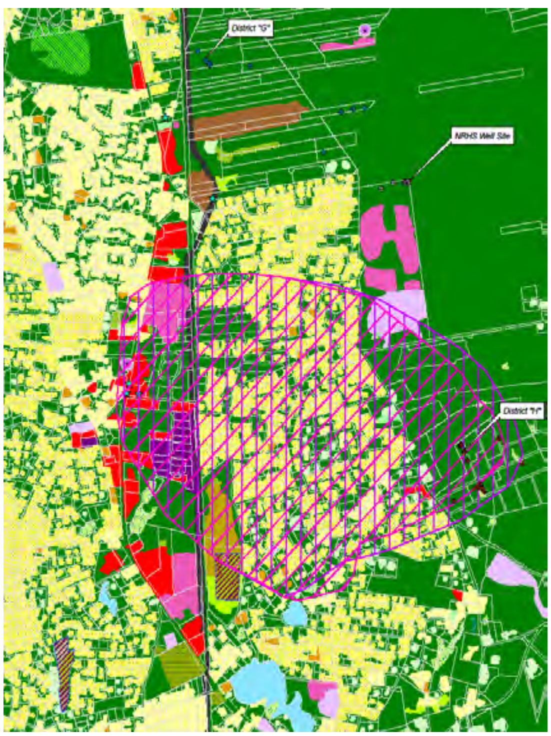
Permit Application # X251003

BRP WS 19
New Water Supply Source
DEP Pumping Test Report

Volume I Text, Tables, Figures, Appendices

Well Field Protection Zoning District H - Eastham, MA

April 2013



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Well Field Protection Zoning District H
New Water Supply Source

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BRP WS 19

Prepared for:
Town of Eastham, Massachusetts

April 2013

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

EXECUTIVE SUMMARY

Introduction

The Town of Eastham has been evaluating potential water resources, with the goal of identifying and permitting sufficient water supplies to serve a town-wide municipal water system. The goal of these efforts is to secure water supplies that can meet the projected water demands for the Town of Eastham, as follows:

Daily demand, annual average	1.0 MGD
Daily demand, seasonal average	1.8 MGD
Peak day demand	2.6 MGD

Over the past several years, several potential sites were identified that are municipally-owned properties for consideration as water supplies. Based on these evaluations, three water supply sites were targeted to serve the system (shown on Figure ES-1): Wellfield Protection Zoning District “H” (District H), Water Resource Protection District “G” (District G), and Nauset Regional High School (NRHS), as well as an interconnection with the Town of Orleans.

The NRHS site was permitted in 2012, with an approved pumping rate of 613 gallons per minute (gpm) and maximum daily withdrawal not to exceed 0.833 million gallons per day (MGD). The District G site was also permitted in 2012, with an approved pumping rate of 691 gpm and a maximum daily withdrawal not to exceed 0.955 MGD.

This permit application (BRP WS 19) and report fulfills the requirements for the Massachusetts Department of Environmental Protection (DEP) required Pumping Test Report for this District H new water supply to permit two water supply wells, TPW-3B and TPW-2C. The report provides the following: soil boring, well installation and aquifer testing activities; analyses of the collected hydrogeologic data to determine site-specific aquifer properties; groundwater modeling performed to determine the recommended yield and Zone II areas; groundwater modeling to evaluate vernal pool response to groundwater pumping; evaluation of land uses and groundwater protection measures within the proposed Zone IIs; and the proposed monitoring program for the well field.

District H Hydrogeology Summary

The District H well field site is owned by the Town of Eastham and is located in a heavily wooded area approximately 900 feet east of the intersection of Schoolhouse Road and Nauset Road (Figure ES-1). A Site Plan for District H is included as Figure ES-2. The Zone I for the test production wells TPW-3B and TPW-2C wells is on Eastham and National Park Service (NPS) owned property. A cluster of Certified Vernal Pools under the National Heritage & Endangered Species Program (NHESP) are located within the vicinity of the TPW-3B and TPW-2C.

The freshwater aquifer, the Nauset Lens, consists of a groundwater mound that forms along the central axis of Lower Cape Cod, generally following the alignment of Route 6. Groundwater flows radially toward the coastlines (eastward and westward) and toward streams and inlets (northward and southward). This freshwater lens is underlain by more dense saltwater. The District H well field site is located on the eastern portion of the Nauset Lens aquifer, approximately 6,200 feet southeast of the high point of the freshwater mound. The groundwater elevation at District H is between 16 to 17 feet NAVD88 (approximately 30 feet bgs) under average conditions. The direction of groundwater flow at the site is toward the east.

The upper zone of unconsolidated material, known as the Eastham Plain Deposits, extends from the ground surface to a depth of approximately 400 feet bgs (-370 feet NAVD 88) and consists primarily of fine to coarse sand with some gravel interbedded with finer grained silt and clay deposits. The freshwater – saltwater transition zone and interface occurs at a depth below 360 feet bgs (-325 feet NAVD88). To the north of District H the Eastham Plain deposits consist of fine to coarse sand with some graved to a depth of approximately 110 feet bgs, underlain by up to 300 feet of glacial lake deposits, consisting predominately of silts and clays. This thick section of fine grained glacial lake deposits were either not deposited or were removed in the District H area.

Four aquifer units are present at the District H site, designated as Zone A, Zone B, Zone C, and Zone D, each separated by leaky aquitards. Zones B and C are potential sources for public water supply. Zone A is the shallow overburden aquifer and is not considered a potential source for public water supply because of potential impacts to nearby vernal pools that would result from groundwater withdrawals in this aquifer zone. Zone D is also not considered a potential source for public water supply because of the potential for salt water intrusion that could result from groundwater withdrawals..

In 2007 District H well TPW-1B, completed in the Zone B aquifer, was permitted as a public water supply for a source less than 100,000 gallons per day.

District H Aquifer Performance Test Summary

New test production wells were installed in the Zone B (TPW-3B) and Zone C (TWP-2C) aquifers. Additional observation wells were also installed in Zone A, B, C, and D aquifers. The observation well network monitored during the APT activities consist of: 4 wells in Zone A, 5 wells in Zone B, 5 wells in Zone C, and 2 wells in Zone D. Water levels were also monitored within and beneath three nearby vernal pools VP-E1, VP-E9 and VP-E11. These wells and piezometers (shown on Figure ES-2) were equipped with data loggers to record groundwater levels before, during and after the production well pumping tests.

Individual pumping tests were performed on the TPW-3B and TPW-2C test production wells in December 2010 and a combined pumping test where both wells were pumped simultaneously was performed in March 2011, pumping both TPW-3B and TPW-2C. The individual well pump tests were performed at a rate of 910 gpm (1.31 MGD) for TPW-3B and 916 gpm (1.31 MGD) for TPW-2C. The combined pump test was performed at the rate of 1.0 MGD per well for a combined pumping rate of 2.0 MGD. On the basis of this work an overall yield of 1.31 million gallons per day (MGD) is recommended for the well field. The yield can be obtained from either the Zone B or Zone C production wells or any combination of the two wells, as long as the combined pumping rate does not exceed 1.3 MGD.

Water quality sampling was also performed each production well, and the laboratory analytical data indicate that the groundwater quality is excellent and suitable for public water supply. The pH levels in both TPW-3B and TPW-2C is slightly acidic, 6.26 and 6.15, respectively; which is consistent with other water supply wells in Eastham and the outer Cape. All other parameters are within DEP drinking water MCLs, secondary MCLs and guidelines.

Water levels in the Zone B, C, and D aquifers show diurnal tidal cycles, with tidal fluctuations of up to approximately 0.3 feet. Because of tidal influences, and as a check of the drawdown stabilization, data from the end of each pump test was plotted on a semi-log plot extrapolation of the time drawdown curve over a 180-day period. Based on these plots, the DEP criteria to have a minimum of 5 feet of water, or 10 percent of the available water column above the well screen at the end of the test, is achieved with a large safety margin.

District H Groundwater Modeling Summary

Groundwater modeling was performed to determine appropriate pumping rates at each production well that a) are protective of the vernal pool and surface water resources of the area, and that b) did not result in adverse salt water upconing affects into the freshwater aquifer. The groundwater modeling activities consisted of the following elements:

A. Removing the diurnal tidal effects from the groundwater elevation data so that the model reflects “true” groundwater elevations.

B. Developing appropriate hydrologic properties of the four aquifers and intervening aquitards underlying District H. This was achieved through the use of a Mulit-Layer Unsteady (MLU) aquifer analysis.

C. Modeling of the vernal pools in the vicinity of the test production wells so that water elevations in the ponds and their response to pumping conditions could be evaluated.

D. Modeling of the salt water transition zone in response to pumping.

Together, these modeling efforts and their results were used as the basis of the recommended pumping rates for TPW-3B and TPW-2C and the monitoring program. These modeling activities are described in more detail below.

Corrections to Water Level Data to Remove Effects of Tidal Fluctuations

Prior to the use of monitoring well water elevation data for the District H aquifer test analyses and SEAWAT model calibrating, the influence of the tidal fluctuation was removed or “filtered” from the data to separate this extraneous effect from that of the pumping well. The method used for filtering tidal effects from District H water level data was developed by Erskine (1991) for removing tidal effects from wells in a highly permeable aquifer located between 160 to 1,300 feet from the shore, which are conditions comparable to those at District H. These filtered water levels were then used for Multi-Layer Unsteady (MLU) aquifer analysis and SEAWAT model calibration.

Multi-Layer Unsteady (MLU) Aquifer Analysis

MLU software was used to analyze data from the two December 2010 pumping tests to estimate hydraulic properties of aquifers and aquitards in the vicinity of the test site and to evaluate the test data for use in parameterizing a SEAWAT model for the site and surrounding aquifer. MLU was selected to perform the data analysis for the District H tests, because it possesses the ability to calculate drawdown for, and estimate properties for, multiple aquifer and aquitard layers in a single model simulation. District H exhibits complex geology that can be generally represented by four higher-permeability units (aquifers) separated by three intervening lower permeability units (aquitards). MLU modeling was used to determine horizontal and vertical hydraulic conductivity and storage coefficient values for the four aquifer and four aquitard units.

Vernal Pool Monitoring

A cluster of NHESP certified vernal pools exist in the area between the Nauset Light Beach and the District H wellfield. Water levels within and beneath three vernal pools (VP-E1, VP-E9 and VP-E11) located within 1,000 feet of test production wells TPW-3B and TPW-2C were monitored prior to, during and after the aquifer tests with dedicated pressure transducers and manual gauging. A staff gauge was installed within each vernal pool and piezometers installed within the peat layer underlying the vernal pool and in the aquifer (Zone A) beneath the peat layer.

A predictive model of vernal pool behavior in response to changes in groundwater levels, such as those that might accompany pump in District H was developed based on: (a) water levels collected as part of the District H testing from December 2010 to December 2011, (b) information from previous vernal pool studies by the National Park Service, USGS, and Cape Cod Commission, and (c) equations from the scientific literature describing vernal pool hydrologic processes.

Vernal pool VP-E11 exhibited the greatest response to production well pumping and was used to develop the vernal pool model. The vernal pool model produced a good match to measured pool VP-E11 water elevations during the 2010-2011 period. The model was then used to predict water level changes within VP-E11 under pumping conditions of 500,000 gpd, which is greater than the anticipated long term average pumping rate for District H.

The model showed that seepage from the vernal pool to groundwater is more rapid when the pool stage is high and inundation overlies the areas of thinner peat mat near the edges of the vernal pools. The model also demonstrated that vernal pool VP-E11 is fed by precipitation and that the vernal pool is most likely not replenished by groundwater. Therefore, a decline in water-table level due to pumping is not anticipated to transmit a similar decline to the vernal pool. As a corollary, while pumping and water level declines do not significantly affect pool water levels, a period with no rainfall would have a much larger impact on pool levels, regardless of pumping.

The vernal pool VP-E11 model results indicate that groundwater level declines in the vicinity of the pool caused by future District H pumping is not anticipated to cause a significant change in the seasonal water elevations in the pool. In addition, because vernal pools VP-E1 and VP-E9 exhibited no apparent responses during the District H aquifer test, it is anticipated that long term District H pumping will have less of an effect on these vernal pools than the very small long-term effect calculated for vernal pool VP-E11.

SEAWAT Modeling

Groundwater modeling was performed using the SEAWAT numerical model developed by the U.S. Geological Survey (USGS) to model freshwater lens conditions of Lower Cape Cod. SEAWAT is a three-dimensional, variable-density, numerical model used to model groundwater flow and transport. The Nauset Lens model was developed by McLane Environmental for analyses of Eastham proposed wellfields and uses SEAWAT (version 4). Under the Nauset Lens model, the SEAWAT model was refined in the vicinities of the NRHS, District G, and District H sites based on site-specific data collected through field investigations. The SEAWAT model was used to:

A. Examine the response of the higher-density saltwater zone beneath the District H well field, and possible total dissolve solids (TDS) concentration impacts in discharged water, and

B. Evaluate the drawdown during no-recharge conditions and the resulting area of contribution to the wells that serves as the basis for the Zone IIs for TPW-3B and TPW-2C.

The Nauset Lens SEAWAT model was used to model changes in TDS concentrations in the aquifer zone beneath the TPW-3B and TPW-2C wells with a constant pumping rate of 1.31 MGD in each well. TDS concentrations were modeled to simulate 100 years of pumping. The modeled TDS concentrations in TPW-3B and TPW-2C after 100 years of pumping each well at 1.31 MGD were 42 mg/L and 148 mg/L, respectively. These simulations do not represent actual anticipated pumping conditions, but demonstrate that pumping at the approvable yield rate for a very long time will not result in TDS concentrations above the drinking water guideline for TDS of 500 mg/L. Dilution from the abundant freshwater contribution to the wells is sufficient to keep the TDS concentrations from deteriorating water quality in the pumping wells.

For the purposes of generating a zone of contribution at the land surface for Zone II delineation using water levels from the 180-day, constant-pumping at 1.31 MGD simulation, particles were placed at the water table and tracked for 5,000 years until the particles stopped at a model boundary (e.g. a groundwater divide or coastal discharge location) or were extracted at the pumping well. Land use within the Zone IIs for the District H TPW-3B and TPW-2C wellfield is shown on Figure ES-3 and is comprised predominately of forested and residential use with some recreational and commercial uses. Other minor land uses within the Zone II include: portions of the NRHS building and parking lots and the northeastern corner of the Eastham Closed Landfill. Particle tracking of groundwater flow from the landfill area shows that groundwater flow is predominantly to the southeast of the landfill toward Salt Pond Bay area of Nauset Marsh, and most importantly it shows that District H is outside the predicted groundwater discharge zone for the landfill.

The landfill has been identified to be, at least in part, the source of impacts to groundwater by vinyl chloride and 1,4-dioxane. Vinyl chloride was first detected in a private well at 325 Schoolhouse Road at concentrations that exceed the MCL for vinyl chloride (VC) of 2 µg/L. An Immediate Response Action (IRA) under the Massachusetts Contingency Plan (MCP) was completed and properties with measurable concentrations of VC and DCE were provided bottled water, where authorized by the homeowner, by the Town. A point of entry granular activated activated carbon filtration water treatment system was installed at the 325 Schoolhouse Road property. A Class A-2 Response Action Outcome (RAO) for the 325 Schoolhouse Road site was completed by the Town after the vinyl chloride concentrations at the influent to activated carbon system were reported as less than the GW-1 standard of 2.0 ppb for ten consecutive quarterly rounds of sampling. The 325 Schoolhouse Road property and 5 nearby properties where VOCs were detected in their private wells are all located outside and to the south-southwest of the Zone IIs for TPW-3B and TPW-2C..

As part of the fall 2012 post-closure monitoring of the landfill 1,4-dioxane was detected in one of the landfill monitoring wells at a concentration that exceeds the Massachusetts Contingency Plan RCGW-1 Standard of 3 µg/L. (MW-3D – 4.3 µg/L). The Town prepared an IRA Plan in January 2013, approved by DEP, that consists of sampling residential drinking water wells in the downgradient area of the landfill. These IRA activities are ongoing. The most recent Immediate Response Action Status Report and Quarterly Landfill Monitoring Report, dated March 29, 2013, summarizes the status of these IRA activities and consists of sampling over 200 residential wells. The results of this sampling program are to be provided to DEP in the next quarterly progress report, to be submitted to DEP before the end of June 2013.

In response to these detections of 1,4-dioxane in groundwater in the vicinity of the landfill, the public water supply wells proposed to be developed by the Town, consisting of District G, Nauset Regional High School, and District H were sampled on January 17, 2013 and analyzed for 1,4-dioxane in accordance with EPA Method 522.1, which has a method reporting limit of 0.2 ppb and a method detection limit of 0.041 ppb. The wells at District G and the Nauset Regional High School had no detections of 1,4-Dioxane. At District H, the well screened in the Zone B aquifer had trace concentrations (below the method reporting limit and therefore are estimated concentrations) below 0.081 ppb, two orders of magnitude below the GW-1 standard of 3.0 ppb for 1,4-dioxane under the Massachusetts Contingency Plan (GW-1) is 3.0 ppb. This GW-1 cleanup standard is to be lowered by DEP in the near future to 0.3 ppb. The analytical results of sampling at each of the proposed public water supply locations are either non-detect or a minimum of an order of magnitude lower than the potentially revised standard of 0.3 ppb, and therefore the wells are suitable for public water supply purposes.

Particle tracking generated by the MODFLOW groundwater model shows that groundwater emanating from the landfill area flows generally to the southeast and does not intersect the District H property. For this reason the source of the trace concentrations of 1,4-dioxane detected at the Zone B and Zone C wells from samples collected in the January 2013 sampling event is not known at this time. The objective of the ongoing IRA investigations by the Town will provide definition on the horizontal and vertical extent of the 1,4-dioxane in groundwater and what the likely sources are.

Groundwater Monitoring Program

Three monitoring programs are proposed for the District H well field:

1 Monitoring to confirm the water quality conditions related to movement of the saltwater transition zone transition zone under actual operating conditions of the well field. The goal of the water quality monitoring plan is to ensure that behavior of the salt water transition zone is consistent with SEAWAT modeling predictions. This monitoring program includes long term water level monitoring in the Zone B, C and D aquifers and water quality monitoring in the Zone C and Zone D aquifers.

2 Monitoring of water levels in select vernal pools and monitoring wells to confirm the vernal pool modeling predictions under actual operating conditions of the well field. This monitoring program includes monitoring of water levels within and beneath in four vernal pools located within 1,000 feet of the District H production wells.

3 Monitoring of water quality in sentinel wells located at the western perimeter of the District H property. Water quality parameters of nitrate, VOCs and 1,4-dioxane will be monitored in the Zone B and Zone C aquifers.

The monitoring programs will begin after the permit is issued and before pumping begins to allow for the comparison of baseline data (i.e., pre-pumping conditions) to wellfield pumping conditions.

