastern Moraine and 11 inches/year was applied over the Western Moraine which is generally finer grained with steeper terrain and experiences more runoff.

A more detailed description of the Martha's Vineyard model is included in Appendix A.

2. Discussion of Modeling Analyses and Results

At the request of Environmental Partners, analyses were performed using the Martha's Vineyard model to determine whether the proposed ESS site lies within the Area of Contribution (AOC) of the Lagoon Pond Wellfield under the three pumping rates listed above. The model was run under steady state conditions at each pumping rate and particles were tracked forward from the ESS site until they discharged at a model boundary. The amount of time required for particles to reach model boundaries were then determined.[1] Additionally, particles were tracked backwards from the top, middle, and bottom of the screened intervals for wells P-1 through P-5 at the Lagoon Pond Wellfield (approximately -30 to -40 ft NAVD88 or 40 to 50 ft bgs) to form the capture zone for the Wellfield under each pumping scenario. Finally, arrival times were determined for particles tracked from the ESS site.

The Eversource Property is located at an elevation of approximately 80 ft NAVD88, with the water table approximately 66 ft bgs (14 ft NAVD88) on the property. Particles were released from the water table beneath the Eversource Property to evaluate pathways that contaminants potentially released at the property may follow through groundwater (both laterally and vertically) upon infiltrating through the unsaturated zone to the water table. Groundwater modeling results indicate that:

- Under the present pumping scenario of 156 gpm, the capture zone for the Lagoon Pond Wellfield does not intersect the ESS Site or the Eversource Property. **Figure 1** shows that all 221 particles released at the Eversource Property discharge to Lower Lagoon Pond after 5 – 6.5 years.
- Under the 349 gpm "wellfield operating capacity" scenario, the capture zone for the Lagoon Pond Wellfield expands slightly towards the Eversource Property but does not intersect it. **Figure 2** shows that 218 of 221 particles released from the Eversource Property at the water table

[1] Travel time analyses are for purely advective transport in the saturated zone and do not account for retardation or degradation that may occur depending on the released contaminants. Additionally, travel times do not take into account the time required for contaminants to move through the vadose zone and reach the water table at 66 ft bgs.

discharge to Lower Lagoon Pond after 5.5 – 6.5 years; the remaining 3 particles discharge to Upper Lagoon Pond in 3.5 years.

- Under the 552 gpm “maximum authorized pumping rate” scenario, the capture zone for the Lagoon Pond Wellfield overlaps the Eversource Property along the southeast portion of the site. As shown on **Figure 3,** particles released from the Eversource Property at the water table discharge to Upper Lagoon Pond (177 of 221 particles) after 3 – 5 years, and discharge to Lower Lagoon Pond (44 of 221 particles) after 6 – 6.5 years.

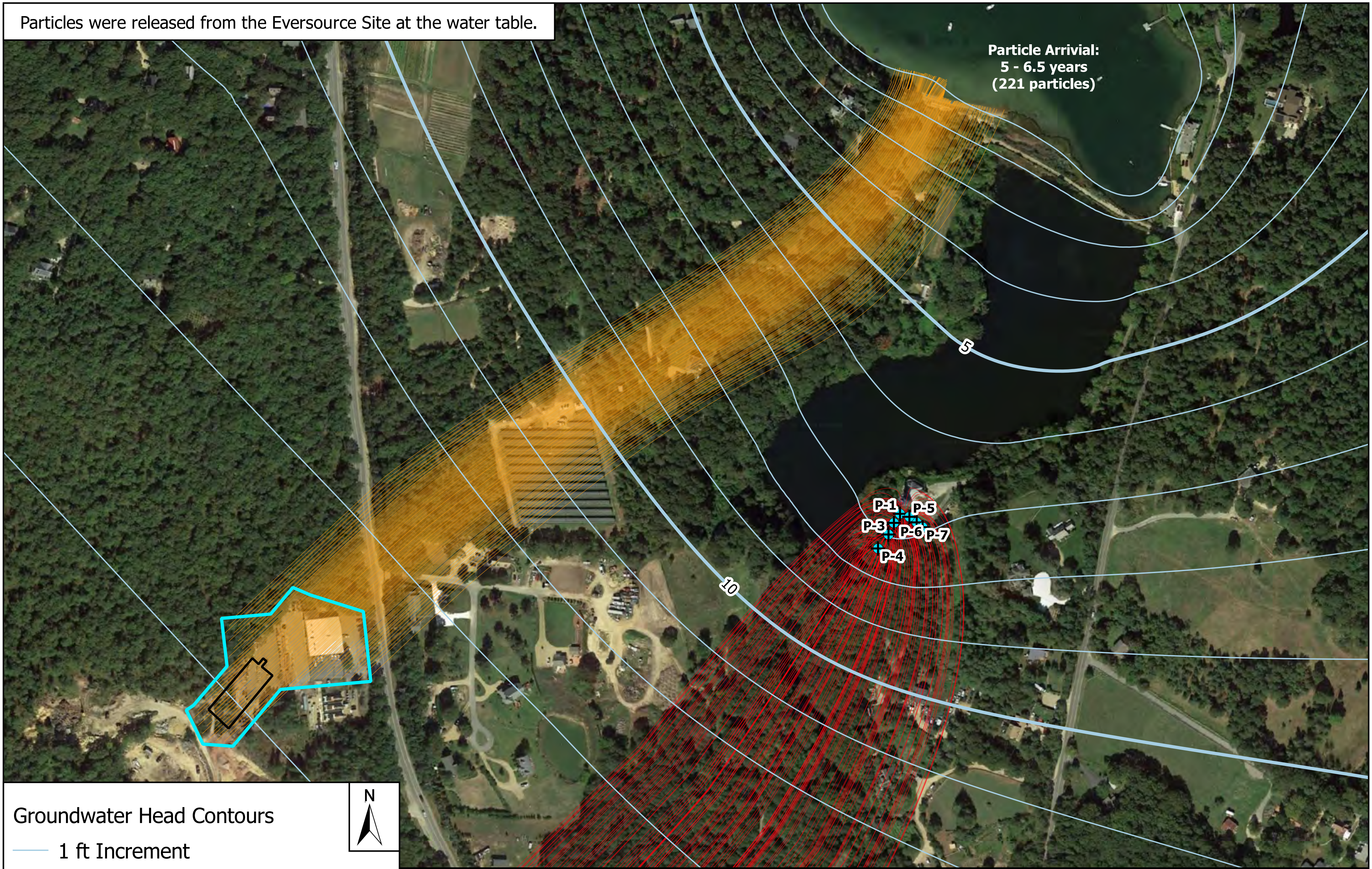
An Analysis was also performed to determine the depth of the Lagoon Pond Wellfield capture zone beneath the Eversource Property under the “maximum authorized pumping rate” scenario. Particles were released at 10-foot intervals from the water table to the clay confining unit (located at -150 ft NAVD88). The results of the analysis indicated that particles released between -80 ft NAVD88 (160 ft bgs or 94 ft below the water table) and the clay confining unit were captured by the Lagoon Pond Wellfield.

References

Earth Tech, 1999. Groundwater flow modeling in support of evaluating operations for groundwater discharge of treated wastewater in Tisbury, Massachusetts.

Whitman and Howard, 1995. A numerical groundwater flow model and Zone II delineations for the Lagoon Pond and State Forest Wells, Oak Bluffs, Massachusetts. *Oak Bluffs Water and Wastewater District.* Oak Bluffs, MA.

Figures



Groundwater Head Contours

- 1 ft Increment
- 5 ft Increment
- Lagoon Pond Wellfield Capture Zone
- Eversource Particle Traces
- ESS Facility
- Eversource Project Location
- Lagoon Pond Wells

0 250 500 750 1000 ft

Proposed Eversource Facility Particle Traces
Lagoon Pond Wellfield Pumping Rate: 156 gpm

Source: Google Aerial Imagry; TRC

Figure 1

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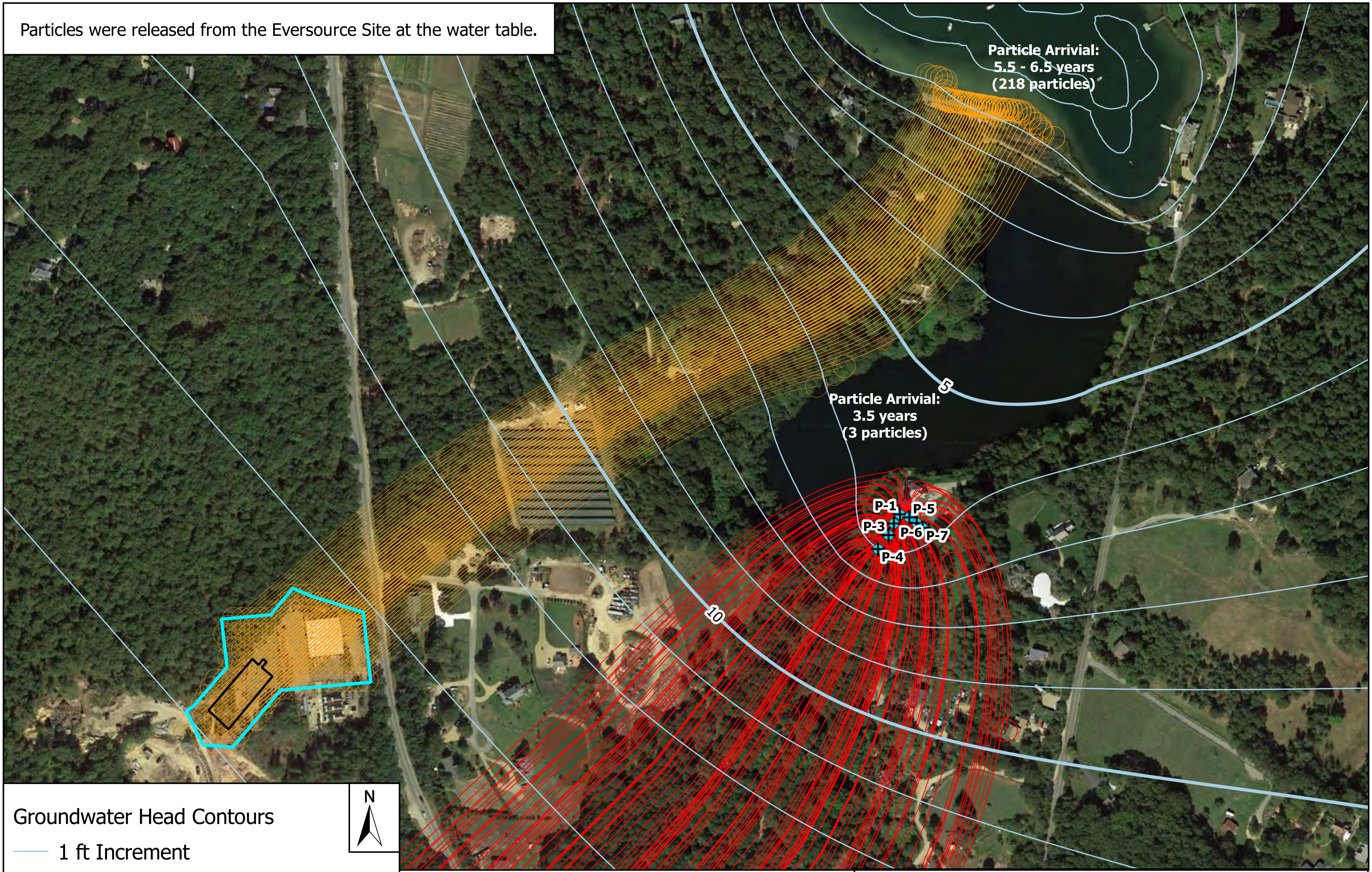
Oak Bluffs, MA

Date
5/23/2019



Proposed Eversource Facility Particle Traces
Lagoon Pond Wellfield Pumping Rate: 349 gpm

Source: Google Aerial Imagry; TRC

Oak Bluffs, MA

Figure 2

Date
5/23/2019

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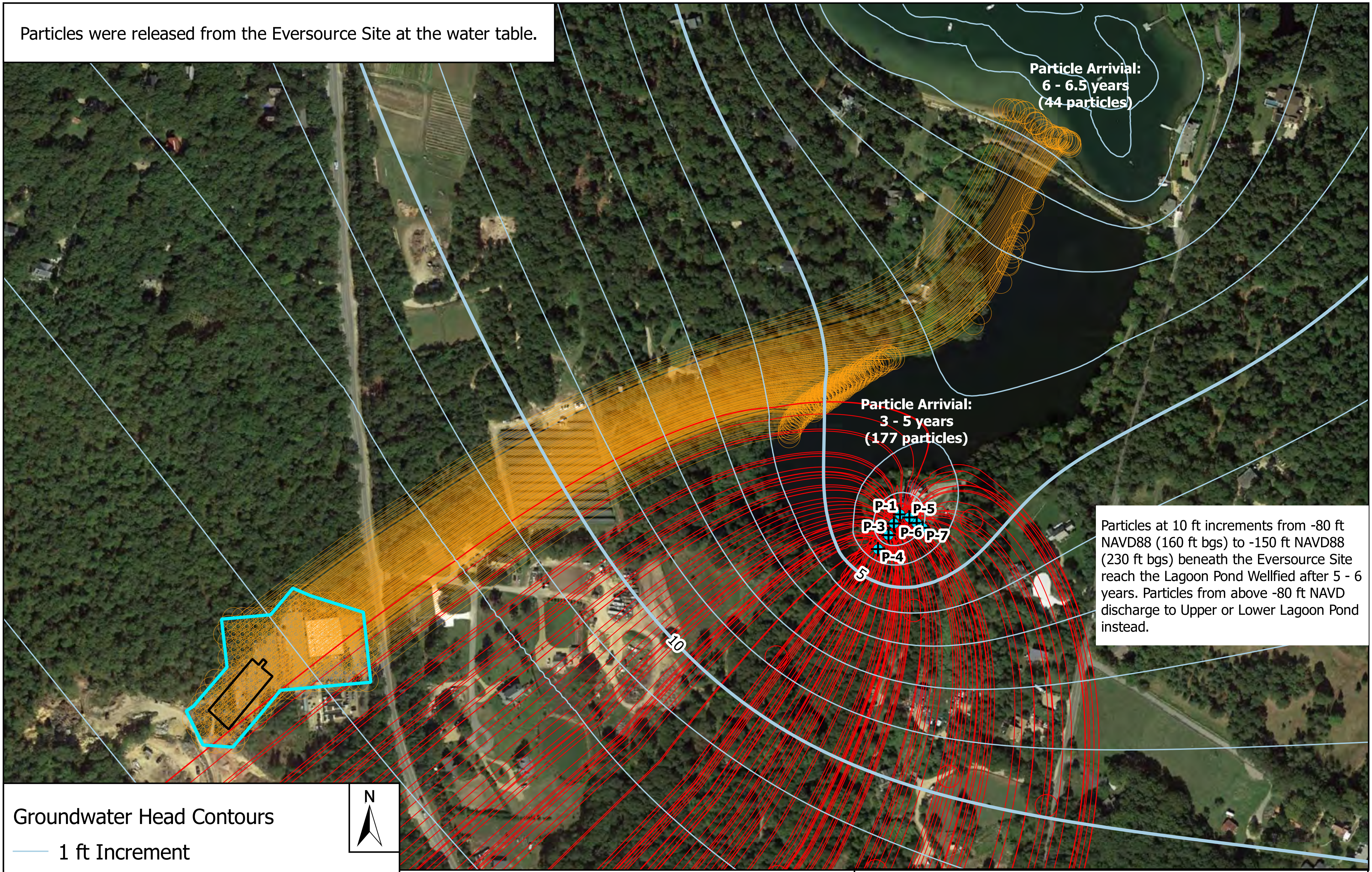

Groundwater Head Contours

- 1 ft Increment
- 5 ft Increment
- Lagoon Pond Wellfield Capture Zone
- Eversource Particle Traces
- ESS Facility
- Eversource Project Location
- Lagoon Pond Wells

Proposed Eversource Facility Particle Traces
Lagoon Pond Wellfield Pumping Rate: 552 gpm

Source: Google Aerial Imagry; TRC

Figure 3

Oak Bluffs, MA

Date
5/23/2019

McLane Environmental LLC
Consulting Scientists & Engineers

APPENDIX A

Overview of Martha’s Vineyard Model

Table of Contents

1 INTRODUCTION

At the request of Environmental Partners, who is working on behalf of the Town of Oak Bluffs, Massachusetts (the Town), McLane Environmental, LLC (McLane Environmental) developed a groundwater model to evaluate potential impacts related to climate change at the Lagoon Ponds Wellfield site (the Site), located along Barnes Road in Oak Bluffs, Massachusetts. The Site, which is operated by the Oak Bluffs Water District, includes five public water supply wells (designated as P-1 through P-5) located adjacent to the freshwater Upper Lagoon Pond and about 1,000 feet to the south of the saline Upper Lagoon Pond.