1 INTRODUCTION

This report fulfills the requirements for the Massachusetts Department of Environmental Protection (DEP) required Pump Test Report (BRP WS 19) for a new water supply at the Wellfield Protection Zoning District “H” (District H) site in Eastham. The site location is shown on Figure 1-1. A DEP Transmittal Form for Permit Application and BRP WS 19 Approval of Pumping Test Report for a Source of 70 Gallons per Minute or Greater are included in Appendix A.

This report presents the results of work performed at the District H site for the installation and testing of two test production water supply wells. The work was performed during 2009, 2010 and 2011 and in accordance with the Aquifer Performance Test Work Plan described in *BRP WS 17 Request for Approval for Site Examination and Conduct Pumping Test for a Source Over 70 Gallons per Minute, Wellfield Protection District H, Eastham, Massachusetts, July 2010 (DEP Transmittal #X231282)* (EPG, 2010a). DEP approved the Request for Site Exam in a letter dated April 8, 2011, a copy of which is included in Appendix B. The project was performed for the Town of Eastham by Environmental Partners Group, supported by McLane Environmental (groundwater modeling), Head First, Inc. (hydrogeology), Boart Longyear Drilling Services (observation and test production well installations), and All Cape Well Drilling (observation well installations).

1.1 Background

The Town of Eastham is considering development of a Town-wide water system and as a first step is identifying water supply sources that can meet the following projected demands for the system (in million gallons per day (MGD)):

Daily demand, annual average	1.0 MGD
Daily demand, seasonal average	1.8 MGD
Peak day demand	2.6 MGD

Over the past several years, several potential sites that could potentially serve as public water supplies were evaluated and three were selected for further consideration: District H, Water Resource Protection District “G” (District G), and Nauset Regional High School (NRHS), shown in Figure 1-2. The NRHS site was permitted in 2012, with an approved pumping rate of 613 gallons per minute (gpm) and maximum daily withdrawal not to exceed 0.833 million gallons per day (MGD). The District G site was permitted in 2012, with an approved pumping rate of 691 gpm and a maximum daily withdrawal not to exceed 0.955 MGD.

This report fulfills the requirements for the Massachusetts Department of Environmental Protection (DEP) required Pumping Test Report for the District H new water supply source, which will serve the Town of Eastham. This is submitted as permit application BRP WS 19 in accordance with the requirements of the Massachusetts Drinking Water Regulations.

The location of the District H well field site is shown on orthophotos Figure 1-3 and 1-4 and a surveyed plan of the site is provided in Figure 1-5. The District H well field is located on property owned by the Town of Eastham, approximately 900 feet east of the intersection of Schoolhouse Road and Nauset Road. The District H well field site has one existing permitted water supply well, designated TPW-1B, that is permitted for up to 100,000 gpd. This well was installed as a potential water supply source, but has never been put into production. The two test production wells installed under this program (District H TPW-3B and TPW-2C) are located 157 feet and 295 feet north, respectively, of the existing TPW-1B water supply well. The Zone I's for both the District H TPW-3B and TPW-2C wells are located on Town of Eastham and National Park Service (NPS) owned property.

The Town of Eastham is located on the outer portion of Cape Cod and is approximately 9,100 acres in size. Approximately 1,500 acres of the Town is part of the Cape Cod National Seashore (CCNS). The Town has a year-round population of approximately 5,646, although there is a large influx of summer residents and vacationers that expand this population during the summer season. Eastham has several areas with medium density residential development characterized by quarter-acre and eighth-acre lots. Route 6, which runs north and south through Eastham, is a major corridor with many hotels, restaurants, and other establishments that support the Town's tourism. The overwhelming majority of these properties are currently served by individual or non-community drinking water supplies and individual wastewater disposal septic systems; with no municipal drinking water supply system or wastewater collection and treatment system.

With the exception of a small number of lots along the border between the Towns of Orleans and Eastham, all home owners and businesses within the Town of Eastham currently utilize private or non-community groundwater wells for drinking water. The northern portions of the Town sit above the Nauset Lens aquifer, whereas southern Eastham rests above the Monomoy Lens. Both flow cells provide the Town with a potable freshwater source. The Town does not currently own or operate a municipal water system. According to the Town of Eastham Local Comprehensive Plan, Third Edition, 2012, there are 7 non-transient/non-community wells and 43 transient/non-community public water supply systems (50 total) within the Town.

1.4 DEP New Source Permitting Activities/Regulatory Setting

This report provides supporting information for the District H Wellfield site Pumping Test Report approval. Below is provided a description of the regulatory requirements and additional supporting information addressed in this report.

The 1986 Massachusetts Water Management Act (WMA) MGL c.21G authorizes the Massachusetts Department of Environmental Protection (DEP) to regulate the quantity of water withdrawn from groundwater supplies. The WMA and associated Water Resources Management Program (310 CMR 36.00) and Drinking Water Regulations (310 CMR 22.00) requires withdrawals of 100,000 gpd or greater to receive a Water Management Act Permit.

1.5 Report Organization

The report is organized into the following Sections

Section 1	Introduction
Section 2	Previous Investigations at Nauset Regional High School
Section 3	Aquifer Performance Testing Background, Scope and Methodology
Section 4	Aquifer Performance Testing Results
Section 5	Regional and Local Hydrogeologic Setting
Section 6	Aquifer Analysis with MLU Software
Section 7	Groundwater and Surface Water Interaction District H – Vernal Pool Characterization
Section 8	SEAWAT Model Development
Section 9	Approvable Yield
Section 10	Zone II Delineation
Section 11	Site Characterization
Section 12	Groundwater Monitoring Program
Section 13	Wellhead Protection Plan

2 PREVIOUS INVESTIGATIONS AT DISTRICT H

Several phases of hydrogeologic investigations have been conducted at the District H well field site that have involved the installation of soil borings, construction of shallow and deep monitoring wells, limited aquifer testing and water quality sampling. These previous investigations provided the site-specific hydrogeologic background used as the basis for the long term aquifer performance testing described in Sections 3 and 4.

The activities performed in each of these earlier investigations and the information collected from them is summarized below.

2.1 Environmental Partners Group, 2006

In 2006 the Town of Eastham contracted Environmental Partners Group to provide engineering services related to development of a limited municipal water system near the Town's capped landfill. Ongoing groundwater monitoring had shown elevated volatile organic compound (VOC) concentrations in areas south and east of the closed landfill. Several potential sites that are municipally-owned properties were identified for consideration as water supplies. Of these, the property known as "District H", which is located within Eastham's Wellfield Protection Zoning District, was selected for further evaluation. A Request for Site Exam and Pump Test Scope of Work was submitted and approved by DEP for siting a new water supply well with a capacity of less than 70 gallons per minute at this location.

Environmental Partners Group oversaw the installation of test wells and observation wells and subsequent pump tests detailing the specific capacity and water quality of the shallow aquifer source at District H. The results of these activities are summarized in the report by *Environmental Partners Group, 2006, BRP WS 15 Pumping Test Report/Approval to Construct Source for a Source under 70 Gallons per Minute* (EPG, 2006). This report included boring logs and well construction diagrams for test well and observations wells installed under this scope of work as well as an estimate of well yield, water quality analysis results and laboratory analytical reports. Following is a summary of the results of this investigation.

1. A 202-foot deep boring was installed, and a 6-inch test production well, a 4-inch observation well and a 1-inch water table piezometer was installed; specific capacity testing of the 4-inch and 6-

inch wells were completed; a constant rate pump testing of the 6-inch test production well was performed; and water samples were collected for laboratory analysis.

2. A 48-hour constant rate test was conducted in the 6-inch test production well (TPW-1B). Maximum drawdown at TPW-1B well was about 3.05 feet, achieved at a pumping rate of 102 gpm. The resulting specific capacity is 33 gpm/foot of drawdown.

3. Water levels in a number of nearby observation points in the upper portion of the aquifer and vernal pools were recorded before, during, and after testing TPW-1B. Water levels were not affected by pumping the well at approximately 100 gpm (i.e., approximately 144,000 gpd). Water levels in the shallow 1-inch diameter well, located 11 feet from the 6-inch well, did not show any observable response to pumping.

4. A separation exists between the upper portion of the aquifer near the water table (Zone A) and the production zone (106-116 feet bgs, Zone B). This conclusion was based on the following observations:

    - there are several clay layers between the water table (Zone A) and production zone (Zone B),

    - water levels in the Zone B show cyclic variations that appear to be tidal and the water table (Zone A) does not show these cyclical variations,

    - the elevation of the piezometric surface at the water table (Zone A) is 1 to 2 feet higher than the elevation of the piezometric surface in the Zone B production zone, and

    - pumping the Zone B production well for 48 hours at approximately 102 gpm did not appear to affect water levels of the water table (Zone A)

5. The results of the 48-hour aquifer test indicated that pumping TPW-1B for a water supply of less than 100,000 gallons per day would not adversely affect water levels in local vernal pools.

6. Approvable yield calculations for TPW-1B were calculated in accordance with the DEP Source Approval Process. The results of this evaluation determined an approvable yield of 1,860 gpm, including a 0.75 safety factor. As such, the calculated approvable yield was significantly greater than the requested yield of 70 gpm.

7. Water quality samples were collected and analyzed as required in the DEP Source Approval regulations. All VOCs, inorganics, radiounuclides, and secondary contaminants were either

below laboratory detection limits or within Massachusetts water quality standards for drinking water, except for pH. The measured pH in the shallow production well was 6.1 to 6.3; therefore, the water quality is slightly acidic, but consistent with other water supply wells on Cape Cod, and would likely need treatment for pH adjustment

2.2 Environmental Partners Group, 2010

Environmental Partners Group prepared a *Permit Application #X231282, BRP WS 17 Request for Approval for Site Examination and Conduct Pumping Test for a Source Over 70 Gallons per Minute, Wellfield Protection Zoning District H Site, Eastham, Massachusetts, July 2010* (EPG, 2010). In conjunction with this Request for Site Exam for District H, Environmental Partners oversaw the installation of a deep boring, one test well and one observation well at the District H Site and subsequent pump tests detailing the specific capacity and water quality of the deeper aquifer source at District H. The results of these activities are summarized in EPG, 2010, Appendix I, Wellfield Protection Zoning District H New Source Development Field Investigation Report. This report includes boring logs, well construction diagrams, the results of a 45-hour pump test, and an estimate of the pumping capacity, aquifer parameters, and water quality. The results of this investigation are summarized below.

Based on the 405 foot deep boring installed at District H in 2009, hydrogeology at the District H site can be divided into four potential aquifer units, separated by silt and clay aquitards (see Figure 2-1), as follows, from the ground surface downward:

a. Zone A comprises the water table aquifer and extends from the water table to a depth of approximately 40 feet bgs, where an approximately 35 foot thick section of interbedded clay, silt and sand is present as a semi-confining layer/aquitard.

b. Zone B is a potentially productive aquifer unit, approximately 25-35 feet thick, and extends from the bottom of the silty clay layer/aquitard, beneath Zone A, at a depth of approximately 78 feet bgs to a lower semi-confining silt and clay layer/aquitard at a depth of approximately 120 feet bgs.

c. Zone C is potentially productive aquifer unit approximately 70 feet thick, and extends from the base of the aquitard beneath Zone B at approximately 150 feet bgs, to a lower silt and clay layer/aquitard beginning at a depth of approximately 220 feet bgs.

d. Zone D is comprised of sands from the base of the aquitard beneath Zone C (approximately 242 feet bgs) to approximately 390 feet bgs where either dense till or bedrock is encountered.

In conjunction with the Request for Site Exam, observation wells were installed in Zone C (OW-1C) and Zone D (OW-1D). A subsequent pump test was performed on the Zone C well to evaluate the specific capacity and water quality of the Zone C aquifer source at District H.

Following is a summary of the result of this investigation.

1. Soil boring, observation well installation, and aquifer testing was performed in August and September 2009. An 8-inch diameter boring was drilled to a total depth of 405 feet bgs to evaluate site geology and hydrogeology. Open borehole geophysical logs were run over the 405 foot boring to provide detailed geologic and hydrogeologic information. Geophysical logging consisted of: (1) polyelectric logging, including probes to measure fluid temp, fluid resistivity, natural gamma, spontaneous potential resistivity (SPR), spontaneous potential (SP), and normal resistivity and (2) electromagnetic (EM) induction logging, with a probe to measure formation conductivity, essentially a combination of the electrical properties of the local sediments and the fluids that fill the pore spaces; this tool was coupled with a natural gamma tool.

   Based on drill cuttings and borehole geophysics, site geology consisted predominately of medium sand, with some fine sand and some coarse sand, interbedded with thinner layers (up to approximately 22 feet thick) of silty clay and clayey silt from the ground surface to 390 feet bgs. Dense till or weathered bedrock was encountered at a depth of 390 feet bgs. Based on borehole geophysical logging, a freshwater – saltwater interface was identified at a depth of approximately 342 feet bgs. Figure 2-1 is a geophysical log showing the subsurface geology at the District H site.

2. A Zone D well (OW-1D) was set at the top of the transition zone for the freshwater – saltwater interface, with the screen set from 346-349 feet bgs. This well was used as an observation well to monitor potential upconing of saltwater during aquifer pumping.

3. A Zone C well (OW-1C) was set with a well screen at 207-217 feet bgs. This well was set immediately above a 23-foot thick silty clay/clayey silt layer. A 45-hour constant rate test was conducted on the intermediate test well. The test was run at the maximum capacity of the pump

or 112 gpm, and had a maximum drawdown of approximately 21.5 feet bgs. The calculated specific capacity for the well was 5 gpm/foot of drawdown.

4. Aquifer parameters, hydraulic conductivity and transmissivity were calculated for the Zone C aquifer based on the calculated specific capacity of 5 gpm/foot of drawdown in the intermediate test well. The calculated hydraulic conductivity and transmissivity were 87 feet/day and 1,045 $feet^2$/day, respectively.

5. Water quality in the Zone C aquifer was excellent. VOCs, metals, and secondary parameters were all either less than MCLs or below method detection limits. Groundwater pH is slightly acidic (pH 6.26). The Secondary MCL for pH is 6.5-8.5, and therefore, the water would likely need treatment for pH adjustment.

6. The Zone B, Zone C and Zone D aquifers show tidal fluctuations in water levels, but the water table (Zone A) does not show these variations indicating some separation between the water table and the deeper production zones.

7. During the Zone C well pumping test, drawdown was observed in the Zone B and Zone D observation wells.

A preliminary site model was developed for the three water supply sites for the Town of Eastham. The goal of the model was to develop an initial assessment of potential yields for the District H, District G and NRHS sites using the USGS groundwater flow model for the outer Cape, upgraded with the extensive hydrogeologic data gathered under this 2009-2010 program. The scope of work for this model included:

1. Compiling and reviewing readily available studies, reports, monitoring well data, USGS computer models, site settings, hydrogeologic data, and topography for the Eastham area and the Nauset Lens underlying the Town.

2. Conducting preliminary model runs using the USGS models updated with site specific information to obtain initial estimates of aquifer properties and potential well yields, and evaluate drawdown and potential saltwater upconing/intrusion effect from pumping.

3. Develop a preliminary conceptual level Zone II for each test site using particle tracking analysis.

4. Provide appropriate input for long term pump tests, and outline subsequent modeling needs following long term pump tests.

The results of the groundwater model are summarized in the report by McLane Environmental 2010, *Exploratory Modeling of Eastham Water Supply Sites – District H, District G and NRHS using the USGS Nauset Lens Model March 2010*, which is included in Appendix J of EPG, 2010a.

The groundwater modeling included development of stratigraphic cross-sections, boundary conditions, and recharge areas for all three potential water supply sites (District H, District G and NRHS). After calibration of the USGS model to site specific conditions at these test sites, various model runs were performed to address potential issues of concern at each of the three test sites.

Several additional modeling runs were conducted for District H site including:

1. Modeling drawdown effects and saltwater content in the pumped interval (total dissolved solids (TDS) concentrations) when pumping the intermediate well (-200 to -220 feet mean sea level (msl)) at 0.5 MGD using two different hydraulic conductivity values (10 feet/day and 40 feet/day)

2. Modeling drawdown effects from pumping the Zone B well (-100 to -120 feet msl) at two different hydraulic conductivity values (30 feet/day and 120 feet/day)

3. Modeled drawdown effects on the water table (Zone A) near vernal pools and saltwater concentrations (TDS) for three different pumping scenarios, as follows:

    - pumping a Zone B (-100 to -120 feet msl) and Zone C (-140 to -160 feet msl) well at the northern well couplet location at 0.5 MGD,
    - pumping a Zone B (-100 to -120 feet msl) and Zone C (-140 to -160) well at a southern well couplet location at 0.5 MGD, and
    - pumping all four wells (the couplet at the northern end and the couplet at the southern end of District H) at a total pump rate of 0.5 MGD (0.125 MGD per well)

4. After calibrating the model for site specific conditions a final simulation was run to model drawdown effects and saltwater concentrations (TDS) pumping a total of 1.0 MGD from the proposed Eastham water supply network including four wells at District H (pumping at a total of 0.25 MGD), two wells at District G (pumping at a total of 0.25 MGD) and two wells at NRHS (pumping at a total of 0.5 MGD).

5. Pumping four wells at District H for a combined pump rate of 0.25 MGD had the least drawdown impacts to the water table and minimized the lateral intrusion of saltwater in the Zone C wells

In addition, a preliminary estimate or conceptual Zone II for the District H pumping wells was developed using a numerical tracking model.

2.3 Environmental Partners Group, 2005 – 2006

Environmental Partners Group provided engineering services to the Town related to development of a limited municipal water system near the Town's capped landfill The first phase of this project involved scoping out the proposed limited municipal water system and preparing a feasibility study developing a conceptual level water system plan. The results of these activities are summarized in the report *Limited Municipal Water System Task 1 – Project Definition, August 2005* (EPG, 2005a). Under this study, the District H site was ranked as "highly favorable." Positive factors included Town owned/NPS owned 400 foot Zone I radius; previous studies indicate good water quality and high potential yield. Issues of concern identified include site access and potentially sensitive environmental resources, e.g., the vernal pools.

The second phase of activities consisted of identifying potential water supply sources for the limited municipal water system. A total of 10 potential water supply sites were screened as well as the option for interconnection with the Town of Orleans. The results of this study are summarized in the report *Limited Municipal Water System Task 2 – Water Supply Source Identification September 2005* (EPG, 2005b).

The third phase of activities involved preparation of a System Master Plan. This assessment was for a town-wide water system and included an assessment of water needs, potential groundwater supply sources, opinion of probable program costs, funding alternatives, and review of regulatory and institutional issues. The product of this work task provided the Town with a conceptual plan to implement a town-wide water supply system. The results of this Plan are summarized in the report *Municipal Water Distribution System Master Plan, May 2006* (EPG, 2006b).

2.4 Other Previous Investigation – District H

<u>Whitman and Howard, 1970</u>

The Town of Eastham and Whitman & Howard, Inc. (W&H) completed a well testing program and preliminary Town wide water supply study circa 1970, as documented in the *Report on Proposed Water System, Eastham, Massachusetts, February 6, 1970* (W&H, 1970). As part of the groundwater investigation, four tests wells (Test Wells No. 1, No. 2, No. 3, and No. 4) were drilled 40-50 below ground surface (bgs) in an area generally around the Nauset and Cable Road area.