The Model was constructed and calibrated using the groundwater modeling software AnAqSim, which is capable of representing groundwater flow, advective particle flow, and the freshwater-saltwater interface present in coastal aquifers. The model encompasses Martha's Vineyard with refinements and calibration focused around the Lagoon Ponds Wellfield

The following report presents a brief description of the model development and calibration.

2 MODEL DEVELOPMENT

Geology, field measurements, and past modeling study reports were used to construct and calibrate a groundwater flow and saltwater interface model for the island of Martha's Vineyard (excluding Chappaquiddick Island and Aquinnah). The model was constructed using AnAqSim (*Fitts*, 2010), a groundwater flow modeling software based on an analytic element approach that places a boundary with specified conditions around a model area of user-specified hydrogeologic and hydraulic properties, and represents hydraulic features (e.g. pumping wells and surface water bodies) within that bounded model area using individual point and line geometric elements. The AnAqSim software is also capable of analyzing fresh-saltwater aquifer interface flow in coastal aquifers (*Fitts et al.,* 2015); such as the aquifer system present beneath the Site.

Sections 2.1 through 2.6 below provide a brief overview of the Site (including a discussion of site geology and hydrogeology); a discussion of previous modeling studies performed for Martha's Vineyard; an overview of data utilized to construct the groundwater flow and saltwater interface model; and a discussion of model calibration.

2.1 Site Description

The Lagoon Ponds Wellfield site is located on a 6.6 acre parcel along Barnes Road near the southeastern shoreline of Upper Lagoon Pond in the town of Oak Bluffs, Martha's Vineyard, MA (***Figure 2.1***). The Oak Bluffs Water District operates five public water supply wells at the Site, designated as P-1 through P-5. Four of these wells (Wells P-1 to P-4) are spaced approximately 30 feet apart in a generally southwest-northeast line along the southern shore of Upper Lagoon Pond, with Well P-5 offset to the southeast of Well P-1. Wells P-1 to P-5 are screened from approximately 40-50 ft below ground surface (ft bgs). Two additional deep wells (Wells P-6 and P-7) are located adjacent to Well P-5 but are no longer utilized because of high iron content. The Site is bounded on the north and west by the freshwater Upper Lagoon Pond, which is separated from the saltwater Lagoon Pond by a dike located 1000 feet north of the wellfield. Another salt water pond, Sengekontacket Pond, is located approximately 2 miles to the east of the Site.

2.2 Geology and Hydrogeology of Martha's Vineyard

2.2.1 Geology

The geology of Martha's Vineyard is generally composed of three principal landforms; the central plain, western moraine, and eastern moraine (Delaney, 1980). The central plain is composed of interbedded sand and gravel outwash deposited by glacial meltwater and is located on the south-central portions of the island (***Figure 2.2***). The western moraine is composed of till and older fine grained marine sediments that were thrust upward by glacial advance (***Figure 2.2***). The western moraine is at a higher topography with greater relief than the western island and has a lower permeability; consequently, it is the only portion of the island that can support perennial streams. The eastern moraine is more similar to the central plain with higher permeability materials overlying interbedded till and sand (***Figure 2.2***). Whitman and Howard (1995) note that the eastern moraine is more consistent with an area very near the ice of the retreating glacier where outwash sediments collapsed and flow till materials were deposited.

2.2.2 Hydrogeology

All fresh groundwater on Martha's Vineyard is a result of precipitation which infiltrates through the upper sandy soils to the water table. Consequently, freshwater beneath Martha's Vineyard can be conceptualized as a bowl-shaped lens with the thickest portion occurring towards the center of the island and decreasing to roughly zero thickness at the coast. The bottom of the "bowl" is compressed or flattened somewhat because the uppermost freshwater zone overlies a thick low-permeability clayey layer.

Delaney (1980) notes that "[m]ost ground-water circulation takes place in permeable Pleistocene deposits above 160 feet below NGVD of 1929." Whitman and Howard (1995) identified a silty and clayey layer between 120 and 160 feet below ground surface that corresponds with the bottom of the aquifer system defined by Delaney (1980). These materials act as an aquiclude separating flow above and below this depth interval. Further, this clay and silt unit has defined the bottom of all modeling studies performed to date.

2.3 Previous Modeling Studies

Since the mid-1990s, there have been several modeling studies conducted on Martha's Vineyard using MODFLOW, a numerical groundwater flow model developed by the USGS. These studies were conducted to support Zone II delineations, wastewater disposal site analyses, and nitrogen loading analyses to Lake Tashmoo and Lagoon Pond. The following is a brief summary of each of these modeling efforts.

2.3.1 1995 Whitman and Howard Model

Whitman and Howard developed a numerical groundwater model using MODFLOW in 1995 which covered an area of approximately 68 square miles, including the town of Oak Bluffs and portions of West Tisbury, Tisbury, and Edgartown. The model was developed to support Zone II delineations for the three public water supply wells operated by the Oak Bluffs Water and Wastewater District. The Whitman and Howard model used constant head boundaries to represent the ocean; drain boundaries to represent Lake Tashmoo, Lagoon Pond, and Sengekontacket Pond; and no flow boundaries along the edge of the western moraine. The Whitman and Howard modeling report presents the hydraulic properties that were utilized in each layer of the model (e.g. hydraulic conductivity, specific yield, and recharge), as well as the seasonally averaged water levels that were used for model calibration. The model developed by Whitman and Howard did not include, and was not designed to evaluate, the movement of the fresh-saltwater interface.

2.3.2 1999 Earth Tech Model

In 1999, Earth Tech (formerly Whitman and Howard) updated the MODFLOW model originally developed in 1995 to support site evaluation for wastewater disposal in the town of Tisbury. The original model was refined around Tisbury and recalibrated to additional measurements collected to support the evaluation of wastewater disposal. Following recalibration of the model, particle tracking analyses were performed using PATH-3D to illustrate groundwater movement (and contaminant movement) from proposed wastewater disposal sites. As with the 1995 Whitman and Howard model, the updated model developed by Earth Tech was not designed to evaluate the movement of the fresh-saltwater interface.

2.3.3 2009 Wright-Pierce Model

In 2009, Wright-Pierce developed a smaller, but more finely discretized, MODFLOW model based on the prior 1999 Earth Tech Model. The Wright-Pierce Model encompassed Tisbury, a small area of Oak Bluffs west of Lagoon Pond, and a small area of West Tisbury. In this investigation, MODPATH was used to perform the particle tracking to illustrate pathways of groundwater movement. As part of the modeling effort, Wright-Pierce changed the boundary conditions for Lake Tashmoo and Lagoon Pond from drain boundaries to constant head boundaries. These two boundary conditions are similar when the constant head boundary is set lower than computed water table so that groundwater only exits the model through the boundary; however, the constant head boundary does not allow for pond bed resistance to be specified and may allow water to move into and out of the model more freely. As with the 1995 Whitman and Howard model and 1999 Earth Tech model, the model developed by Wright-Pierce was not designed to evaluate the movement of the fresh-saltwater interface.

2.3.4 2010 Massachusetts Estuaries Project Model

As part of the Massachusetts Estuaries Project, The School for Marine Science and Technology (SMAST) at the University of Massachusetts Dartmouth updated and refined the model grid of the original Whitman and Howard MODFLOW model to conform to updated orthophotographs of Martha’s Vineyard. As part of this modeling effort, SMAST increased the precipitation recharge to the aquifer from 22.5 inches per year (in/yr) used in the Whitman and Howard model to 28.7 in/yr. Although there is little documentation regarding the 2010 SMAST model, available information indicates that the model was not designed to evaluate the movement of the fresh-saltwater interface.

2.4 Groundwater Flow and Saltwater Interface Model Construction

Using available geologic and hydrogeologic reports and data, along with information compiled from previous modeling studies, a groundwater flow and saltwater interface model was constructed using AnAqSim. A discussion of model development activities is included below.

2.4.1 Delineation of Model Domain

To facilitate model construction, an aerial image and island outline were prepared and brought into AnAqSim as a base map to assist in the creation of the modeled domain. The island outline was based on the 2013-2014 Sandy LiDAR data contoured to the mean highest high water (MHHW) mark of 0.976 ft NAVD88. In modeled areas further from the Site, such as Tisbury Great Pond, the outline was less refined to conserve computational effort during model runs. The domain outline also excludes Chappaquiddick Island and Aquinnah since these two landmasses are largely separated from the main island by water, and as such, are expected to have separate shallow aquifer systems. The modeled domain used for the groundwater flow and saltwater interface model is shown in ***Figure 2.3***.

2.4.2 Pond Water Levels

Two of the key features controlling hydraulic heads and the location of the fresh-saltwater interface at the Site are the Upper and Lower Lagoon Ponds and their respective water level elevations. Water elevation in Upper Lagoon Pond (retained behind the earthen dike) is currently approximately 2 feet greater than Lower Lagoon Pond. The greater freshwater elevation in the upper pond tends to press downward and outward on the saltwater interface (in accordance with the Ghyben-Herzberg Relationship[1]); while beneath the lower pond the saltwater interface can encroach into the aquifer. Representing these pond water levels is important for the saltwater interface analyses using AnAqSim.

To ensure that accurate data were available for model development, Environmental Partners installed staff gauges in Upper Lagoon Pond and Lower Lagoon Pond in June 2018 (***Figure 2.4***). The gauges were continuously monitored from June 6, 2018 to November 1, 2018. As shown in ***Figure 2.5***, the average gauge measurement in Upper Lagoon Pond was 2.086 ft NAVD88 during this period, and the average gauge measurement in Lower Lagoon Pond was -0.161 ft NAVD88. Since it is tidally controlled, Lower Lagoon Pond exhibited a higher degree of variability in water level elevations, whereas the water level in Upper Lagoon Pond, which is primarily controlled by a weir located at its northeast corner as part of a fish ladder, shows a much lower degree of variability.

[1] The Ghyben-Herzberg Relationship is an analytical relationship between the freshwater head in a coastal aquifer and the depth from sea level to the fresh-saltwater interface. The relationship is defined as $z = \frac{\rho_f}{(\rho_s - \rho_f)} h$, where z is the depth of the fresh-saltwater interface relative to sea level, ρ_f is the density of freshwater, ρ_s is the density of saltwater, and h is the freshwater head above sea level. This works out to every foot of freshwater head in the aquifer above sea level equating to approximately 40 feet of freshwater beneath sea level before encountering the fresh-saltwater interface.

Based on data collected by Environmental Partners, pond water levels in the model were set at 2 ft and 0 ft NAVD88 respectively for Upper Lagoon Pond and Lower Lagoon Pond. These constant values were used to represent the average water levels in the two ponds so that a steady state long-term average model could be developed and calibrated.

2.4.3 Step-Wise Model Development

The model was developed in a step-wise manner once the model domain was established and pond water levels were determined. Complexity was gradually added to ensure model stability and convergence, and to assess the influence of each newly added model feature (e.g., salt water ponds) on the flow field. Initially, the model was set up as a uniform homogeneous aquifer system that encompassed the entire island and did not include any of the salt water ponds. Gradually, geologic and hydrologic features were incorporated into the model until the final calibration model was produced that incorporated the three distinct geologic regions of Martha's Vineyard, major salt water ponds, and multiple domain layers near the Site (***Figure 2.3***).

Initial values for the hydraulic conductivities used in the model were based on the 1995 Whitman and Howard model and the 1999 Earth Tech model, as were the recharge values used for the eastern moraine and central plain. The recharge value for the western moraine was set to a lower value to account for greater runoff caused by large variability in topography and less permeable surficial geology.

2.5 Model Calibration

To facilitate model calibration, water level targets from Table 4-2 of the 1995 Whitman and Howard modeling report were converted from NGVD 27 to NAVD 88 and stored in the AnAqSim model file so that comparisons between model-calculated water elevations and these target values could be made. These targets, presented in ***Table 2.1***, represent long-term average water level elevations and cover a large area of Martha's Vineyard, including the area surrounding the Site.

Model parameters representing each modeled domain's hydraulic conductivity were adjusted within the range of reported values. Additionally, the pond bed hydraulic conductivity (which controls flow into and out of Upper Lagoon Pond and Lower Lagoon Pond) was also adjusted during model calibration. Finally, the geometry of the area around the Lagoon Ponds was adjusted slightly to facilitate model calibration. Calibration of the model was performed manually, and using the USGS parameter optimization software PEST. As shown in ***Table 2.2***, manually calibrated values compared favorably to the PEST calibrated values. For the purposes of this analysis, the manually calibrated parameter values were utilized, as they more closely matched observed hydrogeologic conditions presented in available reports and data.

The results of model calibration were assessed using the root mean squared error (RMSE) of the modeled residuals. The RMSE is an assessment tool that squares the difference between the modeled value and observed value (the residual), calculates the mean of the squared residuals, and returns the square root of that mean. This method provides a better estimate of how well the model is performing than simply taking the mean residual because negative and positive values are first squared, and consequently large negative and positive values do not negate each other as they would when calculating the mean.

The final calibrated RMSE for the long-term average AnAqSim model was 0.88 ft, with the largest residual being 1.69 ft and the smallest residual being -2.04 ft. The hydraulic head contours and observed residuals at each target location in the calibrated model are shown in ***Figure 2.6***. Positive (maroon) residual numbers in the figure indicate that the modeled water level is higher than the observed water level, and negative (green) residual numbers indicate the modeled water level is lower than the observed water level. The model RMSE of 0.88 ft, when compared with the groundwater elevation changes in the area of interest, represents an error of approximately 4 percent; indicating a well-calibrated model.

Figures 2.7a-c show the hydraulic conductivity values utilized in the calibrated model. The majority of Martha's Vineyard is modeled as a single layer with hydraulic conductivity vertically averaged over the entire domain thickness, with the exception of areas immediately around Upper and Lower Lagoon Ponds, which have two layers, and the area immediately surrounding the Lagoon Pond wells, which is comprised of nine layers. The use of nine layers in the vicinity of the wells is necessary to get accurate resolution of any potential movement of the salt water interface towards the well screens.

The bed conductance of the both Upper and Lower Lagoon Pond were important parameters to calibrate the model near the Lagoon Pond Wellfield. As shown in ***Figure 2.7c***, adjustments to this parameter during model calibration resulted in a bed conductance of 0.1 ft/d for Upper Lagoon Pond, and a value of 9 ft/d for the Lower Lagoon Pond. The difference in these two values is likely attributed to sediments that make up the pond bottoms and their respective depositional environments. Specifically, Upper Lagoon Pond is expected to exhibit lower water velocities than Lower Lagoon Pond because the dike and weir system separating the two water bodies creates a nearly constant water level in Upper Lagoon Pond that is not affected by tidal action; thereby allowing small particles suspended in the water column to be deposited on the pond bottom. The continued deposition of these small particles effectively reduces the hydraulic conductivity of the pond bed by clogging pores and forming a layer of silt and decomposing biologic material. In contrast, Lower Lagoon Pond is tidally flushed, which increases the velocity along the pond bottom and scours away some fine particles and organic debris. The continued flushing and higher water velocity in Lower Lagoon Pond is expected to maintain a higher pond bed conductance than Upper Lagoon Pond.

3 REFERENCES

Earth Tech, 1999. Groundwater flow modeling in support of evaluating operations for groundwater discharge of treated wastewater in Tisbury, Massachusetts.