Three of the original four test wells (Test Wells No. 1, No. 3, and No. 4) are now located within the Cape Cod National Seashore boundary. The two wells closest to the District H Test Well Site, Test Well No. 3, and Test Well No. 4, were installed approximately 700 and 1,100 feet, respectively, from the proposed well site being considered.

Test Well No. 3 was driven to a depth of 66 feet below ground surface (bgs). Fine brown sand and clay was observed to a depth of 9 feet bgs. Fine to medium brown/yellow sand and gravel was observed from 9-45 feet bgs. Fine to medium brown sand and gravel with trace clay was observed from 45-59 feet bgs. Fine brown sand and clay was observed from 59-66 feet bgs. A well screen was installed at 52 feet and the well pumped at the rate of 50 gallons per minute. Groundwater samples determined that water is of good quality for a public water supply. It was concluded that about 300 gpm would be available at this Test Well No. 3 location from a 48 x 24 inch gravel packed well.

Test Well No. 4 was driven to a depth of 56 feet below ground surface (bgs). Fine to medium brown sand and gravel was observed to a depth of 36 feet bgs. Fine to medium brown sand and gravel with trace clay was observed from 36-49 feet bgs. Fine brown sand and clay was observed from 49-56 feet bgs. A well screen was installed at 49 feet and the well pumped at the rate of 55 gallons per minute. Subsequent testing at this same location using an 8-inch well installed to a depth of 49.5 feet bgs, and 5 observations wells installed within 200 feet of the 8-inch well showed similar results. Analysis of water samples demonstrated that the water is of good quality. Whitman and Howard concluded that about 700 gpm would be available at this Test Well No. 4 location from a 48 x 24 inch gravel packed well.

Observations from W&H Test Wells No. 3 and No. 4 are consistent with the USGS reports (Masterson, 2004; Foster and Poppe, 2003), which described overburden in the Nauset lens as a thin layer (less than a hundred feet) of fine, medium, and coarse sand and gravel, underlain by a thick sequence of layered silts and clays.

3 AQUIFER PERFORMANCE TESTING BACKGROUND, SCOPE AND METHODOLOGY

The aquifer performance testing program at District H was conducted in accordance with the Aquifer Performance Test Work Plan (*Permit Application X231282, BRP WS 17 Request for Approval for Site Examination and Conduct Pumping Test for a Source Over 70 Gallons per Minute, Wellfield Protection Zoning District H, Massachusetts, July 2010* (EPG, 2010), which was approved by the Department of Environmental Protection (DEP) in a letter dated April 8, 2011. The DEP Request for Site Exam Approval Letter is included in Appendix B.

3.1 Summary of District H Site Conditions

Environmental Partners installed a total of 12 observation wells and 2 test production wells at District H under this scope of work. Based on these data, a new conceptual site model was developed for the subsurface hydrogeology in Eastham, and particularly at the District H site. Figure 3-1 shows the District H, District G, and NRHS wellfield sites and existing wells used to develop this conceptual model. Figure 3-2 is a regional geologic cross-section extending from north Eastham at the District G well field site through the NRHS well field site and southeastward to the District H site. To the north of District H the geology consists of predominately fine to medium sand with some coarse sand from the ground surface to a depth of approximately 110 feet bgs (approximately -100 feet MSL) (glacial outwash deposits). Below a depth of 110 feet bgs, the sands transition to finer grained glacial lake deposits consisting of silts and clays. At the District G and NRHS sites, the silts and clays extend to a depth of at least 400 feet bgs (approximately -500 MSL). This is consistent with previous investigations in Eastham. The geology at District H, however, transitions from overburden glacial lake deposits and underlying clay to predominately sands with interbedded aquitard layers of silt and clay.

As detailed in Section 2.2 and shown in Figure 2-1, the subsurface stratigraphy at District H consists of four potential aquifer zones (Zones A, B, C and D), each separated by clay and silty clay layers/aquitards. Figure 3-3 is a north – south geologic cross-section of the District H site and shows the observation wells and test production wells installed to date at the site. This cross-section also shows the stratigraphic characteristics of the four aquifer zones and interbedded aquitards.

Wells installed at the District G and NRHS well field sites are useful for evaluating long term water level trends, but because the site geology at these wellfields is different from District H they cannot be used as background wells for the District H pump tests.

The water table at the District H well field site is approximately 20 to 30 feet bgs and is encountered in Zone A. Natural Heritage and Endangered Species Program (NHESP) certified vernal pools are present in the vicinity of the test production well sites (see Figure 1-4 and 1-5) in connection with the Zone A aquifer, and therefore Zone A was not considered to be the preferred aquifer zone to serve as a potential public water supply source. However, the evaluation of potential drawdown in the Zone A water table aquifer and potential impacts to the nearby vernal pools from water supply well pumping activities was an integral part of this aquifer performance test program.

Based on geophysical logs from the OW-1D boring, a potential freshwater – saltwater interface is identified in Zone D at a depth of approximately 342 feet bgs (see Figure 2-1 and 3-3). The OW-1D well was screened near the top of this saltwater interface at a depth of 346 to 349 feet bgs. Zone D is not considered a potential zone for public water supply development because of the presence of the saltwater interface, however evaluation of the pumping effects on the saltwater interface in Zone D was a critical part of the testing program.

The two water production zones that were evaluated at the District H site are:

- Zone B, a semi-confined aquifer between 80-120 feet bgs (-50 to -90 feet MSL), and
- Zone C, also a semi-confined aquifer, between 150 and 220 feet bgs (-110 to -180 feet MSL)

Well designation nomenclature for the District H site includes OW (observation well) and TPW (test production well), followed by well cluster number (Clusters 1, 2, 3, and 4), followed by a letter designation indicated that aquifer zone the well is screened in (Zones A, B, C and D).

Detailed monitoring of surface water and groundwater elevations in the vernal pools nearest the test production wells was performed throughout the aquifer performance test program. Piezometers and staff gauges were installed in the vernal pools, and continuous water level monitoring was performed. Staff gauges were used to measure water levels within the vernal pools and piezometers were installed within the peat underlying the vernal pool and beneath the peat in the underlying water table (Zone A). Vernal pool piezometer/staff gauge clusters were designated by the vernal pool number (i.e., VP-E9) followed by an A, B, or C depending upon whether they were open to the vernal pool stage, screened within the underlying peat, or screened in the water table beneath the peat (Zone A), respectively.

3.2 Pump Test Objectives

The primary goal of the individual well pumping tests was to evaluate the aquifer response to pumping and to determine the Approvable Yield in accordance with DEP Drinking Water Program Guidelines (Chapter 4, Section 4.3.1). Individual well pump tests were performed on TWP-3B and TPW-2C, screened in the Zone B and Zone C aquifers, respectively. In addition, a combined pump test was performed in which TPW-3B and TPW-2C were pumped simultaneously.

Pumping rates for the individual well pumping tests were determined from a step test. Available water above the well screens at TPW-3B and TPW-2C were approximately 70 feet and 150 feet, respectively; therefore, available water above the well screen was not a limiting factor for the pump tests.

Two additional objectives to the aquifer testing program were to:

1. Evaluate potential drawdown to nearby vernal pools from production well pumping, and
2. Evaluate response in the Zone D aquifer in order to model movement of the saltwater interface in response to well field pumping and develop a safe yield for operating the well field.

In order to address these additional objectives, pumping rates were set at relatively high rates, particularly with respect to the combined pumping test to ensure that a response was observed in the vernal pools and the transition zone. The pumping rate selected for the 5-day tests was the maximum capacity of the pump, provided that the step test did not indicate a decreased well efficiency at this rate. For the combined pump test, TPW-3B and TPW-2C were each pumped at a rate of 1.0 MGD, for a combined pumping rate of 2.0 MGD.

3.3 Aquifer Test Scope of Work

The long-term aquifer pumping test program for District H consisted of installation of additional observations wells in Zones A, B, C, and D, and piezometer and staff gauge clusters in select nearby vernal pools. The location of all observation wells, test production wells and vernal pool piezometers are shown on Figure 1-5. Table 3-1 summarizes the wells and piezometers installed at the site, survey data, screen depths, and well construction information.

3.3.1 Test Production Wells and Observation Wells

TPW-3B and TPW-2C were installed on Town of Eastham property such that the 400 foot Zone I radius is located on Town and CCNS property and as far away from vernal pools as possible, particularly from vernal pool VP-E9 (at the request of CCNS). The test production wells were also located adjacent to the exploratory observation well that had the highest specific capacity and therefore offer the greatest potential pumping yield. The observation well network for this aquifer test program is as follows:

1. The District H OW-1 cluster, with wells screened in all four aquifer zones (OW-1A, OW-1B, OW-C, OW-1D, and TPW-1B).

2. The OW-2 well cluster, approximately 300 feet north of the OW-1 cluster. The following wells were installed at the District H OW-2 cluster: TPW-2C, OW-2C1 and OW-2C2, OW-2A and OW-2D

3. The OW-3 well cluster, approximately 150 feet north of the OW-1 cluster. The following wells were installed at the District H OW-3 cluster: TPW-3B, OW-3B1, OW-3B2, OW-3A, and OW-3C.

4. The OW-4 well cluster, approximately 500 feet south of the OW-1 cluster on the north edge of vernal pool VP-E9. The following wells were installed at the District H OW-4 cluster: OW-4A, OW-4B and OW-4C

3.3.2 Vernal Pool Piezometers and Staff Gauges

Three vernal pools were monitored under the APT program; vernal pools VP-01, VP-09, and VP-11. These three vernal pools were selected based on recommendations by CCNS and because of their close proximity to the test production wells. The vernal pool monitoring program was reviewed with CCNS prior to initiating the long term aquifer tests. Two piezometers and a staff gauge were installed at each of the three vernal pools. The piezometers were installed in the peat underlying the vernal pools and in the water table beneath the vernal pool (Zone A).

3.3.3 Long Term Water Level Data

Long term water level trends were measured in onsite wells OW-1A, TPW-1B, OW-1C and OW-1D and vernal pool VP-E9 and at the District G well field site (OW-7/OW-8) and NRHS (OW-1A). The locations of these wells are shown on Figure 1-5 and 3-1. The long term water level locations and all of the District H wells, piezometers and staff gauges were equipped with an electronic data logger that collected water levels continuously throughout the field program.

3.3.4 Test Production Well Testing

TPW-3B was completed with a 10-foot, 80-slot, stainless steel well screen and TPW-2C was completed with a 20 foot, 50-slot, stainless steel well screen. Five-day constant rate tests were performed on each test production well at a pumping rate of 1.31 MGD. A third constant rate test was performed over a six-day period in March 2011, where both TPW-2C and TPW-3B were pumped simultaneously at a rate of 1.0 MGD each for a combined pumping rate of 2.0 MGD. The preliminary results of the combined pump test were reviewed and discussed with Mr. Kermit Studley of DEP and the conclusion was reached that the stabilization parameters for the individual pumping tests and combined pumping test were adequately characterized by these tests, and extending the combined test for longer was not necessary.

For the individual pump tests water quality samples were collected throughout the pumping periods in accordance with the approved APT plan. The samples for Gross Beta and Radon collected at the end of the December 2010 5-day constant rate test at TPW-2C were analyzed outside of the standard holding time due to holiday delays. After consultation with DEP, TPW-2C was resampled for these parameters at the end of the combined constant rate test in March 2011.

3.4 Aquifer Test Field Activities

The field activities for the aquifer test began in July 2010 and continued through May 2011. A description of the observation and test well construction, well development, quality control, the monitoring network and long-term aquifer testing activities is provided in the following Sections.

3.4.1 Observation and Test Well Construction

The observation wells and the pilot hole for the test production wells at District H were installed using the sonic drilling method. An 8-inch diameter drill bit was used to drill the observation wells and pilot holes for the two test production wells (TPW-2C and TPW-3B). The sonic drilling technique uses high frequency vibrations to advance the drill bit. Vibrations on the order of 50-180 Hz resonate down the drill pipe and create a condition that essentially fluidizes the surrounding soil within a quarter of an inch of the tooling, thus reducing friction and allowing for a quick and efficient advancement of the bore hole (Barrow 1994). This technique also eliminates the need to introduce drilling fluid additives to the formation (only potable water was used for drilling). A 10 or 20 foot core barrel was used for drilling and near 100% recovery of soil cores from the formation was achieved.

Sonic core samples were characterized in the field (using visual and manual methods) for depth, grain size, sorting, and color, in order to facilitate the selection of a screen zone for that particular well and to guide the placement of subsequent wells. For each boring, soil samples were collected at two foot intervals. These samples were then described, photographed and bagged for future reference. Boring logs for the observation wells and test production wells are included in Appendix C.

During well installation, each set of well materials was suspended in the borehole during sand pack installation. Sand pack for the observation wells was vibrated into place with the sonic rig and grout was installed using the tremie method. These methods assured complete filling of the annular space with sand pack and grout, and assured straight and plumb wells.

For the test production well pilot hole, select samples were submitted to Groundwater Analytical Laboratory for sieve analysis and the analytical results were used to select the best possible stratigraphic zone for the well screen and to optimize the well construction.

Both test production wells were drilled with a Barber dual-rotary drilling rig using reverse circulation. The dual rotary rig operates using two drive heads, one that advances a 16-inch drill casing, and the other that drives a roller bit that leads the way through the formation. After reaching the desired depth for the test production well the dual-rotary rig was pulled off the hole leaving the 16-inch casing in the ground. A cable tool rig was used to finish the well construction and development. Water for all drilling operations was obtained onsite from TPW-1B and OW-2C1.

Well construction details and well coordinates for the OWs and the TPWs are shown in Table 3-1. Well construction logs for TPW-3B and TPW-2C are included in Appendix C.

TPW-3B is constructed as follows: 10 feet of 12-inch diameter, 0.080-inch slot stainless steel, wire wrapped Johnson Hi-Flow well screen with a 12-inch diameter, five-foot long bottom sump and 12-inch diameter, welded carbon steel casing to above the ground surface. Artificial sand pack (US Silica, #4) fills the annular space around the test production well screen. The sand pack extends from 104 to 91 feet bgs with transition sand from 91 to 90 feet bgs. Above the sand pack is volclay bentonite to 80 feet bgs, then a bentonite grout slurry from 80 to 20 feet bgs and neat cement to 10 feet bgs.

TPW-2C is constructed as follows: 20 feet of 12-inch diameter, 0.050-inch slot stainless steel, wire wrapped Johnson Hi-Flow well screen with a 12-inch diameter, five-foot long bottom sump and 12-inch diameter, welded carbon steel casing to above the ground surface. The well screen was set from 185 to

205 feet bgs. Artificial sand pack (US Silica, #2) fills the annular space around the test production well screen. The sand pack extends from 206.5 to 183 feet bgs with transition sand from 183 to 182 feet bgs. Above the sand pack is volclay bentonite to 172 feet bgs, then a bentonite grout slurry from 172 to 20 feet bgs and neat cement to 10 feet bgs.

3.4.2 Well Development

The observation wells were developed by using a submersible pump and surging and over-pumping the well until the discharge was clear and well yield did not noticeably increase over a 1 to 2 hour period. Observation wells were development from four to six hours per well.

TPW-2C and TPW-3B were developed in 5-foot increments while the sand pack was being installed. The sand pack was installed across the lower 5-feet of well screen and was developed using a combination of pumping, surge blocks, and surge blocks with pumping. Periodic specific capacity tests were performed during the well development process. Development was determined to be complete when the discharge was free from sand (at moderate pumping rates), the turbidity was less than 5 NTU, specific conductance was stable, and the results of specific capacity tests showed no significant increases. Once the lower five feet were developed, the sand pack was installed around the next 5 feet of well screen and developed in the same manner. This method of development continued until the sand pack was completed, then the 10-feet or 20-feet of well screen area was developed using surge blocks and pumping. All water produced during development was discharged to the ground approximately two hundred feet or more downgradient from the test production well.

3.4.3 Quality Control

Quality control measures were implemented during borehole drilling and well installation to ensure that no contamination was introduced into the aquifer. All completed wells were fitted with protective steel casings, set in concrete and with locking caps.

Records of pumping rates, weather conditions, and water levels were maintained during the well drilling, construction, and development phases and also the pumping test and recovery period. Weather condition records include precipitation; and water-level measurements include static, drawdown, and recovery readings. The information was recorded in a field notebook that was kept on site during the testing. Additionally, data from the data loggers have been stored electronically.

3.4.4 Water Level Measurements

Electronic data loggers were deployed in the entire observation well network, vernal pool network, and in the test production wells. The data loggers are capable of producing measurements accurate to within 0.01 feet.

The data loggers are the sealed type and therefore record total pressure (i.e., the head of water above the sensor plus atmospheric/barometric pressure). All water-level measurements presented in this report have been adjusted for barometric pressure and are water levels only (i.e., not total pressure nor a combination of water levels plus barometric pressure). A barometric pressure recording data logger and the data logger software (HOBOware Pro version 3.1.1, 2010) was used for the barometric compensation of the water levels.

One barometric data logger was deployed at the NRHS site and one deployed at the District H site. Each barometric data logger was suspended in a well above the piezometric surface and approximately 15-20 feet bgs. This was done to provide a stable temperature environment for the barometric loggers and thereby increase their accuracy.

Long-term background data were compensated using hourly barometric readings. Data that were collected before, during, and after the aquifer testing of TPW-3B and TPW-2C were compensated using barometric readings taken every 15 minutes.

Manual depth-to-water readings were taken periodically in all of the wells. An electronic water level meter, with markings every 0.01 feet, was used for the manual readings. All water levels were measured from top of PVC and the lock notch at the top of each casing was used as the reference point for each reading. The manual readings combined with surveyed elevations of the top of PVC were used to adjust the data logger information to the NAVD 88 datum.

3.4.5 Observation Well Network

All wells in the OW-1, OW-2, OW-3, and OW-4 clusters were used as observation wells for the long-term aquifer tests. The coordinates of these wells and well screen elevation information are provided in Table 3-1. Their distances from TPW-3B and TPW-2C are also included on Table 3-1

3.4.6 Vernal Pool Monitoring Network

Water level monitoring was performed in vernal pools VP-01, VP-09 and VP-11 before, during and after the aquifer performance tests. Two piezometers were installed at each of the three vernal pools, one screened within the underlying peat layer and one screened beneath the peat layer in the water table aquifer (Zone A). Photographs of the vernal pools are included in Appendix D. The water table and peat piezometers were installed with a hand auger. A sand pack was installed around the screen and a bentonite seal was placed on top of the gravel pack up to the bottom of the vernal pool. Both the water table and peat piezometers were developed with a peristaltic pump to ensure they were in good connection with the formation.