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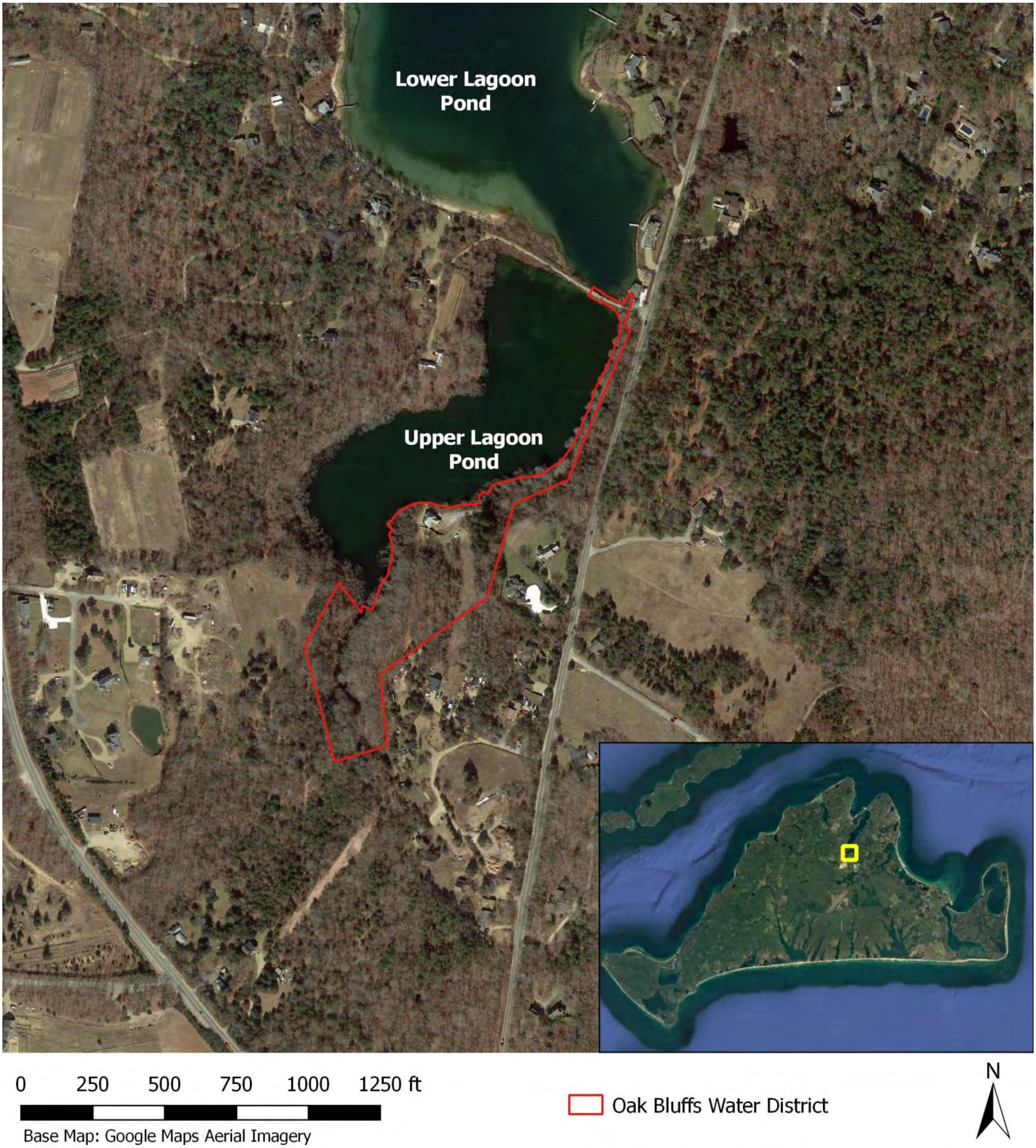
Figures



Oak Bluffs Water District
Upper Lagoon Pond Wellfield
Oak Bluffs, MA

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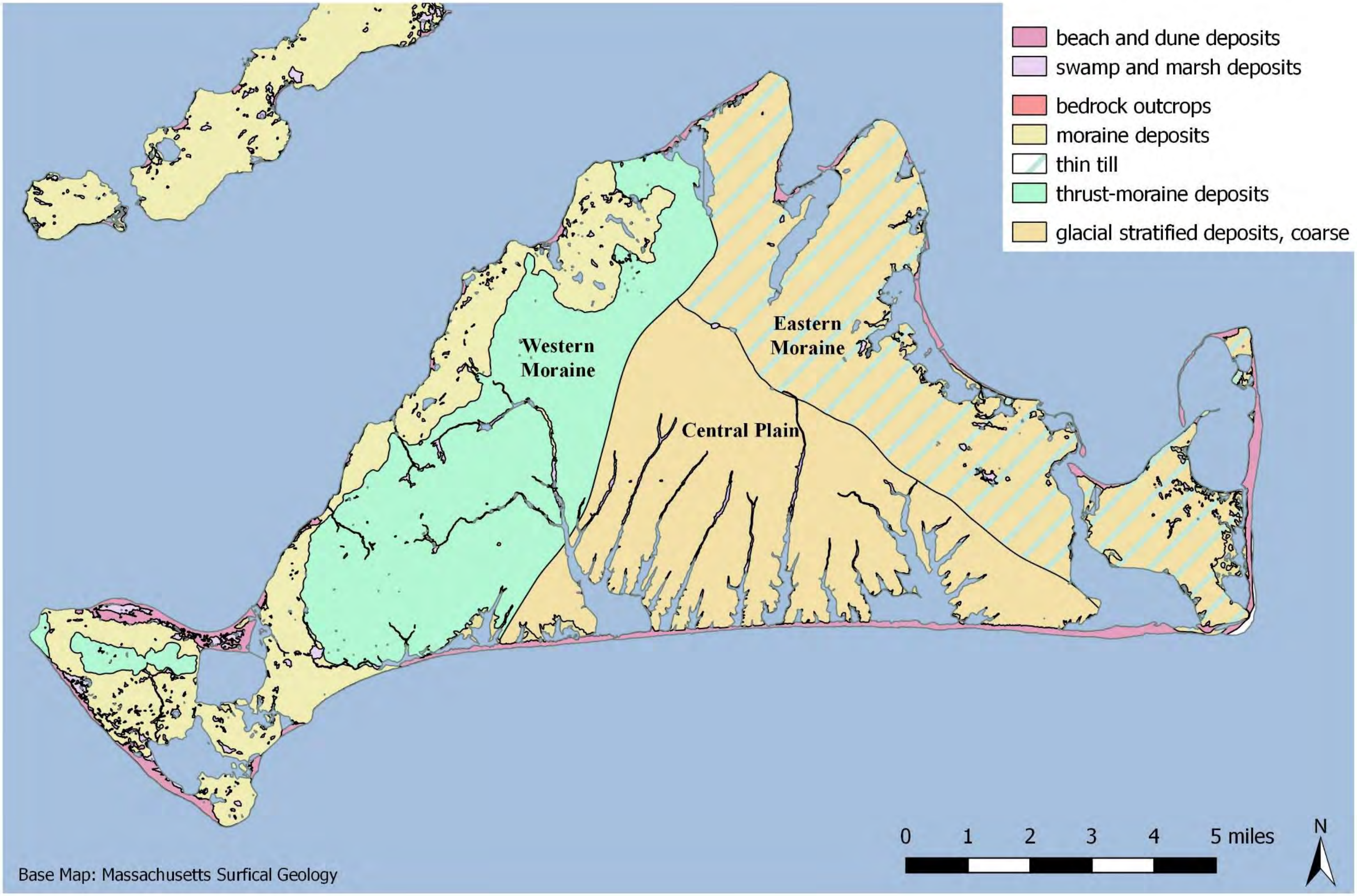
Figure 2.1



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Martha's Vineyard Surficial Geology

Figure 2.2

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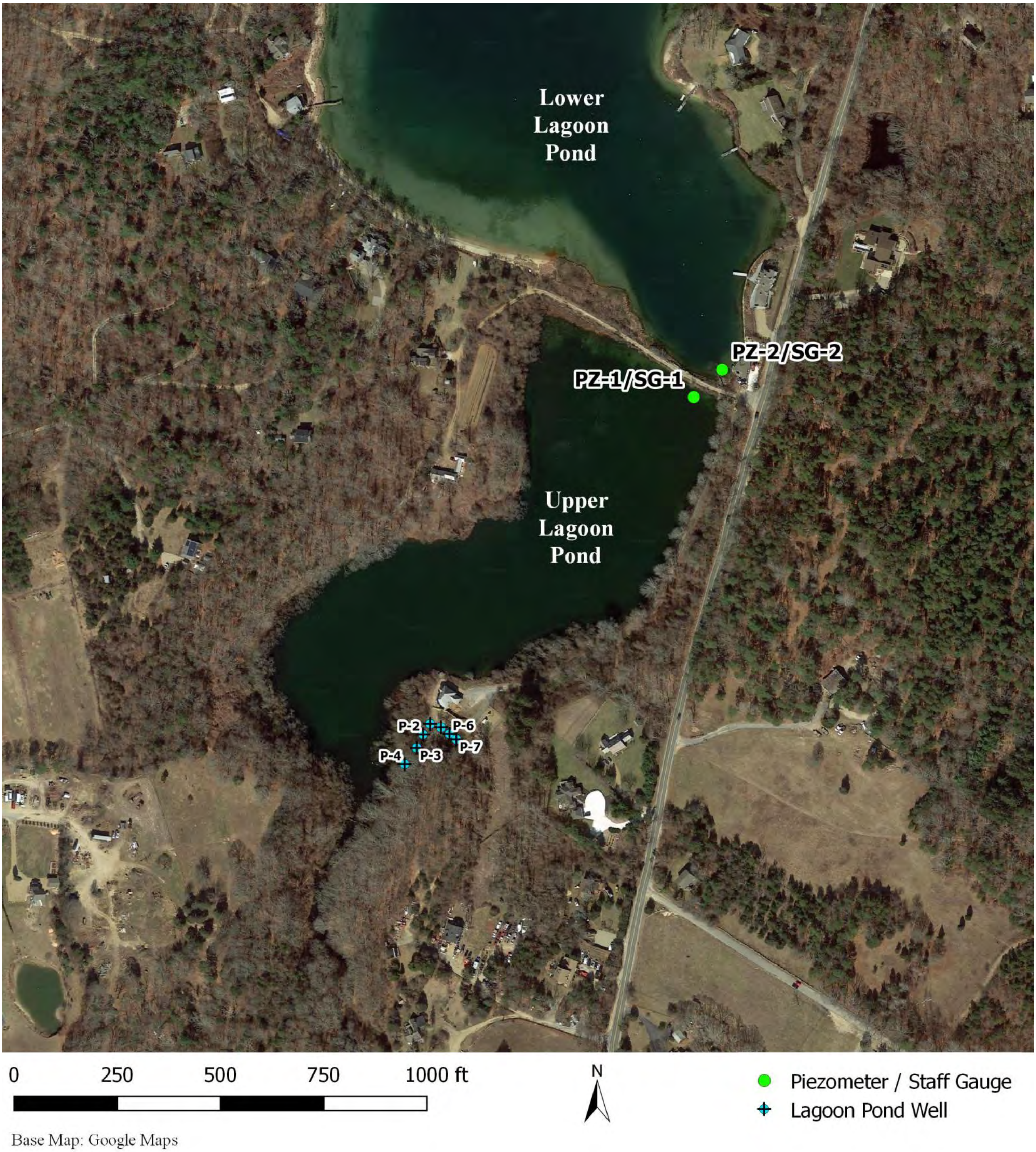
AnAqSim Model Domains

Figure 2.3



Piezometer and Staff Gauge Locations in Upper Lagoon Pond and Lower Lagoon Pond
Oak Bluffs, MA

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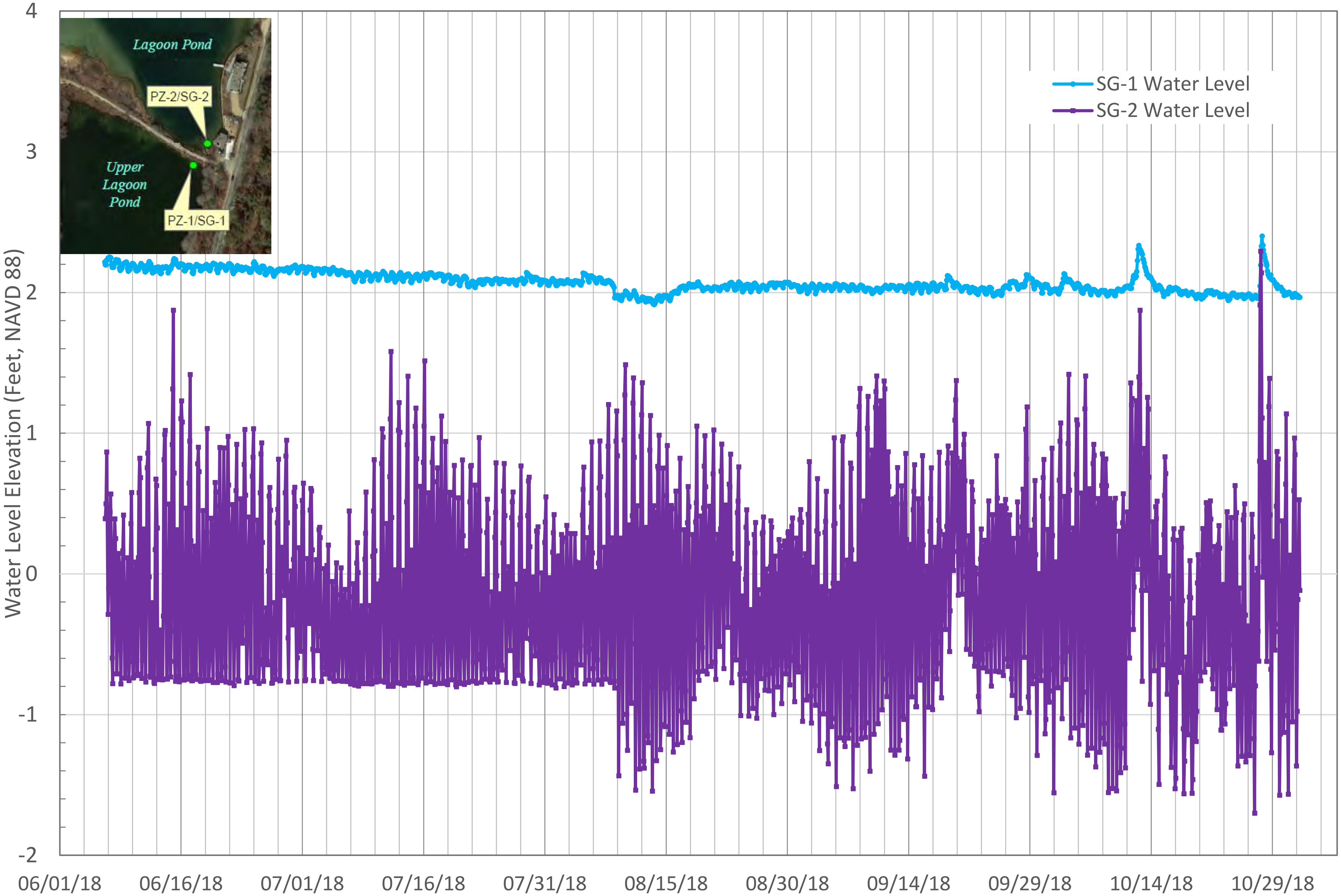
Figure 2.4