Water levels were recorded from three intervals at each vernal pool: the surface water level within the vernal pool, water levels within the peat underlying the vernal pools and water levels at the water table beneath the vernal pools. These water levels were measured from the top of the piezometers, VP-01C, VP-11C, and VP-09B. The vernal pool monitoring locations are shown on Figure 1-5. The coordinates of these piezometers and staff gauge, the piezometer screen elevation, and their distances from TPW-3B and TPW-2C are also provided in Table 3-1.

3.4.7 Background Observation Wells

Long term water level record has been collected from 2009 through 2011 from wells in the OW-1 cluster (TPW-1B, OW-1A, OW-1C, and OW-1D). Long term water level records from the same time period have also been collected at the NRHS (OW-1A) and District G (OW-7/OW-8) well fields. These data were used to evaluate background fluctuations in water levels due to seasonal variations. Background water level measurements were also collected at well EGW-36, located near the intersection of Nauset Road and Cable Road. This well appears to be screened in the Zone A aquifer and, therefore is only useful for evaluating seasonal fluctuations in the shallow water table.

3.4.8 Production Well Step Testing

The step testing of the production wells was performed to determine the pumping rate to be used for the long term pump test and to establish the preliminary specific capacity at the well. Available water column above the well screen was not a limiting factor for the pump test rate.

TPW-3B Step Test

Table 3-2 summarizes the water level measurements and flow rates from the TPW-3B step test. The results of the TPW-3B step test are shown graphically in Figure 3-4. TPW-3B was step-tested at rates of 466, 602, 749, 896, 1,199 (the maximum capabilities of the pump) gpm for one hour at each step. Drawdown at those rates was 7.1, 10.0, 13.2, 16.1 and 21.4 feet, respectively. At these rates the specific capacity ranged between approximately 56 gpm/foot of drawdown (at 896 gpm) to 68 gpm/foot of drawdown (at 466 gpm). A pumping rate of 900 gpm, equivalent to 1.3 MGD was selected for the test.

TPW-2C Step Test

Table 3-3 summarizes the water level measurements and flow rates from the TPW-2C step test. The results of the TPW-2C step test are shown graphically in Figure 3-5. TPW-2C was step-tested at rates of 456, 605, 749, 900, 1,080 (the maximum capabilities of the pump) gpm for one hours at each step. Drawdown at those rates was 13.5, 18.0, 22.8, 27.8 and 33.6 feet, respectively. At these rates the specific capacity ranged between approximately 32.2 gpm/foot of drawdown (at 1,080 gpm) to 34 gpm/foot of drawdown (at 456 gpm). A pumping rate of 900 gpm, equivalent to 1.3 MGD was selected for the test.

3.4.9 Background Water Level Measurements and Precipitation

Long-term, background water-level measurements were taken at the District H OW-1 cluster, NRHS and District G sites from October 2009 through May 2011. Water-level measurements were taken at one-hour intervals using data loggers. Monitoring at these locations is ongoing.

Precipitation data were obtained from the Weather Underground rain gauge station KMAEASTH3, located on Straight Lane off of Old Orchard Road. The Weather Underground station KMAEASTH3 was used in place of the Environmental Partners Group rain gauge, for long term data trends, because the Environmental Partners rain gauge was not installed until August 2010. The Weather Underground station KMAEASTH3 is located approximately 0.5 miles southwest of the Environmental Partners rain gauge station and approximately one mile southwest of the OW-1 well cluster.

A graph comparing long term water levels and precipitation for the District H OW-1 cluster, NRHS OW-1A, and District G OW-7/OW-8 are shown on Figure 3-6, 3-7 and 3-8, respectively. Precipitation is shown as monthly totals in inches. These graphs show a strong seasonal trend to water level elevations. Seasonal fluctuations in water levels indicate water levels decline over the period from June through November and rise from January through May. Seasonally, water levels rise from January through May in response to increased winter and spring precipitation and reduced evapotranspiration and water levels decline from June through November in response to less rainfall and increased evapotranspiration. The graph of the District H OW-1 cluster (Figure 3-6) also shows that wells OW-1B, OW-1C and OW-1D water levels are tidally influences and show diurnal water level fluctuations. Tidal influences on water level data are discussed in more detail in Sections 4.

Long term water level records (Figures 3-6 through 3-8) indicate that the two individual well, five day aquifer performance tests (December 2010) were performed during the seasonal low water levels. At District H, water levels were rising in Zones B and C during December 2010. At District G and NRHS water levels were transitioning from declining water levels in early December 2010 to rising water levels at the end of December 2010. The combined pumping test was performed in March 2011, when water levels were rising in response to seasonal water level fluctuations at all three sites. Background water level changes for each pump test are discussed in more detail in Section 4.

3.5 Pumping Test Procedures

The following is a summary of common aspects to all three District H aquifer tests; TPW-3B, TPW-2C and the combined TPW-3B and TPW-2C aquifer tests:

1. **Pump:** the test production wells were equipped with an electric submersible pump. Power to the pump was supplied by a portable generator.

2. **Flow Regulation:** the flow rate was adjusted by and set through the use of a mechanical valve to regulate the flow rate.

3. **Water Meter:** a 6-inch diameter, factory calibrated, digital, totalizing flow meter was used to measure instantaneous and total flow readings. Flow rates were recorded with an Onset U-30GSM remote monitoring system. Flow rates were recorded at 1 minute intervals throughout the test. In addition flow rates were recorded manually every hour from 7:00 AM to 4:00 PM. Ten feet of 6-inch diameter rigid hose was installed upstream and downstream of the flow meter. The meter and hose were level during the entire duration of the test. Manual flow rate readings for the TPW-3B, TPW-2C and combined pump tests were recorded in a field book kept onsite. A digital file with the remote monitoring flow rates is included in Appendix E.

4. **Sample Port:** a sample port was installed at the wellhead, upstream of the flow meter. Samples for laboratory and field analyses were obtained from the sample port.

5. **Field Water Quality:** samples were measured with a YSI Professional Plus multi-parameter meter for pH, conductivity, specific conductance, temperature, and dissolved oxygen. Samples were either collected in a glass jar and analyzed immediately upon collection or a piece of flexible tube was attached to the wellhead sample port and connected to a flow through cell and the measurements were taken in-line. The meter was calibrated prior to the start of the test and once daily during the test. Odor was analyzed on site by the oversight geologist.

6. **Discharge Hose and Discharge Area:** the discharge hose was 6-inch diameter lay-flat hose. Because of the high flow rates two 6-inch discharge hoses were used. Details about the discharge sites are discussed below in the aquifer performance test summaries. For the TPW-3B and TPW-2C individual well pump tests, the discharge lines were run approximately 1,700 feet east-southeast and downgradient of the test production wells, as shown on Figure 3-9. For the combined aquifer performance test, the discharge lines were run to the same discharge site approximately 1700 feet east-southeast of the test production wells. Polyethylene sheeting and straw bales were used to dissipate the discharge. Three days into the combined pump test, significant ponding was observed at the discharge site. The pump in TPW-2C was shut down for 22 minutes and the discharge line extended an additional 300 feet east-southeast of the first discharge site. No leaks were observed in the discharge lines during the individual pump tests. During the combined aquifer performance test, three days into the test, the discharge line for TPW-2C had a leak and the pump was shut off for 55 minutes to repair the leak.

   The discharge site for the individual 5-day pumping tests was located in a slight depression located approximately 1,650 and 1,700 feet east-southeast and downgradient of test production wells TPW-3B and TPW-2C, respectively. For the combined pumping test, two discharge sites were used, one located 1,700 feet east-southeast of the test production wells and a second site located approximately 2,000 feet east-southeast of the test production wells.

7. Precipitation measurements prior to, during, and after the pumping tests were measured at a rain gauge set up at the Eastham Department of Public Works property (DPW), located approximately 4,700 feet west of the District H test production wells. The rainfall data is included in Appendix F.

8. **Water Level Measurement Frequency:** for the individual well tests (TPW-3B and TPW-2C) the data loggers collected data at the following intervals (for both drawdown and recovery phases): 5 seconds to 10 minutes; 30 seconds to 110 minutes; 1 minute to 1,110 minutes; 10 minutes to end of

test. For the combined pumping test, the data loggers collected data at the following intervals (again for both drawdown and recovery phases): 10 seconds to 20 minutes, 1 minute to 1,000 minutes, 10 minutes to end of test.

9. **Manual Water Level Measurements:** manual water level measurements were collected from the test production wells and nearby observation wells at regular intervals throughout the 5-day pump test, between 7:00 AM and 4:00 PM. During this time period water levels in the test production wells were measured at a minimum every two hours or less.

4 AQUIFER TESTING RESULTS

Three aquifer performance tests were performed at District H, to evaluate aquifer characteristics in the Zone B and Zone C aquifers and to evaluate combined pumping effects from pumping Zone B and Zone C together. Table 4-1 summarizes the pump test results from these aquifer tests, and Table 4-2 summarizes the related water quality sampling and analytical results.

4.1 TPW-3B Constant Rate Test

4.1.1 Summary

The Zone B aquifer is tidally influenced, with water levels showing diurnal tidal cycles. Pre-test water level data from TPW-3B show tidal fluctuations of up to approximately 0.3 feet. These tidal affects had to be considered when determining whether or not a stable drawdown has been achieved for the pump test. Graphs showing the OW-3 cluster pre-test water levels and daily tidal influences on water levels are attached as Figure 4-1. As shown, the water levels at the OW-3 cluster were rising in the 5-days prior to the pump test. Water levels in the Zone B wells at the OW-3 cluster were rising at a rate of approximately 0.03 to 0.052 feet per day.

Manual water level measurements for the TPW-3B test production well, observation wells and vernal pool monitoring locations are summarized in Table 4-3. The pumping period (referred to as the drawdown phase) for the TPW-3B constant rate test took place over a 5-day period between December 6 and 11, 2010. The pump test was run from 09:02 December 6 through 09:04 December 11, 2010. The average pumping rate was 910 gpm or 1.31 MGD. The results of the pump test, including flow rates, drawdown, and available water above the well screen are summarized in Table 4-1. Because of the tidal influence on the Zone B water levels and to be conservative, when determining the maximum drawdown in the pumping well, the value reported is the maximum value measured over the last three days of the test. The top of the well screen is located at 93 feet bgs (95.09 feet below TOC). The static water level at the start of the pump test was 21.28 feet below TOC. At the pumping rate of 910 gpm, maximum water level at the end of the 5-day test was approximately 38.86 feet below TOC. The top of the well screen was 93 feet bgs (95 feet below TOC); therefore, available water above the screen at the end of the 5-day pump test was 56.23 feet.

Induced infiltration at the discharge location does not appear to have occurred.

4.1.2 Pre-Test Water Levels and Tidal Effects on Water Levels

Figures 4-1 show water levels for the District H OW-3 cluster wells prior to the start of the pump test. Prior to the drawdown phase of the test, water levels in the Zone B wells were rising at a rate of 0.03 to 0.046 feet per day. This rise in water levels is probably related to a seasonal rise in water levels.

Appendix G – Attachment 1 contains graphs of the District H wells for the month of December 2010. These plots overlay the tidal cycle from the NOAA web site as recorded at the Chatham, MA Station ID: 8447435. As shown on these graphs, water levels at District H are rising over the month of December, but the lunar tidal cycle also appears to have an effect on the Zone B, C and D water levels. Overall measured water levels in Zones B, C, and D show a slight rise as the lunar tidal cycle is rising and slight decline as the lunar tide cycle is waning. The exception to this trend is the OW-4B, which shows no tidal response. Water levels in all Zone A wells do not show a tidal response.

After the drawdown and recovery phase of the test was complete, water levels at District H wells recovered to water levels equal to or higher than the pre-test water levels. The higher water levels are the result of a seasonal rise in water levels, which can be seen in the water level plots in Appendix G – Attachment 1. A review of long term water level data from the OW-1 cluster wells for December 2009 (see Figure 3-6), also shows water levels in TPW-1B, OW-1C and OW-1D increasing over the month of December, with an overall rise in water levels at a rate of approximately 0.015 feet/day.

Pre-test tidal water level fluctuations in the TPW-3B well range up to 0.3 feet; therefore, it is not possible to meet the requirements outlined in DEP's Guidance Manual *Groundwater Supply Development and Source Approval Process* (Chapter 4, Section 4.3.1.4.5.c.(1)) "the well will be considered stabilized when the drawdown reading recorded at the pumping well…has not varied more than 0.04-foot during the final 24-hours."

4.1.3 Drawdown stabilization

Drawdown at TPW-3B, OW-3A, OW-3B1, OW-3B2 and OW-3C just prior to, during, and after the drawdown phase of the TPW-3B pumping test are shown on Figure 4-2. Figure 4-3 shows the drawdown levels in the Zone B wells at the site (TPW-3B, OW-3B1, OW-3B2, OW-2B, TPW-1B, and OW-4B) during this same time period. Figure 4-4 is a long-linear plot of the drawdown at TPW-3B and OW-3 cluster observations wells for the drawdown and recovery phase of the pump test, and Figure 4-5 shows the same information for the TPW-3B and Zone B observations wells. Additional water level plots for other District H well clusters and manual gauging data plots are included in Appendix H.

Figures 4-6 is a zoom-in of water-level data from TPW-3B for the last 48-hours, prior to turning off the pump, using data logger data. The range of tidal effects on water levels at TPW-3B is greater than the DEP drawdown stabilization criteria of less than 0.04 feet within 24 hours. A time period of 48-hours was selected in order to average the tidal effects on the water levels. The graphs show that at the end of the pumping test water levels began to rise slightly by 0.02 feet per day. This rise in water levels in consistent with a seasonal rise in water levels for December and with the rise in water levels observed during the five days prior to the pumping test.

Because of the tidal effects on water level data and to confirm drawdown at the end of the pump test, a 180-day log-liner plot of the drawdown data was plotted to document available water above the screen using the drawdown data from the last 70 hours (three days) of the test. This is shown in Figure 4-7. As on Figure 4-7 the total drawdown in feet after 180 days would be 17.75 feet, or a water depth of 38.86 feet below TOC. To meet the DEP criteria of having 10 percent of the water column (7.4 feet) above the well screen or a minimum of five feet of water above the well screen at the end of the test, the water level at the end of the test must be less than 85.6 feet below TOC. Approximately 56 feet of water is available above the well screen at the end of the test, well above DEP's safety buffer.

The maximum drawdown at TPW-3B was 38.86 feet below TOC (17.58 feet of drawdown). Drawdown at the water table (Zone A) at TPW-3A, located 10 feet from TPW-3B, was 0.18 feet at the end of the test, indicating that the Zone B aquifer is semi-confined.

Figures 4-8 and 4-9 show the Zone B piezometric surface of the Zone B aquifer at the District H site immediately before the constant rate test and at the end of the constant rate test, respectively. Drawdown in the Zone B aquifer was 13.12 feet at OW-3B2, 11.36 feet at OW-3B1, and less 7.5 feet at the OW-1 and OW-2 clusters. These wells are located 4 feet, 25 feet, 157 feet, and 158 feet, respectively from the TPW-3B well. Drawdown at the W-04B well was 0.41 feet. The OW-4B well is screened slightly higher than TPW-3B; with OW-4B screened at elevation -44.32 to -54.32 feet and TPW-3B screened at -57.32 to -67.32 feet NAVD88. The OW-4B well does not appear to be in direct connection with TPW-3B and the other Zone B wells, because the OW-4B well does not show as much tidal influence as the other Zone B wells, and more drawdown was observed in the OW-4C well (2.85 feet) than in the OW-4B well.

Figure 4-10 is a log-linear plot showing observed drawdown in the Zone B aquifer at the end of the 5-day pumping test verses distance from TPW-3B. This plot was prepared using drawdown data from the OW-1, OW-2, and OW-3 cluster wells. The OW-4B well was not included in the plot because this well does not appear to be in hydraulic connection with TPW-3B.

4.1.4 Recovery Period

Figures 4-2 and 4-3 are linear plots showing the recovery and post-test water levels for the OW-3 cluster wells and for the Zone B wells, respectively. Figures 4-4 and 4-5 are log-linear plots of the recovery data and post-test water levels for the OW-3 cluster wells and Zone B wells, respectively. As shown on these figures, water-levels stabilize after the pump is shut down, but at the same or higher level than the pre-test water-level elevations. Post-test water levels are affected by the overall seasonal rise in water-level elevations as shown by the water level plots in Appendix G – Attachment 1.

4.1.5 Evaluation of Induced Infiltration

Induced infiltration does not occur at the TPW-3B production well. The Zone B aquifer is semi-confined with an overlying clay/silty-clay layer. The nearest surface water bodies are the vernal pools, with the nearest vernal pools being VP-5 and VP-11 located approximately 650 feet down-gradient and to the east of TPW-3B. The vernal pools are also underlain by a peat layer that minimizes hydraulic connection with the underlying aquifer, as discussed in more detail in Section 7.

4.1.6 Influence from Other Pumping Wells

There are no pumping wells in the immediate vicinity of the TPW-3B well; therefore, there is no influence on the TPW-3B pumping test from nearby wells.

4.1.7 Water Quality

The analytical results of water samples collected during the District H TPW-3B test are summarized on Table 4-2, and the laboratory reports are provided in Volume 2 of this report. The results show that water quality is suitable for public supply. The water quality parameters are consistent through the pumping period with only minor variations. All of the laboratory analytical parameters are within the standards and recommendations set forth for drinking water, except pH.

The groundwater pH during the 5-day pump test was slightly acidic, with the pH at 5-days being 6.26, and therefore will need adjustment to meet the Secondary Maximum Contaminant Level (MCL) (6.5 to 8.5). This is consistent with other public water supply wells in the outer Cape Cod area, with the permitted District H TPW-1B well, and the NRHS water supply well.

4.2 TPW-2C Constant Rate Test

The Zone C aquifer is tidally influenced, with water levels showing diurnal tidal cycles. Pre-test water level data from TPW-2C, OW-2C1 and PW-2C2 show tidal fluctuations of up to approximately 0.3 feet. These tidal affects had to be considered when determining whether or not a stable drawdown has been achieved for the pump test and the pump could be turned off. Figure 4-11 is a graph showing the OW-2 cluster pre-test water levels and daily tidal influences on water levels. As shown in this graphs, the water levels at the OW-2 cluster were rising in the 5-days prior to the pump test. Water levels in the Zone C wells at the OW-2 cluster were rising at a rate of approximately 0.038 to 0.052 feet per day.

Manual water level measurements for the TPW-2C test production well, observation wells and vernal pool monitoring locations are summarized in Table 4-4. The pumping period (referred to as the drawdown phase) for the TPW-2C constant rate test took place over a 5-day period between December 16 and 21, 2010. The pump test was run from 09:02 December 16 through 09:04 December 21, 2010. The average pumping rate was 916 gpm or 1.31 MGD. The results of the pump test, including flow rates, drawdown, and available water above the well screen are summarized in Table 4-1. Because of the tidal influence on the Zone C water levels and to be conservative, when determining the maximum drawdown in the pumping well, the value reported is the maximum value measured over the last three days of the test. The top of the well screen is located at 185 feet bgs (187 feet below TOC). The static water level at the start of the pump test was 30.54 feet below TOC. At the pumping rate of 916 gpm, maximum water level drawdown at the end of the 5-day test was approximately 59.94 feet below TOC. The top of the well screen was 185 feet bgs (187 feet below TOC); therefore, available water above the screen at the end of the 5-day pump test was 127 feet.