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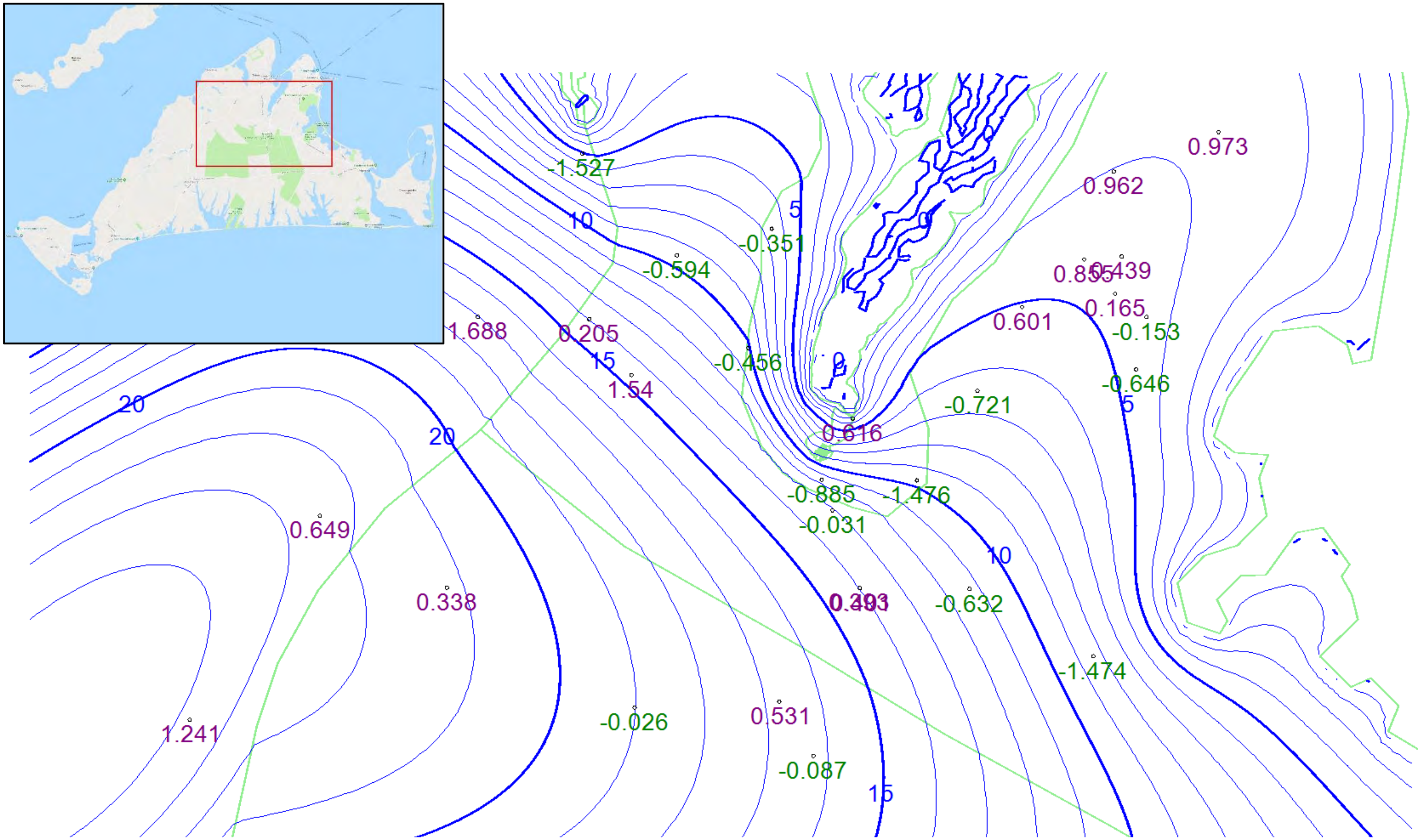
Water Levels in Staff Gauges 1 and 2
Oak Bluffs, MA
June 2018 – November 2018

Figure 2.5



Maroon (positive) values indicate that the modeled head is higher than the measured head
Green (negative) values indicate that the modeled head is lower than the measured head

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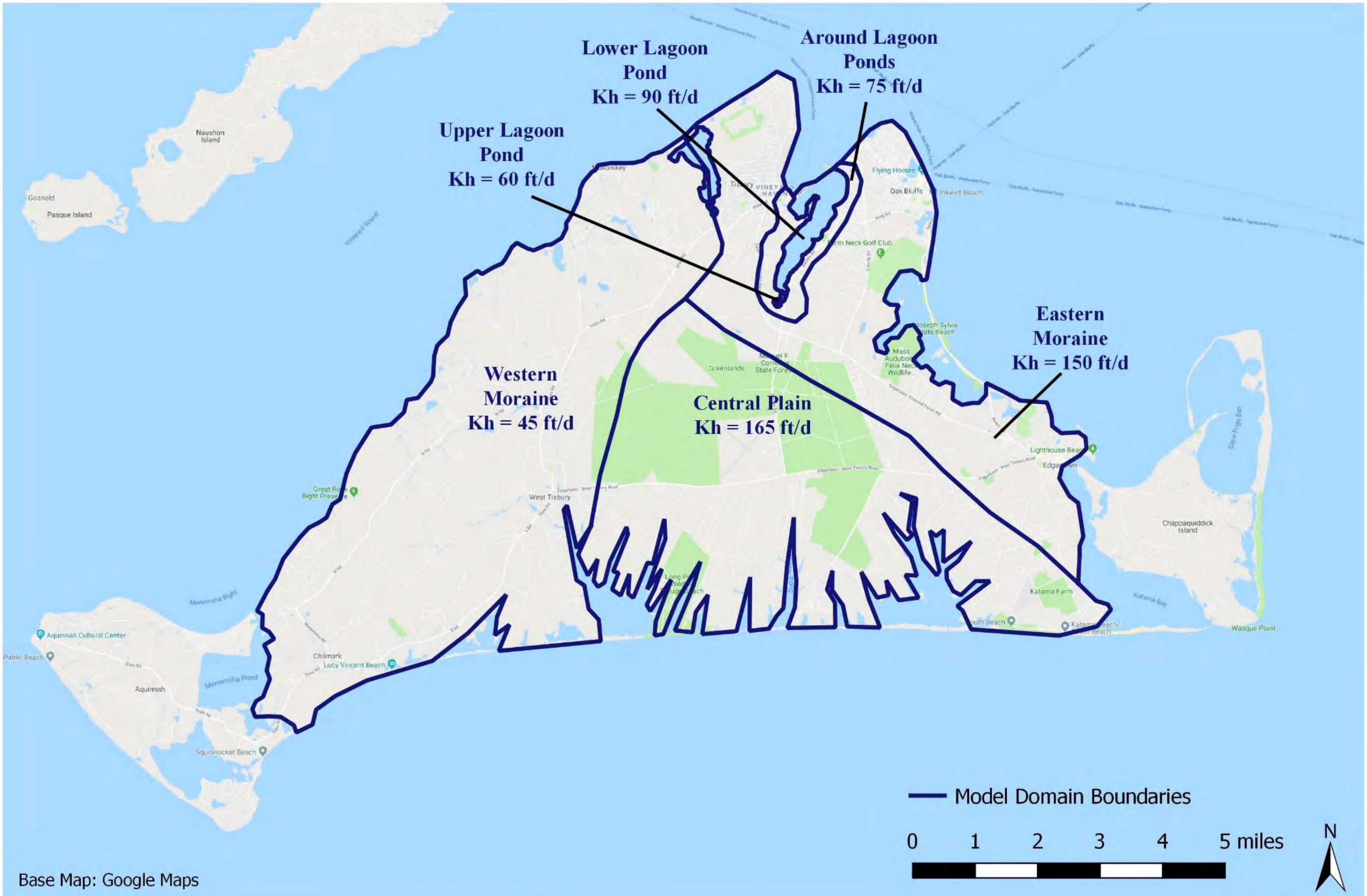
Calibrated Flow Model