Induced infiltration at the discharge location does not appear to have occurred.

4.2.1 Pre-Test Water Levels and Tidal Effects on Water Levels

Figure 4-11 show water levels for the District H OW-2 cluster wells prior to the start of the pump test. Prior to the drawdown phase of the test, water levels in the Zone C wells were rising at a rate of 0.038 to 0.052 feet per day. This rise in water levels is probably related to a seasonal rise in water levels in response to precipitation.

Appendix G – Attachment 1 contains graphs of the District H wells for the month of December 2010. These plots overlay the tidal cycle from the NOAA web site as recorded at the Chatham, MA Station ID: 8447435.

Water levels at District H rose over the month, but the lunar tide cycle also has an effect on the Zone B, C and D water levels. Overall, measured water levels in Zones B, C, and D show a slight rise as the lunar tidal cycle rises and wanes with the tidal cycle. The exception to this trend is at OW-4B, which shows no tidal response. Water levels in all Zone A wells do not show a tidal response.

After the drawdown and recovery phase of the test was complete water levels at District H wells recovered to water levels equal to or higher than the pre-test water levels. The higher water levels are a result of a seasonal rise in water levels, which can be seen in the water level plots in Appendix G – Attachment 1. A review of long term water level data from the OW-1 cluster wells for December 2009 (see Figure 3-6), also shows water levels in TPW-1B, OW-1C and OW-1D increasing over the month of December, with an overall rise in water levels at a rate of approximately 0.015 feet/day.

Pre-test tidal water level fluctuations in the TPW-2C well range up to 0.3 feet; therefore, it is not possible to meet the requirements outlined in DEP's Guidance Manual *Groundwater Supply Development and Source Approval Process* (Chapter 4, Section 4.3.1.4.5.c.(1)) "the well will be considered stabilized when the drawdown reading recorded at the pumping well…has not varied more than 0.04-foot during the final 24-hours."

4.2.2 Drawdown stabilization

Water levels at the OW-2 cluster wells, TPW-2C, OW-2A, OW-2B, OW-2C1, OW-2C2 and OW-2D, prior to, during, and after the drawdown phase of the TPW-2C pumping test are shown on Figure 4-12. Figure 4-13 shows the water levels in the Zone C wells (TPW-2C, OW-2C1, OW-2C2, OW-3C, OW-1C, and OW-4C) during this same time period. Figure 4-14 is a long-linear plot of the drawdown at TPW-2C and OW-2 cluster observations wells for the drawdown and recovery phase of the pump test. Figure 4-15 is a long-linear plot of the drawdown at TPW-2C and Zone C observations wells for the drawdown and recovery phase of the pump test. Additional water level plots for other District H well clusters and manual gauging data plots are included in Appendix H.

Figures 4-16 is a zoomed-in view of water-level data from TPW-2C for the last 48-hours, prior to turning off the pump, using data logger data. The range of tidal effects on water levels at TPW-2C exceeds DEP's drawdown stabilization criteria because at the end of the test water levels began to rise slightly by 0.13 feet per day. This is suspected to be due to the seasonal rise in water levels occurring During December 2010, and a gradually increasing tide elevation.

Because of these tidal effects on water level data and as a confirmation of the end of test drawdown, a 180-day log-liner plot of the drawdown data at the end of the test was plotted to document available water above the screen using water level data for December 18 and 19, 2010. This is shown in Figure 4-17 with an extrapolation of the trend line to 180-days. The total drawdown after 180 days would be 29.24 feet (59.78 feet below TOC). Based on DEP criteria to have either 10 percent of the water or a minimum of five feet of water above the well screen, the drawdown water level in TPW-2C must be less than 171 feet below TOC. The time-drawdown plot indicates that at 180 days, approximately 127 feet of water is available above the well screen, which is well above DEP's criteria.

The maximum drawdown at TPW-2C was 59.94 feet below static water level. Drawdown at the water table (Zone A) at OW-2A, located 11 feet from TPW-2C, was 0.16 feet at the end of the test, indicating that the Zone C aquifer is semi-confined. Figures 4-18 and 4-19 show the piezometric surface of the Zone C aquifer at the District H site immediately before and at the end of the TPW-2C constant rate test. Drawdown in the Zone C aquifer was 14.9 feet at the OW-2C2 well, 10 feet at the OW-2C1 well, 5.15 feet at the OW-3C well, 3.76 feet at the OW-1C well and 2.47 feet at the OW-4C well. These wells are located 6 feet, 19 feet, 123 feet, 300 feet, and 780 feet away from the TPW-2C well, respectively.

Figure 4-20 is a log-linear plot showing observed drawdown in the Zone C aquifer at the end of the 5-day pumping test verses distance from TPW-2C using drawdown data from the OW-1, OW-2, OW-3 and OW-4 cluster wells.

4.2.3 Recovery Period

Figures 4-12 and 4-13 are linear plots showing the recovery and post-test water levels for TPW-2C and the OW-2 cluster wells, respectively. Figures 4-14 and 4-15 are log-linear plots of the recovery data and post-test water levels for the OW-2 cluster wells and Zone C wells, respectively. As shown on these figures, water-levels stabilize after the pump is shut down, but at the same or higher level than the pre-test water-level elevations. Post-test water levels are affected by the overall seasonal rise in water-level elevations as shown by the water level plots in Appendix G – Attachment 1 and Appendix H.

4.2.4 Induced Infiltration Evaluation

Induced infiltration does not occur for the TPW-2C production well. The Zone C aquifer is semi-confined with two overlying clay/silty-clay layers. The nearest surface water bodies are the vernal pools, with the nearest vernal pools being VP-5 and VP-11 located approximately 550 and 700 feet down-gradient to the east of TPW-2C.

4.2.5 Influence from Other Pumping Wells

There are no pumping wells in the immediate vicinity of the TPW-2C well; therefore, there is no influence on the TPW-2C pumping test from nearby wells.

4.2.6 Water Quality

The analytical results of water samples collected during the District H TPW-2C test are summarized on Table 4-2 and the laboratory reports are provided in Volume 2. The results show that water quality is suitable for public supply. The water quality parameters are consistent through the pumping period with only minor variations. All of the laboratory analytical parameters are within the standards and recommendations set forth for drinking water, except pH.

The groundwater pH during the 5-day pump test ranged from 5.67 to 6.20. Adjustment of the pH will be required to meet the DEP Secondary Maximum Contaminant Level (MCL). This is consistent with other public water supply wells in the outer Cape Cod area, with the permitted District H TPW-2 well and the nearby NRHS water supply well.

The samples for radon and radionuclide gross beta were analyzed outside of holding times, because of holiday closings. Based on discussions with Mr. Kermit Studley of DEP, TPW-2C would be re-sampled for radon and gross beta as part of the combined pumping test. As indicated in Section 4.3.7, analytical results for radon and gross beta at TPW-2C were within MCLs.

4.3 Combined TPW-3B and TPW-2C Constant Rate Test

4.3.1 Summary

After the individual well pumping tests for TPW-3B and TPW-2C were completed, a combined pumping test was conducted in which TPW-3B and TPW-2C were pumped both pumped at the rate of 1.0 MGD, for a combined pumping rate of 2.0 MGD. The Request for Pump Test Report (EPG 2010) stated that the combined pump test would be performed for five days. The purpose of the combined pump test was to:

a) attempt to see changes in water quality in the Zone D wells, since little change was observed during the individual well tests, and

b) provide additional data for modeling pumping effects on the nearby vernal pools and on the behavior of the saltwater interface.

Manual water level measurements for the TPW-3B and TPW-2C test production wells, observation wells and vernal pool monitoring locations are summarized in Table 4-5. The pumping period (referred to as the drawdown phase) for the combined constant rate test was scheduled to be performed over a 10-day period; however, the pump in well TPW-3B failed after 6 days and 17 hours of pumping. Preliminary test results were reviewed with DEP and it was agreed that the test data collected was sufficient. The pumping period for the combined constant rate test was performed between March 22, 2011 and March 28, 2011.

The Zone B and Zone C aquifers are tidally influenced, with water levels showing diurnal tidal cycles. As discussed above, pre-test water level data from TPW-3B and TPW-2C both showed tidal fluctuations of up to approximately 0.3 feet. The static water level at TPW-3B was 20.33 feet below TOC and at TPW-2C was 29.82 feet below TOC. At a pumping rate of 1 MGD per well, the maximum water level drawdown at the end of the combined pumping test was 35.72 feet below TOC at feet at TPW-3B and 54.20 at TPW-2C. Available water above the screen at the end of the combined pumping test was 59 feet at TPW-3B and 132 feet at TPW-2C.

Induced infiltration at the discharge location does not appear to have occurred.

4.3.2 Pre-Test Water Levels and Tidal Effects on Water Levels

Figure 3-6 is a graph showing long term water levels in the OW-1 well cluster. The water levels in the were rising slightly during the month of March 2011. Graphs showing water levels at the OW-2 and OW-3 clusters for five days prior to the pumping test are attached as Figures 4-21 and 4-22, respectively. The water levels in the Zone B and Zone C aquifers show diurnal tidal cycles and were rising in the five days prior to the pump test at a rate of 0.02 to 0.03 feet per day in the Zone B wells (except OW-3B2, which had a larger rise of 0.05 feet per day) and 0.02 to 0.04 feet per day in the Zone C wells. This rise in water levels is probably related to seasonal rise in water levels.

Pre-test tidal water level fluctuations in the TPW-3B and TPW-2C were approximately 0.3 feet. After the drawdown and recovery phase of the test was complete, water levels at District H wells recovered to water levels equal to or higher than the pre-test water levels. The higher water levels are a result of a seasonal rise in water levels.

4.3.3 Drawdown stabilization

Graphs of the water levels just prior to, during, and after the drawdown phase of the pumping test are summarized in the following figures:

	OW-3 Well Cluster	OW-2 Well Cluster	Zone B Wells	Zone C Wells	TPW-3B	TPW-2C
Drawdown vs. Time Data Logger Data	Figure 4-23	Figure 4-27	Figure 4-24	Figure 4-28		
Drawdown vs. Time Log-Linear	Figure 4-25	Figure 4-29	Figure 4-26	Figure 4-30		
End of Test Water Levels (Zoom)					Figure 4-31	Figure 4-33
End of Test Water Levels Log-Linear Plot with 180 day Extension					Figure 4-32	Figure 4-34

Additional water level plots for other District H well clusters and plots of manual gauging data are included in Appendix H.

As shown on Figures 4-23 through 4-30, the rate of drawdown began to stabilize after approximately 3 days of pumping (March 24, 2010) and pumping continued until March 28, 2010. Figure 4-31 shows a zoom-in of water level data from TPW-3B for the last 30-hours, prior to the pump shutting down, using data logger data. The range of tidal effects on water levels at TPW-3B is greater than the DEP drawdown stabilization criteria of less than 0.04 feet within 24 hours. A time period of 30-hours was selected instead of 24-hours to average out the tidal effects. The graphs show that at the end of the test water levels began to rise slightly, consistent with a seasonal rise in water levels for March and with the rise in water levels observed during the five day, pre-test water levels.

Because of the tidal effects on water level data and as a confirmation of the end of test drawdown, a 180-day log-liner plot of the drawdown data at the end of the test was plotted to document available water above the screen. Figure 4-32 shows water levels at TPW-3B for the last 30-hours of the pump test with a 180-day extrapolation of the trend line. The total drawdown after 180 days is 15.63 feet or 35.96 feet below TOC. The DEP criteria requires that the drawdown water level must be less than 87 feet below TOC; the time-drawdown plot indicates that at 180 days approximately 59 feet of water is available above the well screen, well above DEP's safety buffer.

Figure 3-33 shows water level data from TPW-2C for the last 30-hours of the test. The range of tidal effects on water levels at TPW-2C is greater than the DEP drawdown stabilization criteria. At end of the test water levels were decreasing slightly. Figure 4-34 shows water levels at TPW-2C for the last 30-hours of the pump test with a 180-day extrapolation of the trend line. The total drawdown after 180 days is 25.31 feet or 55.13 feet below TOC. The DEP criteria require that the drawdown water level must be less than 171.34 feet below TOC. The time-drawdown plot indicates that at 180 days approximately 132 feet of water is available above the well screen, well above DEP's criteria.

Figures 4-35 and 4-36 show the Zone B piezometric surface at the District H site immediately before the constant rate test and at the end of the constant rate test, respectively. The maximum drawdown at TPW-3B was 15.39 feet below static water level. Drawdown in the Zone B aquifer was 12. 2 feet at OW-3B2, 10.79 feet at OW-3B1, and less 7.8 feet at the TPW-1B and OW-2B wells. These wells are located 4 feet, 25 feet, 157 feet and 158 feet from TPW-3B, respectively. Drawdown in the Zone B aquifer at OW-4B, located 774 feet from TPW-3B, was less than 0.52 feet.

Figures 4-37 and 4-38 show the Zone C piezometric surface at the District H site immediately before the constant rate test and at the end of the constant rate test, respectively. The maximum drawdown at TPW-2 was 24.38 feet below static water level. Drawdown in the Zone C aquifer was 13.45 feet at the OW-2C2 well, 9.26 feet at the OW-2C1 well, 6.05 feet at the OW-3C well, 5.09 feet at the OW-1C well and 4.15 feet at the OW-4C well. These wells are located 6 feet, 19 feet, 123 feet, 300 feet, and 780 feet away from the TPW-2C well, respectively.

Figures 4-39 and 4-40 are log-linear plots of distance vs. drawdown graphs for the Zone B and Zone C aquifers, respectively.

Drawdown in the water table (Zone A) wells at the end of the test was 0.31 feet at OW-2A (located 11 feet from TPW-2C) and 0.30 feet at OW-3A (located 10 feet from TPW-3B). These data confirm that the Zone B and Zone C aquifers are semi-confined and have minimal effect on the water table aquifer.

4.3.4 Recovery Period

Figures 4-23 and 4-25 are linear and log-linear plots showing the recovery and post-test water levels for TPW-3B during the combined pumping test. Figures 4-27 and 4-29 are linear and log-linear plots showing the recovery and post-test water levels for TPW-2C during the combined pumping test. Water levels stabilize after pumping at the same or higher level than the pre-test water-level elevations. Post-test water levels are affected by the overall seasonal rise in water-level elevations as shown in the long term water level plot (Figure 3-6) of the OW-1 cluster wells.

4.3.5 Induced Infiltration Evaluation

Induced infiltration does not occur for the TPW-3B or TPW-2C production wells. The Zone B aquifer is semi-confined with an overlying clay/silty-clay layer and the Zone C aquifer is semi-confined with two overlying clay/silty-clay layers. The nearest surface water bodies are shallow vernal pools, with the nearest vernal pools being VP-5 and VP-11 located downgradient to the east of the test production wells.

4.3.6 Influence from Other Pumping Wells

There are no pumping wells in the immediate vicinity of the TPW-3B and TPW-2C wells; therefore, there is no influence on the combined pumping test from nearby wells.

4.3.7 Water Quality

Comprehensive water quality testing (Appendix A list) was performed for both the TPW-3B and the TPW-2C pump tests. After consultation with DEP, it was determined that water quality analyses were not required for the combined pumping test except to re-collect and analyze samples from TPW-2C for radon and gross beta. Analytical results for radon and gross beta were within MCLs for TPW-2C.

Laboratory reports for the TPW-2C analyses are included in Volume 2 of this report. Trace levels (0.1 ppm) of iron were detected at TPW-2C during the 5-day pumping test. The MCL For iron is 0.3 ppm. To confirm these results a sample was collected from TPW-2C at the end of the combined pumping test and analyzed for inorganics. Iron was detected at a concentration of 0.2 ppm. Both samples were below regulatory levels for all inorganic parameters.

Samples were collected from both the TPW-3B and TPW-2C wells for field parameters pH, specific conductance, temperature and turbidity. Samples were collected after one hour of pumping and then once daily until the pump test was completed. Consistent with the individual well test, pH levels were slightly acidic, ranging from 6.03 to 6.21.

4.4 Constant Rate Test Evaluation

The constant rate test data were evaluated to determine aquifer parameters, transmissivity, hydraulic conductivity and storativity. Only the data from the individual well aquifer tests performed in December 2010 were analyzed for aquifer properties. Water levels collected for TPW-3B and TPW-2C were evaluated using time-drawdown, distance-drawdown, and time-recovery data and are summarized in the table below. Complete data plots are included in Appendix I.

Aquifer Test Pro software, version 2010.1 (Schlumberger Water Services, Inc.) was used to support these evaluations. A combination of both manual and automated curve-matching techniques was utilized for the solutions. Time-drawdown analyses were performed using both the Theis method and the Hantush

Method for leaky confined aquifers with storage in the aquitard. Distance-drawdown evaluations utilized the Cooper-Jacob method at 1,000 and at 10,000 minutes. Recovery data were evaluated using the Agarwal method with Theis type curve solution.

The test production wells (TPW-3B and TPW-2C) were not used for the evaluations, because the drawdown in the well was affected by well inefficiency and the distance for drawdown evaluations was too small. The following table summarizes the results of the aquifer test evaluations.

Calculated Transmissivity (T), Hydraulic Conductivity (K) and Specific Yield (Sy) for TPW-3B and TPW-2C

		TPW-3B		TPW-2C	
		High	**Low**	**High**	**Low**
Time-Drawdown	**T**	37,400	12,700	39,600	9,600
	K	249	13.9	528	128
	Sy	1.09E-04	3.68E-08	8.26E-3	2.63E-8
Distance-Drawdown	**T**	12,300	12,200	11,100	11,100
	K	94.3	81.3	148	148
	Sy	2.33E-02	1.09E-02	4.05E-2	1.71E-2
Recovery	**T**	19,300	14,100	33,300	21,800
	K	129	94.3	444	291
	Sy	1.67E-04	2.30E-05	2.92E-4	4.03E-8
Average	**T**	18,800		23,000	
	K	119		306	
	S	2.46E-3		4.44E-3	

T is transmissivity in $feet^2/day$
K is hydraulic conductivity in feet/day
S is the storage coefficient

The aquifer test analyses provided a baseline for evaluating the aquifer properties for Zone B and Zone C at the District H site. More extensive analyses were performed using the Multi-layer Unsteady (MLU) model to develop aquifer parameters for Zones A, B, C and D and for the semi-confining layers which separate these aquifers. The MLU modeling is discussed in detail in Section 6 and Appendix G Attachment 2.

4.5 Cluster Well Testing

4.5.1 Zone B and Zone C Wells

The following observation wells at District H were tested after installation to further characterize the site hydrogeology: OW-3B1, OW-3C1, and OW-2C1. A 6 hour constant rate test was performed at each of these wells at a rate of 60 gpm. The calculated specific capacity for wells OW-3B1, OW-3C1, and OW-2C1 were 36.8 gpm/foot, 13.3 gpm/foot and 28.9 gpm/foot, respectively. An observation well was installed in the Zone B aquifer at the OW-2 cluster (OW-2B), but the material was not suitable for water supply development and a 6-hour pump test was not performed on this well. The results of these constant rate tests indicate that there may be some variability within the Zone B and C aquifers at District H.

Water quality samples were collected at the end of each 6-hour pump test wells (OW-3B1, OW-3C1, and OW-2C1) and submitted for laboratory analysis of VOCs by EPA Method 524.2, iron, sodium, total dissolved solids (TDS), chloride, nitrate, nitrite, and sulfate. Samples were also analyzed in the field for pH, specific conductivity, and temperature. The results of these analyses are summarized in Table 4-6. All parameters were within MCLs at all three observation wells tested with the exception of pH, which is slightly acidic.

4.5.2 Zone D Wells

Manual water level measurements and data loggers were used to monitor water levels in the two Zone D wells, during the TPW-3B and TPW-2C individual well, 5-day pumping tests and during the combined pumping test, to determine water level responses in the Zone D aquifer. A saltwater interface was identified on borehole geophysical logs at approximately 342 feet bgs at OW-1D. Water level drawdown was measured at both OW-1D and OW-2D during all three pumping tests; however, the response was less than observed in the Zone B or Zone C aquifers. Drawdown in the OW-1D and OW-2D was less than 2.2 feet for all three pumping tests. Aquitards separate the Zone A, Zone B, Zone C and Zone D aquifers. The presence of an aquitard between Zone C and Zone D and two aquitards between Zone B and Zone D result in a reduced drawdown effect in the Zone D aquifer. The relationship between the aquifer zones and aquitards are evaluated in detail with the SEAWAT model and MLU model, discussed in detail in Sections 5, 6 and 8.

Water quality samples were collected from Zone D wells in order to evaluate potential pumping effects on the Zone D aquifer and associated saltwater interface. These data are summarized in Table 4-6. Water quality samples were collected from Zone D wells OW-1D and OW-2D prior to the TPW-3B aquifer test to collect static water quality data. During the TPW-3B and TPW-2C pumping tests, water quality samples were collected from the two Zone D wells after two days and four days of pumping. Water quality samples were collected from the Zone D wells during the combined pump test, prior to the test, after two days of pumping and after the TPW-3B pump failed (at six days and four hours). The water quality samples were analyzed for parameters the following parameters: field analyses of pH, specific conductance and temperature; and laboratory analysis for total iron, sodium, TDS, chloride and sulfate.

The results are presented in Table 4-6 and summarized as follows:

1. Total iron, sodium, TDS, chloride, and specific conductance are higher in the OW-1D well than in the OW-2D well, although the two wells are screened at approximately the same elevation.

2. TDS, sodium, and chloride concentrations exhibit a slight increase over the TPW-3B 5-day pumping test.

3. TDS and chloride exhibit a slight increase over the TPW-2C 5-day pump test.

These results indicate a slight response in water quality to pumping activities in the OW-1D well, but not in the OW-2D well.

4.6 Vernal Pool Monitoring

Water levels were monitored in vernal pools VP-E1, VP-E9 and VP-E11 before, during and after all three pumping tests. Piezometers were installed within the peat layer and in the water table beneath the vernal pool, to monitor water levels in these zones. Surface water and groundwater elevations in the peat layer and the zone beneath the peat were monitored with water level loggers at the same frequency as the pumping test. Manual water levels were also collected at all three vernal pools at least once daily during all three pumping tests to confirm and correct the data logger measurements. Manual vernal pool water level measurements for the TPW-3B, TPW-2C and combined pumping tests are summarized in Tables 4-3, 4-4, and 4-5, respectively.   Figures 4-41, 4-42, and 4-43 show the water levels in vernal pools VP-E1, VP-E9 and VP-E11, respectively, from December 2010 through May 2011based on water level logger data. These plots also show precipitation as measured at the rain gauge set up at the Eastham DPW.

As shown in these figures, precipitation events have the largest effect on vernal pool and peat layer water levels. Little or no response to production well pumping was observed at vernal pools VP-E01 and VP-E09. Vernal pool VP-E11 is the only vernal pool that showed a response to production well pumping. The maximum observed drawdown observed at VP-E11 in the vernal pool, peat layer, and water table (Figure 4-47) was 0.09 feet, 0.19 feet, and 0.53 feet, respectively. These drawdowns were observed during the combined pump test with a combined pumping rate of 2.0 MGD.

The vernal pool data were used to evaluate the effects of production well pumping on vernal pool water levels and to develop a site specific model for assessing the effects of production well pumping on vernal pool VP-E11. These results are discussed in detail in Section 7.

4.7 Maximum Approvable Yield

The Drinking Water Program Guidelines (Chapter 4, Section 4.3.1.5) state that, for a pumping test conducted on the well that will be used as the final production well the calculated approvable yield will be the rate at which the pumping test was conducted, provided that a 5-foot safety margin exists when the applicable stabilization criteria is met (as discussed in Chapter 4, Section 4.3.1.4.5.c). The potential approvable yield for each well was therefore determined by:

(1) Calculate Available Water (AW):

AW = depth of pumping well – bottom sump – length of screen – static water level – 5 foot safety factor

(2) Calculate Specific Capacity (SC) of the pumping well:

$$\text{SC (gpm/foot)} = \frac{\text{Pumping rate}}{\text{Drawdown at stabilization}}$$

(*Note*: Drawdown is measured in the production well or, in the case where the pumping test is conducted on a test well, drawdown is measured in the observation well that is located 2 feet from the test well.)

(3) Calculated Approvable Yield (AY):

AY (gpm) = AW x SC x 0.75 (safety factor)

Note: the 0.75 multiplier is only applied if the pumping test was conducted on a test well rather than the final production well, and therefore, is not applicable for the District G TPW-1 well.

Calculation of Approvable Yield for District H Test Production Wells

Well Parameter	*TPW-3B*	*TPW-2C*	*Combined APT*	
			TPW-3B	*TPW-2C*
Depth of Well (feet bgs)	108	210	108	210
Length of Bottom Sump	5	5	5	5
Length of Well Screen (feet)	10	20	10	20
Static Water Level (feet bgs)	19.2	28.5	18.2	27.8
Pumping Rate (gpm)	910	916	716	722
Drawdown (feet)	17.6	29.4	15.4	24.4
Available Water (feet)	68	151	69	152
Specific Capacity (gpm/ foot)	51	31	46	29
Approvable Yield (gpm)	3,468	4,681	3,174	4,408

Where:
Static Water Level is the depth to water just prior to turning on the pump for the 7-day test
Pumping Rate is the average pumping rate
Drawdown is based on the last manual depth to water reading just prior shut down.

According to the calculations in the above table, the approvable yields for TPW-3B and TPW2C, either pumping individually or combined, are much higher than the pumping rate at which the tests were conducted. DEP regulations require that for wells in which the pumping test was conducted on the production well, the permit requested pumping rate not exceed the APT pumping rate. Therefore, the maximum approvable yield based on individual well pumping tests for TPW-3B is 910 gpm (1.31 MGD) and TPW-2C is 916 gpm (1.31 MGD).

The long term safe yield of the wells needs to consider the water quality conditions at the well screen under prolonged (100+ years) pumping conditions. This analysis, performed through the groundwater modeling activities described in Section 5 through 9, evaluates the calculated approvable yields described above to develop the recommended safe yield for the District H wellfield.

5 GROUNDWATER MODEL DEVELOPMENT

5.1 HYDROGEOLOGY OF LOWER CAPE COD

Chapter 4 of the DEP Drinking Water Program Guidelines outlines the source approval process and presents requirements and methods for determining the approvable yield of a well and delineation of the Zone II protection area. Computer groundwater modeling analyses were performed to address these requirements, as described in the sections below, using data collected from the field investigation program and long-term aquifer tests to provide information regarding the calculated approvable yield, and Zone II area for the proposed District H well field site. The modeling results also provided information that was useful in developing a long term monitoring plan for the well field.

301 CMR 22.21 and the Drinking Water Program Guidelines (Chapter 4, Section 4.5.2 Zone II Delineation and Protection) require the delineation of a Zone II protection area around public water supply wells for which a permit is sought. The Guidelines describe a recommended procedure for delineating a Zone II area that includes, among other steps, the use of an appropriate analytical or numerical model to predict drawdown around the production well by imposing "Zone II criteria" (180 days of pumping at the approved yield, with no recharge from precipitation). As stated in the Guidelines, "In certain complex hydrogeologic situations, it is difficult to predict the zone of contribution for a well without employing a numerical computer model." (Chapter 4, Section 4.1, Additional Requirements, 1.) To meet these requirements a numerical model was used, as described in the sections below, to delineate a Zone II area for the proposed District H water supply wells.

The following sections develop and present information intended to meet the requirements of Chapter 4 of the Drinking Water Program Guidelines. This information begins with a description of the regional groundwater flow lens in which the site is located (Section 2), followed by the Hydrogeologic Conceptual Model of the District H well field site (Section 5.2). It includes a summary of aquifer test data analyses that were performed to develop estimates of aquifer properties (Section 5.3) which were then employed in developing a SEAWAT numerical model (Section 8) to perform analyses to confirm an approvable yield withdrawal rate (Section 9), delineate a Zone II area (Section 10) for the District H wells, and demonstrate the Area of Influence (Section 11).

Given the water quality requirements of 310 CMR 22.00, and the possible presence of a zone of saline water (seawater) at depth in the aquifer beneath the District H site, an evaluation of potential salinity impacts to the District H wells was performed to determine the effects that might occur if the TPW-3B and TPW-2C wells were pumped at the calculated approvable yield withdrawal rate (described in Section 4) for a long period of time. This evaluation was designed to provide important information with respect to both the appropriateness of the calculated approvable yield and the requirements for, and specifications for, a long-term periodic monitoring program.

SEAWAT (Guo and Langevin 2002) is a three-dimensional numerical model capable of simulating density dependent groundwater flow and solute (dissolved salt) transport, and the sections below include the inputs and results for the approvable yield and Zone II modeling calculations.

The SEAWAT modeling incorporated the key features and processes of the aquifer including recharge, groundwater flow to the District H supply wells, drawdown at and near the pumping wells, the resulting rise in the elevation of the freshwater/saltwater transition zone that forms the lower limit of the freshwater lens aquifer, and the potential impacts of saline water on the quality of water discharged from the wells. For this reason, it provided a single self-consistent quantitative tool with which to evaluate (1) the water quality that will result for the proposed approvable yield, and (2) the drawdown during no-recharge conditions and the resulting area of contribution to the wells for that aquifer water level configuration (as required by the Zone II guidelines).

SEAWAT, which was developed by the U.S. Geological Survey, was used for these calculations because it is capable of calculating groundwater flow and solute (dissolved salt) transport in an aquifer system where density differences between the freshwater lens aquifer and the underlying zone of denser saltwater are important. Pumping of the proposed District H water supply wells will create drawdown (lowered water levels) in an area around the well field. This lowering of water levels in the freshwater aquifer will cause a rise in the elevation of the freshwater/saltwater transition zone. This upward shift in freshwater/saltwater transition zone, and the potential transport of saline water from the upper portion of the transition zone to the intake screens of the supply wells, is a complex hydraulic process that must be solved as accurately as possible to obtain useful results for the permitting of the District H water supply wells. As described below, the SEAWAT model was designed based on geologic studies conducted at the District H well field site, and was capable of closely matching the aquifer response observed during the two five-day day aquifer tests at the District H production wells. Once calibrated in that manner, the model was deemed to be a reliable tool for use in this study. The model was then used to confirm that the proposed approvable yield would result in acceptable water quality for a long period of time into the future, and to delineate the required Zone II protection area for the District H well field.

In addition, the proximity of the District H test production wells to vernal pool sites requires the inclusion of a surface water monitoring component to the aquifer test data. Insofar as the vernal pools are within the Area of Influence of the proposed District H wells, these vernal pools are not a significant source of water to the wells, however, the vernal pools are certified and three of these vernal pools were monitored prior to, during, and after the aquifer tests as requested by the National Park Service. The collection of data at the vernal pools during the aquifer test was performed to meet the requirements of assessing induced infiltration from the vernal pools during pumping (Massachusetts Drinking Water Program Guidelines, Chapter 4 Section 4.3.1.2). Staff gages and piezometers were installed in selected vernal pools as requested by Massachusetts DEP. A characterization and analysis of the vernal pool data is presented in Section 7.

The analysis of induced infiltration from the vernal pools was performed using aquifer test data as well as historical data collected at the vernal pools. In 2003, Sobczak et al. presented a conceptual model of the vernal pools and demonstrated that vernal pool levels are dependent upon the relation between rainfall rate (input) and pond drainage and evapotranspiration rates (outflow). The parameters influencing outflow to groundwater of water from the pools include peat bottom thickness, peat bottom hydraulic conductivity, and mineral sediment hydraulic conductivity. The aquifer test data was used to develop the groundwater leakage portion of an analytic vernal pool hydrology model. That model, which incorporated hydrologic inputs and outputs to predict pool levels in vernal pool E11, is described in Section 7.

5.2 HYDROGEOLOGY OF LOWER CAPE COD

5.2.1 Glacial Sediments

The glacial sediments of Lower Cape Cod were deposited both by glaciers, glacial lakes and glacial melt-water processes that left a variety of deposits ranging from layers of low permeability clay to coarse sand and gravel materials (Oldale and Barlow 1986; Oldale 1992). Much of the aquifer deposits in Lower Cape Cod are stratified outwash deposits, some of which extend to bedrock in many areas or are underlain by glacial lake deposits in other areas (Foster and Poppe 2003). The outwash deposits of Lower Cape Cod have been divided into genetic units, the oldest being the Wellfleet Plain deposits, followed by the increasingly younger Truro Plain and Eastham Plain deposits (Oldale and Barlow 1986). The District H site is located in the Eastham Plain deposits (Oldale and Barlow 1986). In the area of District H, the surface topography of the Eastham Plain deposits is hummocky and some topographically low areas are sites of pools or kettle ponds (Oldale and Barlow 1986). Elsewhere in Eastham, the Eastham Plain deposits are reportedly underlain by at least 300 feet of glacial lake deposits (LeBlanc et al. 1986;

Sobczak et al. 2003, Appendix 6). The absence of glacial lake deposits in District H is significant and contributes to the productivity of the District H aquifer.

5.2.2 Freshwater Lenses

The groundwater flow system that occurs in the glacial sediments of Lower Cape Cod consists of 1) freshwater lenses where recharge occurs, 2) surface water bodies such as streams and ponds where recharge and discharge occurs, 3) shoreline and nearshore areas where discharge occurs, and 4) underlying saltwater that forms the lower and lateral boundaries of the freshwater lenses. These hydrologic zones and recharge/discharge processes are described in more detail in the following sections.

Freshwater contained in Lower Cape Cod sediments is underlain by saltwater (Masterson 2004). The source of freshwater in the aquifer and surface water bodies is entirely from precipitation that recharges the sediments. The saltwater beneath is from intrusion of seawater from the Atlantic Ocean and Cape Cod Bay and is denser and heavier than the freshwater. The system of groundwater flow on Lower Cape Cod is the result of groundwater mounds that form along the central axis of Lower Cape Cod, from which groundwater flows radially toward the coastlines (eastward and westward) and toward streams and inlets (northward and southward) (Guswa and LeBlanc 1985). Figure 5-1 from Masterson (2004) depicts the Lower Cape Cod groundwater mounds with groundwater contour lines. Each of the groundwater mounds is referred to as a flow cell or freshwater lens. Lower Cape Cod contains five freshwater lenses; the freshwater lenses from north to south are the Pilgrim, Pamet, north and south Chequesset, and Nauset (Figure 5-1).

The aquifers are called freshwater lenses because lens-shaped mounds of freshwater overlies denser saltwater that occurs at depth (Figure 5-2). The zone where the freshwater and saltwater meet is gradational such that, at the top of the zone, groundwater is fresh (less than the Massachusetts Secondary Maximum Concentration Limit for Total Dissolved Solids of 500 milligrams per liter (mg/L)) (310 CMR 22.07 (d)), with salt concentrations increasing with depth through the zone until the salt concentration is near that of seawater (Chloride content approximately 19,200 mg/L) (Thurman 1993). This zone between overlying freshwater and underlying saltwater is called the freshwater/saltwater transition zone (Masterson 2004; Bear and Cheng 2010). Another term commonly used to describe the boundary between fresh and saltwater, especially in areas where the transition zone is relatively thin, is the saltwater interface (SWI). In this report, the SWI is defined as the isoconcentration boundary (surface) with a concentration of 17,500 mg/L Total Dissolved Solids (TDS), which is one-half the concentration of average seawater. Figure 5-2 shows that the SWI is shallow near the coastline and deepest in the center of the lens. Therefore, the approximate center of the lens is where the freshwater thickness is greatest.

5.2.3 Recharge

Recharge from precipitation on Lower Cape Cod has been estimated to be approximately 45 to 55 percent of annual rainfall based on an average annual precipitation rate of between 40 to 42 inches/year (Le Blanc et al. 1986; Masterson et al. 1997), which yields a recharge rate between 18 to 23 inches/year. Recent modeling studies have reported higher aquifer recharge rates of approximately 24 inches/year (Masterson 2004). Recharge at ponds is reportedly less (14 inches/year) because evaporation rates are higher for surface water bodies than for land surface (Masterson 2004). Although the average monthly precipitation reported for the period between 1972 and 2010 at the weather station in nearby Chatham, Massachusetts is approximately 3.9 inches (NOAA 2011b), the amount of recharge varies seasonally due to evapotranspiration (Barlow and Dickerman 2001; Walter and Masterson 2003). The rate of recharge is smallest in the summer and fall months and greatest in the winter and spring months (Barlow and Dickerman 2001).

Seasonally variable recharge has an effect on the water levels in Lower Cape Cod (LeBlanc et al. 1986). Annual fluctuations in water levels in the Provincetown, Pamet, and north Chequesset lenses are up to 3 feet, whereas annual fluctuations in the Nauset and south Chequesset lenses are up to 4 feet (LeBlanc et al. 1986). A 35-year record of groundwater levels at U.S. Geological Survey monitoring well EGW-36 indicates that the annual fluctuation near the central portion of the Nauset Lens ranges between 0.9 and 4.75 feet (Figure 5-3) (U.S. Geological Survey 2012). The location of EGW-36 is shown on Figure 5-4.

5.2.4 Surface Water

On Cape Cod, streams or ponds occur in low areas or depressions in the ground surface that are low enough to intersect the water table (Masterson 2004). When the water table is higher than the stream or pond level, the ponds receive groundwater discharge (Masterson 2004). When the water table drops below these depressions, the streams and ponds will go dry (Sobczak et al. 2003). Therefore, surface water runoff in many locations does not contribute a sufficient amount of water to maintain stream and pond levels. Vernal pools (i.e. seasonal ponds) differ from ponds in that they are not necessarily fed by groundwater but are filled by runoff and by direct precipitation (Sobczak et al. 2003, Liebowitz and Brooks 2008).