Figure 2.6



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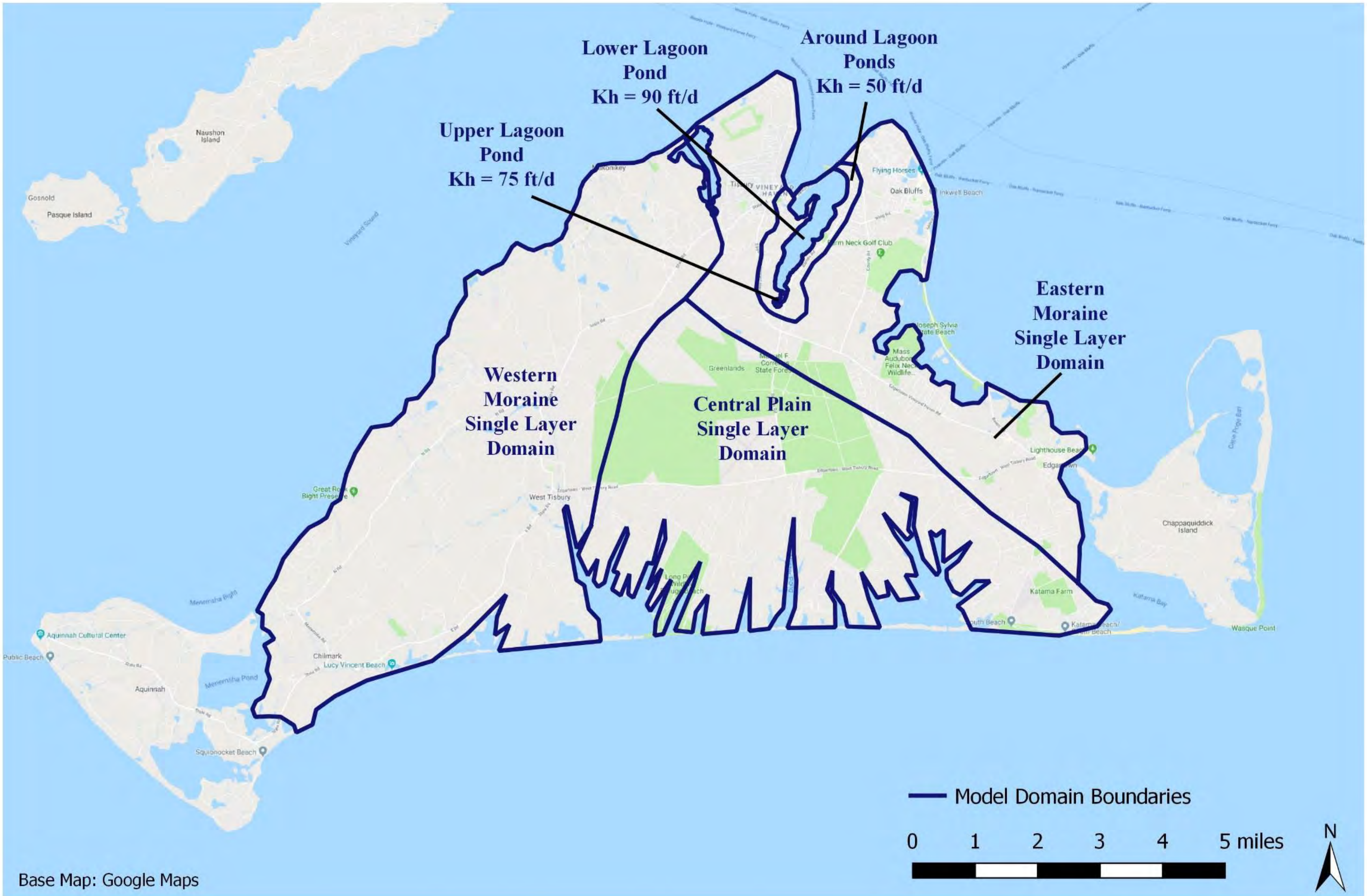
Calibrated Hydraulic Conductivities in Layer 1

Figure 2.7a



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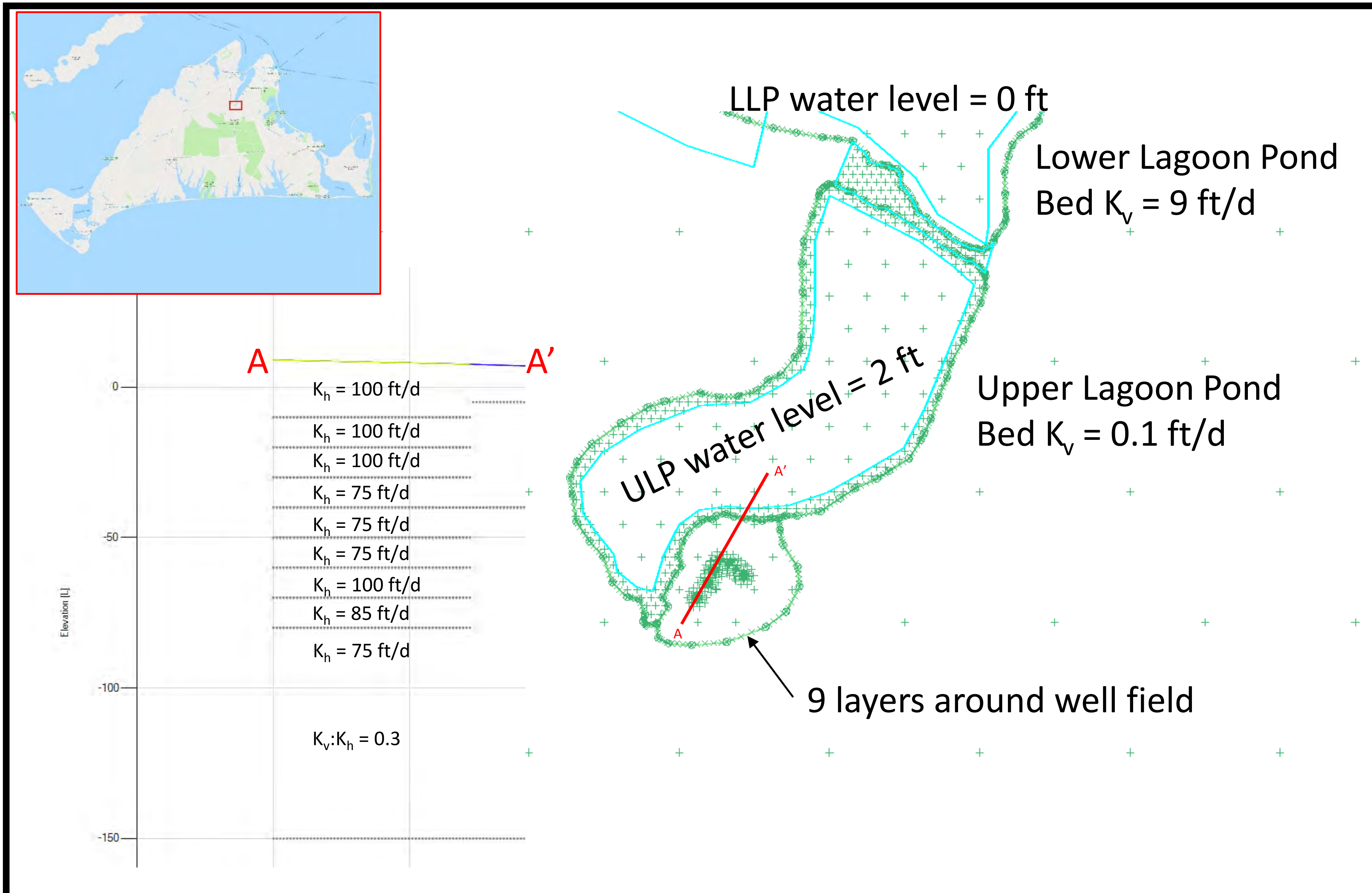
Calibrated Hydraulic Conductivities in Layer 2

Figure 2.7b



Calibrated Hydraulic Conductivities in 9 Layer Wellfield Area

Figure 2.7c

Tables

Table 2.2. Manually Calibrated and PEST Calibrated Parameters

Parameter Name	Manual Cailibration	PEST Calibration
Well area layer 1 hydraulic conductivity (ft/d)	100.000	87.120
Well area layer 2 hydraulic conductivity (ft/d)	100.000	135.617
Well area layer 3 hydraulic conductivity (ft/d)	100.000	137.005
Well area layer 4 hydraulic conductivity (ft/d)	100.000	132.101
Well area layer 5 hydraulic conductivity (ft/d)	75.000	142.597
Well area layer 6 hydraulic conductivity (ft/d)	75.000	112.819
Well area layer 7 hydraulic conductivity (ft/d)	75.000	104.877
Well area layer 8 hydraulic conductivity (ft/d)	100.000	103.324
Well area layer 9 hydraulic conductivity (ft/d)	85.000	48.681
Lower Lagoon Pond layer 1 hydraulic conductivity (ft/d)	90.000	300.000
Lower Lagoon Pond bed conductance (ft/d)	9.000	30.000
Lower Lagoon Pond Layer 2 hydraulic conductivity (ft/d)	90.000	300.000
Upper Lagoon Pond layer 1 hydraulic conductivity (ft/d)	60.000	62.929
Upper Lagoon Pond bed conductance (ft/d)	0.100	0.049
Upper Lagoon Pond layer 2 hydraulic conductivity (ft/d)	75.000	25.000
Araound Lagoon Ponds layer 1 hydraulic conductivity (ft/d)	75.000	124.853
Around Lagoon Ponds layer 2 hydraulic conductivity (ft/d)	50.000	25.000
Central Plain hydraulic conductivity (ft/d)	165.000	151.146
Western Moraine hydraulic conductivity (ft/d)	45.000	60.096
Eastern Moraine hydraulic conductivity (ft/d)	150.000	145.177