Major surface freshwater features in the Nauset Lens aquifer include Black Fish Creek, Hatches Creek, Great Pond, Depot Pond, Herring Pond, Minister Pond, Moll Pond, Muddy Pond, and Schoolhouse Pond (Eichner et al. 2009). Fresh groundwater and some surface runoff discharges into the headwaters of the streams in the central portions of Lower Cape Cod (Masterson 2004). However, near the shoreline along Cape Cod Bay, the streams and rivers become brackish (Martin 1993; U.S. Army Corps of Engineers 1998).

5.2.5 Coastal Areas

The coastal areas of Lower Cape Cod which form the outer boundaries of the freshwater lenses are dominated by beach, lagoonal, and estuarine environments (Oldale 1992). Near the shorelines, shallow groundwater may be fresh, brackish, or saline, depending upon the interaction between the nearshore environment and the influx of fresh groundwater and/or surface water (Barlow 2003). Groundwater discharge occurs in these coastal, estuary and bay areas (Masterson 2004).

5.3 HYDROGEOLOGY OF THE NAUSET LENS AND DISTRICT H SITE

The following sections describe the geologic and hydrologic conditions for the Eastham area and the District H well field site (Figure 5-4). This information aided in developing the site conceptual model that formed the basis for the numerical groundwater model used in the Zone II and Area of Influence analyses required for the new source permit. Working from the conceptual model, a program of aquifer testing was planned and executed to provide estimates of aquifer hydraulic properties for the aquifers that were identified during the site field investigation program. A field program of data collection for the groundwater and surface water characterization of three vernal pools (VP-E1, VP-E9, and VP-E11) in District H, was conducted as part of the aquifer test program and is discussed in detail in Sections 3 and 4 and summarized briefly in Section 5.3.1.2 below. Analysis of the aquifer test data provided key parameter values for the approvable yield and Zone II modeling analyses.

5.3.1 General Hydrogeology

Previous geologic and hydrogeologic studies have described the glacial depositional environment and depositional sequences of deposits in the Eastham area (Oldale et al. 1971; Oldale and Barlow 1986; LeBlanc et al. 1986; Oldale 1992; Masterson 2004). These studies report that the Nauset Lens occurs in the sand, gravel, and silt deposits of the Eastham Plains which overlie Cape Cod Bay deposits composed of silt and clay. The conceptual model described in previous studies has been modified for the current well field site evaluation project using site specific hydrogeologic information collected from 2008 through 2011. The modified conceptual model is described below.

The lithologic logs completed for the investigation of three proposed well field locations in Eastham (Figure 5-4) and from a previously completed deep borehole (Sobczak et al. 2003) were used to construct a northwest-southeast hydrogeologic cross-section through a portion of the Nauset Lens aquifer that extends from District G in the north to District H in the south (Figure 5-5). The cross-section (Figure 5-5) depicts the genetic, lithologic, and hydrogeologic relations between the geologic materials. The genetic relations are based on the cross-sections reported by Oldale et al. (1971), Oldale and Barlow (1986) and Masterson (2004). The lithologic relations are based on lithologic descriptions from 105 boreholes (Sobczak et al. 2003; EPG 2010). The deepest boreholes, G-OW-7, EGW-48, EGW-45/47, NRHS-OW-1B, and OW-1D are 402, 607, 607, 400, and 405 feet deep, respectively. In two of the boreholes (EGW-45/47 and EGW-48) bedrock was encountered at 503 feet below ground surface (bgs) (approximately -440 feet North American Vertical Datum 88 (NAVD88)) and in OW-1D refusal occurred at a depth of 405 feet (approximately -370 feet NAVD88) which may be due to the presence of bedrock. The lithologic information from EGW-48 and EGW-45/47 was available at the time the Lower Cape model was constructed and the sequence of sediments in these wells has been included in the published conceptual model of the Nauset Lens aquifer (Masterson 2004). The lithologic information from boreholes G-OW-7 and NRHS-OW-1B are consistent with the previous conceptual model (Masterson 2004). However, the lithology encountered in borehole OW-1D has not been described previously and leads to a significant change in the conceptual hydrogeologic model.

The cross-section A-A' (Figure 5-5) depicts that the Nauset Lens aquifer from District G to NRHS occurs within interbedded sand, gravel, silt and clay materials of the Eastham Plain glacial outwash deposits which overlie the predominantly silt and clay materials referred to as the Cape Cod Bay lake deposits (Oldale et al. 1971; Masterson 2004). The aquifer between District G and NRHS is approximately 80-ft-thick, and the lake deposits are up to 307-ft-thick. Beneath the lake deposits a 20-ft thick layer of coarse gravels overlies bedrock. Somewhere between NRHS and District H, there is a transition from lake deposits to interbedded sand, silt, and clay deposits at depth and the lake deposits were either not deposited or were removed from District H area. As a result, the aquifer extends much deeper in District H than in the other two proposed well fields. Based on electrical conductivity logs collected at OW-1D (Figure 2-1) and described in Section 2.2, the SWI likely occurs at a depth below 360 feet (-325 feet NAVD88) in District H.

This finding is consistent with the previous conceptual depositional model described by Masterson (2004), in which the remnant of the South Channel lobe occupied the southeast portion of Eastham after retreat of the Cape Cod Bay lobe which occupied most of Lower Cape Cod in the past. The hummocky topography in the vicinity of District H is attributed to buried ice blocks left by the retreating South Channel lobe (Masterson 2004). The cross-section A-A' (Figure 5-5) depicts that the transition between lake deposits to ice-contact deposits occurs where the topography becomes hummocky to the southeast, although the actual location and nature of the subsurface transition cannot be determined with the information available.

The modification to the conceptual hydrogeologic model is substantial in the area of the District H proposed well field but does not change the previous conceptual model in the vicinity of the Eastham District G or NRHS proposed well fields. The site hydrogeology at District H is discussed in Section 5.3.2 below.

5.3.2 District H Site Hydrogeology

5.3.2.1 Site Location in Nauset Lens

The District H site is located in Eastham, Massachusetts, approximately 1.2 mile to the east of Route 6 in the southern portion of the Nauset Lens aquifer (Figures 5-1 and 5-4). The site is located approximately 6,200 feet southeast of the high point of the freshwater mound, where the ground surface elevation is approximately 46 feet NAVD88, and the groundwater elevation is between 16 to 17 feet NAVD88, under average conditions.

According to the U.S. Geological Survey (Masterson 2004), District H is located along the southeastern flank of the Nauset Lens groundwater mound. The Nauset Lens groundwater model, described in Section 8.2, indicates groundwater flow in District H is toward the east. A groundwater contour map of May 2, 2011 water level elevations measured in District H monitoring wells indicates groundwater flow is eastward under a gradient of approximately 0.0018 feet/foot (Figure 5-6). Long-term records of water levels in OW-1A (Figure 5-7) demonstrate that the seasonal fluctuation over the past several years of 2 to 3 feet is consistent with the seasonal fluctuation reported for the U.S. Geological Survey long-term groundwater monitoring in EGW-36 (U.S. Geological Survey 2012).

5.3.2.2 Monitoring Well Network

The District H aquifer observation well network includes four monitoring well clusters, three of which (OW-1, OW-2, and OW-3) are clustered around pumping wells (Figure 5-8). The fourth cluster (4) is located near vernal pool VP-E9. The District H vernal pool monitoring network includes three clusters, one at each of the three vernal pools VP-E1 (A, B, and C), VP-E9 (A, B, and C, C1, and 3), and VP-E11 (A, B, C) (Figure 5-8).

5.3.2.3 Aquifer Zones and Properties

The aquifer observation wells at the District H site are completed in four depth intervals representing four potential production zones, which are separated by semi-confining clayey and silty zones. The potential production zones have been designated aquifer zones A, B, C, and D, and the intervening lower-permeability zones have been designated aquitard zones A/B, B/C and C/D which are described below. Cross section B-B’ (Figure 5-9) is a northwest-southeast transect through the District H wells from the OW-2 well cluster to vernal pool VP-E9 and shows the locations of all boreholes except near vernal pools VP-E1 and VP-E11 which are located west and east of the transect, respectively. Cross Section B-B’ is oriented perpendicular to direction of groundwater flow in the proposed District H well field.

Nine monitoring wells, OW-1A, OW-2A, OW-3A, OW-4A, VP-E1C, VP-E9C, VP-E9C1, VP-E9-3, and VP-E11C are completed in the shallow water table aquifer, Zone A. Five monitoring wells and two pumping wells are completed in the zone B aquifer including OW-1B, OW-2B, OW-3B1, OW-3B2, OW-4B, TPW-1B, and TPW-3B. Five monitoring wells and one pumping well are completed in the Zone C aquifer including OW-1C, OW-2C1, OW-2C2, OW-3C, OW-4C, and TPW-2C. Two monitoring wells (OW-1D and OW-2D) are completed in the deepest aquifer Zone D. While the boreholes in a well cluster are within a few feet to a few tens of feet from each other, there is some variability in the lithology among a cluster. Where this occurs, cross-section B-B’ (Figure 5-9) depicts a good representation of the lithologic contacts. Detailed lithologic logs for each borehole are included in the Appendix C.

The shallow Zone A is composed of predominantly well sorted to poorly sorted fine- to coarse-grained sand and extends from the water table (approximately 9 to 12 feet NAVD88) to the top of the A/B aquitard at elevations between approximately -20 and -32 feet NAVD88 in well clusters OW-2 and OW-3. The saturated thickness at well clusters OW-2 and OW-3 is approximately 30 to 40 feet, but this varies seasonally (LeBlanc et al. 1986). At well cluster OW-1, the water table aquifer thins to approximately 15 feet thick due to the presence of clay layers. The elevation of the first significant clay layer is approximately -5 feet NAVD88. Lithologic logs of the southern-most well cluster OW-4 indicate that the water table aquifer is likely 40 feet thick, the bottom of which is at an elevation of -30 feet NAVD88 corresponding to the first significant clay layer.

The A/B aquitard zone is composed of silty clay to clayey sand intervals between well clusters OW-2 and OW-3, but south of well cluster OW-3 it appears to be composed of silty to clayey lenses with intervening sand materials. The A/B aquitard zone is between 20 to 25 feet thick in the vicinity of well clusters OW-2 and OW-3. The base of the aquitard is at an elevation of -42 feet NAVD88 in well cluster OW-2 and is at -50 feet NAVD88 in well cluster OW-3. In well cluster OW-1, the A/B aquitard occurs over approximately 38 feet and contains layers of sand between -4 to -42 feet NAVD88 (Figure 5-9). At well cluster OW-4, the A/B aquitard may be the 8 feet thick clay layer that occurs at an elevation of -30 feet NAVD88. It is likely that there are many lenses of clay and silt that comprise the A/B aquitard between well clusters OW-1 and OW-4 as depicted on cross-section B-B' (Figure 5-9). It is also likely that some kettle holes in District H are underlain by collapse structures, thus disrupting the apparent layering of sandy, silty, and clayey deposits and creating complex hydrogeologic relations. For instance, vernal pool VP-E9 is within a kettle hole (Sobzack et al. 2003) and might be underlain by complex hydrogeology that is responsible for the enigmatic response to pumping in Zone B well at the cluster OW-4 as described in Section 8 below.

The Zone B aquifer underlies the A/B aquitard (Figure 5-9). The upper and lower surfaces of the Zone B aquifer interval are variable and occur between approximately -20 and -52 feet NAVD88. The Zone B aquifer is composed predominantly of well to poorly sorted fine- to medium-grained sand with some silt layers. The aquifer materials coarsen in well cluster OW-4 to medium sand to cobble gravel. The thickness of the Zone B aquifer is approximately 19 to 28 feet in well clusters OW-2 and OW-3, and increases to approximately 47 to 54 feet in well cluster OW-1. In well cluster OW-4, the Zone B aquifer is approximately 40 feet thick and occurs between -39 to -79 feet NAVD88. The response of water levels to pumping in well cluster OW-4 indicates that hydraulically, aquifer Zones A, B, and C have a transitional character between well clusters OW-1 and OW-4, therefore the stratigraphic correlation of the aquitard zones to well cluster OW-4 is shown by dashed lines and question marks on Figure 5-9. The evidence for this is discussed further in the Aquifer Analysis Section 8 below.

The aquitard B/C interval underlies the Zone B aquifer and is comprised, to a greater extent, of silt and sand and, to a lesser extent, of clay. In well cluster OW-3, the approximately 40 feet thick B/C interval is almost entirely a silty sand whereas in well cluster OW-2, the silty sand and silt layers are underlain by a silty clay layer. In well cluster OW-1, the B/C aquitard thins and is a layer of silt approximately 7 feet thick. Figure 5-9 shows a tentative correlation of the B/C aquitard interval between the silt in well cluster

OW-1 and the 17 feet thick clay layer in well cluster OW-4. The upper and lower surfaces of the B/C aquitard interval are variable and occur between approximately -70 and -117 feet NAVD88.

The Zone C aquifer occurs below the B/C interval and is predominantly composed of poorly sorted, fine- to medium-grained sand and, to the southeast, contains 2 to 3 feet thick silt and clay lenses. In well clusters OW-2 and OW-3 the zone C aquifer is approximately 78 to 68 feet thick, respectively, and occurs between elevations of -107 and -185 feet NAVD88. In well cluster OW-1, the zone C aquifer is approximately 90 feet thick and occurs between -98 and -186 feet NAVD88. In well cluster OW-4, the Zone C aquifer thickens to 102 feet thick and occurs between -93 and -196 feet NAVD88.

The C/D aquitard interval underlies the Zone C aquifer and at least one borehole in each well cluster extends to the top of the C/D aquitard. Only two boreholes (OW-1D and OW-2D) penetrate the entire thickness of the aquitard. This aquitard interval is characteristically clay or silty clay, the upper surface of which is encountered between -182 and -196 feet NAVD88. In boreholes OW-1D and OW-2D, the C/D aquitard is 21 and 23 feet thick, respectively.

The Zone D aquifer is the deepest and thickest aquifer and is composed of gray, fine-to medium-grained sand with silt and some intervening 1 foot thick clay lenses. The Zone D aquifer may be up to 125 feet thick. Borehole OW-1D likely penetrated the entire thickness of the zone D aquifer from -209 to -334 feet NGVD88. Near the base of the borehole (-334 feet NAVD88) a gray clay interval was encountered. OW-2D was terminated at -319 feet NGVD88, above the base of the Zone D aquifer.

Below the Zone D aquifer in borehole OW-1D, a till or weathered bedrock material (angular rock fragments) was encountered at -354 feet NAVD88. The borehole penetrated 15 feet of this material before encountering refusal. It is important to note that the U.S. Geological Survey deep boreholes EGW-47 and EGW-48 (Sobzcak et al. 2003) encountered a 20 feet thick interval of cobble and pebble material immediately overlying bedrock at approximately -426 feet NAVD88. In District H, it may be that bedrock is not far below an elevation of -367 feet NAVD88.

The aquifer zones and intervening semi-confining aquitard units described above were identified based on their lithologies and the response of water levels to pumping. The aquifer zones in District H are hydraulically connected to one another such that the entire thickness can be considered one multi-layered aquifer. A multi-layered aquifer analysis is complex because it involves the process of calculating hydraulic parameters from single well pumping tests that may be drawing water from above and below zones of differing hydraulic conductivity and leakage. Section 6 below is a description of the aquifer analysis method and summarizes the hydraulic properties of the multi-layered aquifer in District H.

6 AQUIFER ANALYSIS WITH MULTI-LAYER UNSTEADY (MLU) SOFTWARE

The Multi-Layer Unsteady (MLU) state software (Hemker, 1999, 2011) was used to analyze data from the two December 2010 District H pumping tests (one test pumping from aquifer Zone B and one test pumping from Zone C) to estimate hydraulic properties of aquifers and aquitards in the vicinity of the test site and to evaluate the test data for use in parameterizing a SEAWAT model for the site and surrounding aquifer. Aquifer parameters estimated by MLU (zonal horizontal and vertical hydraulic conductivity values and storage coefficients) were used in developing initial values for the SEAWAT model, which was further calibrated to refine the aquifer property estimates, and then used to calculate approvable yield and delineate the Zone II area for the District H well field as described in Section 9 and Section 10 of this report, respectively. A complete description of the MLU aquifer test analysis is presented in Appendix G – Attachment 2. The following is a brief description of the application and results of the MLU analysis.

6.1 Software Selection

MLU was selected to perform the data analysis for the District H test because it possesses the ability to calculate drawdown for, and estimate properties for, multiple aquifer and aquitard layers in a single model simulation. Eastham District H exhibits complex geology that can be generally represented as four higher-permeability units separated by three intervening lower-permeability units. Traditional aquifer test data analysis methods are not suitable for estimating the parameters of multi-aquifer hydrogeologic formations such as that found at Eastham District H. While MLU is capable of manual or automatic fitting of water-level drawdown curves, manual curve fitting for parameter estimation was performed in the analyses described below.

6.2 MLU Conceptual Model

The District H MLU model is based on a simplified conceptual model of the multi-layered aquifer system at the District H site. Aquifer layers in the model are assumed to be horizontal and of constant thickness, extending radially an infinite distance from the pumping well being analyzed. The aquifer layers for the model are conceptualized as follows: one layer each for Zones A, B, and C; two layers for Zone D; and an aquifer layer of lower hydraulic conductivity for each intervening aquitard. Figure A2.1 in Appendix G – Attachment 2 is a conceptual cross-section through District H. Aquifer Zone A is 30 feet thick and is confined on the bottom by a leaky aquitard (A/B aquitard) and represented on top by the water table. Aquifer Zone B is 35 feet thick aquifer unit and is bounded by the A/B aquitard on top and the B/C aquitard on bottom. The B/C aquitard, the thickest aquitard, is between aquifer Zones B and C and is 33 feet thick. The aquifer Zone C is between the B/C aquitard above and the C/D aquitard below and is 78 feet thick. The C/D aquitard is between aquifer Zones C and D and is 22 feet thick. Aquifer Zone D is the thickest aquifer with a thickness if 125 feet.

The model aquifer and aquitard layers are separated by MLU resistance layers to allow the estimation of vertical hydraulic conductivity values for the layers. Also, as discussed in Appendix G – Attachment 2, the model layer representing aquifer Zone D was subdivided into two subzones using a MLU resistance layer for the purpose of more accurately representing drawdown measured in the partially penetrating observation wells in the lower portion of aquifer Zone D and to allow for the calculation of the vertical hydraulic conductivity within this zone.

6.3 Aquifer Test Analysis Results

Test wells TPW-3B and TPW-2C, with pumping rates of 910 gpm and 915 gpm respectively, were placed in the Zone B and C aquifers of the MLU model, respectively. During the District H test, TPW-3B was pumped five days, followed by five days of recovery, and five days of pumping TPW-2C. Two separate five-day MLU model simulations were performed; one for each pumping period. The recovery period was not analyzed.

A manual matching of measured drawdown curves to MLU calculated drawdown curves was performed for data collected from monitoring well clusters OW-1, OW-2, OW-3, and OW-4. The results of the evaluations and graphs of the curve matching are detailed in Attachment 2.

Horizontal hydraulic conductivity and storage coefficient values, estimated with MLU for the four aquifer and three aquitard zones, are summarized in the table below.

Aquifer Parameters Calculated from 8 Analyses Using MLU

	B Zone Test			C Zone Test		
Zone	**Kh (ft/day)**	**Kv (ft/day)**	**S**	**Kh (ft/day)**	**Kv (ft/day)**	**S**
A (Aquifer)	150	75	0.1 - 0.2	150	75	0.15 - 0.2
A/B (Aquitard)	1	0.125 - 0.067	0.008	2	0.25 - 0.067	0.005
B (Aquifer)	110 – 230	5.5 - 11.5	0.0003 - 0.00008	100 - 120	3.33 - 8.57	0.001 - 0.0003
B/C (Aquitard)	50	2.87 - 3.57	0.0015 - 0.002	50	2.5 - 3.85	0.0001 - 0.002
C (Aquifer)	110 - 160	6.4 - 11	0.0002	75 - 125	9.09 - 11.4	0.0002 - 0.0005
C/D (Aquitard)	10	0.385 - 0.4	0.0001 - 0.0002	10	0.37	0.0001
Upper D (Aquifer)	20 - 40	0.4 - 0.571	0.0001 - 0.002	30	0.429	0.0004
Lower D (Aquifer)	20 - 40	0.4 - 0.67	0.0001 - 0.002	30	0.429	0.0004

Horizontal hydraulic conductivity for Zone A is estimated to be 150 feet/day, vertical hydraulic conductivity is 75 feet/day, and specific yield ranges from 0.1 to 0.2. Horizontal hydraulic conductivities for aquifer Zone B range from 100 feet/day to 230 feet/day, vertical hydraulic conductivities range from 3.33 feet/day to 11.5 feet/day, and storage values for this zone range from 8.0×10^{-5} to 1.0×10^{-3}. The aquifer Zone B hydraulic conductivity value of 230 feet/day resulted from an attempt to match drawdown data in well cluster 3 where enhanced hydraulic communication between wells may be occurring. Therefore, this value likely represents an over-estimate of hydraulic conductivity for this aquifer zone. Horizontal hydraulic conductivities for aquifer Zone C have a range of 75 feet/day to 160 feet/day, vertical hydraulic conductivities range from 6.4 feet/day to 11.4 feet/day, and storage values range from 2.0×10^{-4} to 5.0×10^{-4}. Horizontal hydraulic conductivities for aquifer Zone D have a range of 20 feet/day to 40 feet/day, vertical hydraulic conductivities range from 0.4 feet/day to 0.67 feet/day, and storage values for this zone range from 1.0×10^{-4} to 4.0×10^{-4}.

7 GROUNDWATER AND SURFACE WATER INTERACTION IN DISTRICT H – VERNAL POOL CHARACTERIZATION

A cluster of vernal pools exist in the area between the Nauset Light Beach and the proposed District H well field site as shown on Figure 1-3, 1-4, and 5-8 (Sobczak et al. 2003). The pools are located within the District H boundary or nearby but within the National Sea Shore (Figure 5-8). Eleven vernal pools that occur in this area are designated Certified Vernal Pools under the National Heritage & Endangered Species Program (NHESP) and one is designated a potential vernal pool (Mass DEP 2012). Four of the Certified Vernal Pools at the District H well site (E1, E5a, E9, and E11) are located within approximately 1,000 feet from the test production wells TPW-3B and TPW-2C (Figure 5-8). Three of these vernal pools were monitored prior to, during, and after the aquifer tests as requested by the National Park Service.

A simple predictive model of pool behavior in response to changes in groundwater levels, such as those that might accompany pumping in District H, was developed for this investigation. This was accomplished using groundwater and vernal pool levels collected as part of the 2010-2011 District H well field investigation, information from previous vernal pool studies, and equations from the scientific literature describing vernal pool hydrologic processes. The objectives of this vernal pool investigation are to:

1. use site-specific data on vernal pool inputs and fluctuations to develop a quantitative relationship that describes pool leakage for given pool and groundwater levels, and

2. apply the derived relationship to examine likely long-term declines in pool level that may be associated with groundwater level declines near the vernal pools due to pumping at the District H site.

An in depth description of the model and model development are presented in Appendix G – Attachment 3 of this report. The following sections briefly describe the background information available, recently collected data used in model development and understanding of the vernal pools, the model development, model results and conclusions.

7.1 Previous Vernal Pool Study (Sobczak et al. 2003)

From the late 1990's through the early 2000's, the vernal pools in District H were the subject of a study with the objectives of 1) characterizing the nature of groundwater and surface water relationships and 2) predicting the vernal pool levels response to groundwater withdrawals in District H and the Cape Cod

National Sea Shore (Sobczak et al. 2003). While the study collected and analyzed a large quantity of data to characterize vernal pool area, volume, and stage elevation changes in response to natural hydrologic factors over a period of several years, it did not derive a quantitative model to predict pool level response to pumping. Therefore, it was necessary to develop a model to predict the effects of pumping the District H test production wells on vernal pools in the vicinity of these wells. A more complete summary of the previous vernal pool study can be found in Appendix G – Attachment 3, Section A3.2.

7.2 2010-2011 Aquifer Test Program

Three of the vernal pools at the District H well site (VP-E1, VP-E9, and VP-E11) are located within approximately 1,000 feet from the test production wells TPW-3B and TPW-2C (Appendix G – Attachment 3, Figure A3-1). Groundwater and surface water levels at vernal pools VP-E1, VP-E9, and VP-E11 were collected from December 2010 to December 2011. Evaluation of those data indicated that, of the three vernal pools (VP-E1, VP-E9, and VP-E11), water-table response to pumping was more pronounced at vernal pool VP-E11 (Figures A3-3 and A3-4) than at pools VP-E1 (Appendix G – Attachment 3, Figure A3-6) and VP-E9 (Appendix G – Attachment 3, Figure A3-7), the response of water levels to pumping was not apparent due to the confounding effects of precipitation and regional/local water-level trends. By comparing the vernal pool and water table responses to pumping, it was determined that vernal pool VP-E11 is the most susceptible to induced infiltration under pumping at TPW-3B and TPW-2C. A more detailed explanation of the 2010-2011 vernal pool monitoring data and interpretation is provided in Appendix G – Attachment 3, Section A3.3.

7.3 Vernal Pool VP-E11 Model Development

To examine potential long-term effects of District H pumping on water levels in vernal pool VP-E11, an empirical model relating pool water levels to surrounding groundwater levels was developed. The empirical model is intended for use under average climatologic and hydrologic conditions in the Eastham area.

Model equations were initially formulated based on the District H aquifer test data and data from previous vernal pool studies (Sobczak et al. 2003). The model initially incorporated the effects of precipitation input to the pool and pool losses due to leakage to groundwater (neglecting evapotranspiration effects during the relatively short duration of the aquifer test periods). The model, which was calibrated to measured vernal pool stage data collected during the December 2010 District H pumping tests, produced a very good fit to measured vernal pool water elevations during this period (see Appendix G – Attachment 3, Figure A3-13).

The calibrated model was then used to simulate vernal pool response to pumping during the District H combined pumping test conducted in March 2011. The ability of the model to accurately reproduce measured vernal pool VP-E11 water elevations from the combined pump test verified the accuracy of the model. In addition, an enhanced version of the model that included evapotranspiration losses was used to simulate vernal pool VP-E11 stage elevations under longer-term natural precipitation, evapotranspiration, and groundwater fluctuation conditions from December 2010 to December 2011. The vernal pool model produced a good match to measured pool VP-E11 water elevations during the one-year period (see Appendix G – Attachment 3, Figure A3-19). Further details regarding model development are presented in Appendix G – Attachment 3, Section A3.4.

7.4 Estimating Pumping Effects on Vernal Pools

The calibrated vernal pool VP-E11 model was applied to examine the potential response of pond water levels to declines in groundwater elevations that are anticipated to accompany normal pumping conditions in District H. The model shows that the pumping would have had a very small effect on the vernal pool stage (an average drop of 2.5 inches) from December 2010 to December 2011. Figure A3-21 shows simulated and measured pond levels relative to elevation NAVD88 under pumping conditions and non-pumping conditions. The SEAWAT calculated groundwater level decline is approximately 7.4 inches (0.62 feet) in the vicinity of pool VP-E11, in response to a withdrawal rate of 0.5 million gallons per day (MGD) in TPW-3B. Figure A3-22 shows the same results in terms of relative water level difference so that seasonal factors are removed.

The geometry and hydrologic processes (see Figure A3-8) of vernal pool VP-E11 interact to mitigate pool stage declines in response to declines in surrounding groundwater elevations. Groundwater elevation declines in the range anticipated to be caused by District H pumping result in only a relatively small increase in pool bottom seepage rate. Model results indicate that, following a period of precipitation that raises the pond water level, this slightly increased seepage would initially act to reduce pond water levels, and the pool area would contract. This contraction in area 1) causes a reduction in average evapotranspiration loss rate, and 2) places pond water over the thickest portion of the peat layer, thereby reducing the rate of seepage loss to groundwater. Thus, while the initial leakage would be slightly greater under pumping conditions, natural pond hydrologic processes would act to mitigate pumping effects over the longer time period following precipitation infilling.

7.5 Conclusions

The vernal pool model developed in this study provides valuable insight into pool hydrologic processes. The model demonstrates that seepage is more rapid when the pool stage is high and inundation overlies the areas of thinner peat mat (Figure A3-8). The model also demonstrates that vernal pool VP-E11 is fed by precipitation and that the vernal pool is most likely not replenished by groundwater. Therefore, a decline in water-table level due to pumping is not anticipated to transmit a similar decline to the vernal pool. As a corollary, while pumping and water level declines do not significantly affect pool water levels, a period with no rainfall would have a much larger impact, regardless of pumping.

The vernal pool VP-E11 model results indicate that groundwater level declines in the vicinity of the pool caused by future District H pumping is not anticipated to cause a significant change in the seasonal water elevations in the pool. In addition, because vernal pools VP-E1 and VP-E9 exhibited no apparent responses during the District H aquifer test, it is anticipated that long term District H pumping will have less of an effect on these vernal pools than the very small long-term effect calculated for vernal pool VP-E11. Monitoring of groundwater and vernal pool water elevations, along with collection of data including precipitation and temperature, would provide a check on the model results regarding potential pumping effects, and would provide input data that would allow the model to be applied, and modified as necessary, for use as a hydrologic management tool for the vernal pool area surrounding the District H well field.

8 SEAWAT MODEL DEVELOPMENT

The three-dimensional variable-density groundwater flow and transport program SEAWAT (Guo and Langevin 2002) has been utilized to model freshwater lens conditions of Lower Cape Cod since 2002 (Masterson 2004). SEAWAT was developed for the U.S. Geological Survey to simulate the porous media transport of dissolved constituents, such as saltwater, that impart density effects to the movement of groundwater. SEAWAT couples the groundwater flow equation using the numerical groundwater flow model MODFLOW (Harbaugh and McDonald 1996) with the solute transport equation using the numerical transport model MT3D (Zheng and Wang 1999). SEAWAT has been verified against benchmark test problems as described in the SEAWAT documentation (Guo and Langevin 2002).

8.1 Lower Cape Model

The Lower Cape model was developed using the SEAWAT program by Masterson (2004) at the U.S. Geological Survey for the purpose of analyzing the effects of increased pumping on the sole-source freshwater lens aquifers of Lower Cape Cod, from Eastham to Provincetown. The model represents the Nauset, south Chequesset, north Chequesset, Pamet, and Pilgrim freshwater lenses and includes hydraulic effects of the many ponds, estuaries, and streams on the aquifer system.

The Lower Cape model was used by the U.S. Geological Survey to demonstrate the effects of pumping at the District G site, in addition to other proposed water supply locations in the Nauset Lens aquifer and in other lens aquifers. The model was also used to demonstrate the potential effects of sea-level rise on the freshwater lens thickness for the 48-year period between 2002 and 2050. While detailed coastal discharge estimates were not available as calibration targets, good calibration of the model was achieved using long-term average groundwater levels and pond levels measured between 1975 and 2001 and stream-flow measurements from 2000 and 2001 (Masterson 2004). A complete description of the model is presented in Masterson (2004).

The Nauset Lens model developed by McLane Environmental for analyses of Eastham proposed well field sites including District H was initially developed using the same version of SEAWAT (version 2.5) that was used to develop the U.S. Geological Survey Lower Cape model. Subsequently, the Nauset Lens model files were adapted for use in the latest version of SEAWAT (version 4), which utilizes saltwater head in model input and output rather than freshwater head equivalent values used in SEAWAT version 2.5. Development and calibration of the version 4 SEAWAT model used in delineating the Zone II and

Area of Influence for the proposed well field at Eastham District H is described in Sections 8.2 through 8.5 below.

8.2 Nauset Lens Model Development

The District H site is located within the Nauset Lens aquifer that is bounded on the south by Boat Meadow River, Town Cove, Nauset and South Pond Bays and on the north by Black Fish Creek (Figure 5-4). For the District H well field project, a model of the Nauset Lens was developed by extracting only that portion from the larger U.S. Geological Survey Lower Cape model to reduce computational time and expedite the modeling process. The Nauset Lens model was extracted from the Lower Cape model by the Telescopic Mesh Refinement (TMR) Technique (Ward et al. 1987; Leake and Claar 1999). Boundary conditions of the Nauset Lens model were based on the steady-state conditions for that portion of the Lower Cape model, and the Nauset Lens model grid was refined for some of the modeling analyses as described in the sections below. The Nauset Lens model was developed using Groundwater Vistas (Rumbaugh and Rumbaugh 2004) which was used as a pre- and post-processor, and calculations were made using SEAWAT Version 4 (Langevin et al. 2008).

The boundaries of the Nauset Lens model that correspond to the Atlantic Ocean, Cape Cod Bay, Boat Meadow River, Town Cove, Nauset and South Pond Bays are essentially the same as those in the Lower Cape model (Masterson 2004). Constant head and constant concentration boundaries are used to represent the northern model boundaries. This differs slightly from the Lower Cape model, in which these cells were internal to the model grid, but care was taken to apply the appropriate values from the Lower Cape model to the Nauset Lens model at these locations. The Black Fish Creek is an area of lower hydraulic head and acts to separate the Nauset Lens aquifer from the adjacent South Chequesset Lens aquifer. Pumping effects from the District H site do not encroach significantly on either of these boundaries and therefore, the boundary effects are negligible for the purposes of predicting the drawdown response to pumping in the vicinity of the District H site.

The recharge rates of 24 inches/year over most of the model area and 14 inches/year for surface water bodies that were used in the Lower Cape model for the Nauset Lens aquifer portion of that model (Masterson 2004) are also applied in the Nauset Lens model.

Similar to the Lower Cape model, the Nauset Lens model has 23 layers that extend from the water table (approximately 16.8 feet NAVD88) in the center of the lens to an arbitrary elevation of approximately -500 feet NAVD88. The thicknesses of layers 2 through 23 range from 15 feet to 30 feet with the water table (layer 1) having a variable thickness with a bottom set at -6 feet NAVD88 over most of the model area. In District H, the layer thicknesses and elevations have been adjusted from the Lower Cape model to incorporate the geometry of site hydrogeology. Figure 8-1 is a cross-section of the model grid through District H depicting the thickness and elevations of the model in District H. For layers where the difference between the general layer elevation and the District H elevation was greater than 5 feet, an intermediate step was added across a few grid cells to create a smoother transition between grid node elevations. The general model elevations are not shown on Figure 8-1, which only shows the model layer elevations within District H. The model layers are grouped to represent the aquifer and aquitard zones described in Section 5.3 (Figure 8-1). During calibration (Section 8.4 below), the properties of the grouped layers were assigned the same values. The following table shows how the model layers are grouped into aquifers and aquitard zones.

District H Model Layers and Aquifer Zones

Zone	District H Layer
A-aquifer	1 & 2
A/B-aquitard	3
B-aquifer	4, 5, & 6
B/C-aquitard	7
C-aquifer	8, 9, & 10
C/D-aquitard	11
D-aquifer	12, 13, 14, 15, & 16

The discretization of the District H aquifer hydraulic conductivity and storage values were separated into a near-field area directly around the District H well field, and a far-field area based on the higher hydraulic conductivity areas assigned to District H area in the Lower Cape model (Figures 8-2 to 8-4). Within the near-field, the aquitard materials are represented in discrete layers as shown in the table above. For the far-field the aquitard materials are not explicitly represented because there is no information on the extent of the aquitard layers beyond the well field. Instead, hydraulic conductivities of both aquifer and aquitard layers in the far-field were assigned hydraulic conductivities representing aquifer materials. The glacial depositional environments are highly heterogeneous (Hambrey 1994) and therefore extrapolating clay layers from the District H well field over 3,000 feet to the Atlantic coastline would be imprudent. The calibrated values of hydraulic conductivity and storage are described in Section 8.4.

The District H aquifer zones represent a significant change in the site conceptual model and in the groundwater model compared with the Lower Cape model. These changes are based on the modified conceptual model for this area of the Nauset Lens, as discussed in Section 5.3. Specifically, the observed aquifer materials extend 250 feet deeper than originally represented in the Lower Cape model. Therefore, the Lower Cape layers 7 to 16 representing the Cape Cod Bay clay deposits were modified to represent materials that are up to 10 times more permeable than the clay. This fundamental change resulted in a significant deepening of saltwater concentrations beneath District H. Within the Lower Cape model the top of the transition zone in District H occurs in layer 13 (from approximately -225 to -250 feet NAVD88), whereas within the Nauset Lens model, the top of the transition zone occurs in layer 16 (approximately -300 to -335 feet NAVD88) which corresponds to aquifer Zone D.

The deepening of the saltwater transition zone in the Nauset Lens model improves the model representation of the saltwater transition zone in District H because groundwater samples from the aquifer Zone D wells OW-1D and OW-2D indicate freshwater conditions at depths up to -357 feet NAVD88; and because the electromagnetic conductance and electrical resistivity logs for OW-1D indicate that TDS concentrations begin to increase only near the base of aquifer Zone D.

The areas modified in the model were selected to preserve the basic distribution of conditions represented in the Lower Cape model. The District H aquifer was defined in the Lower Cape model as a parabolically shaped area oriented in an east-west direction with the apex portion pointing westward, then widening toward the east in the direction of the glacial lobe recession (Masterson 2004). The near-field area lies within the central and western portion of the surrounding far-field area. Figures 8-2 to 8-4 show the near-field and far-field areal extents and their calibrated hydraulic conductivity values. The table below shows the former Lower Cape model values and the Nauset Lens District H model near-field calibrated values for hydraulic conductivity and anisotropy ratio (Kh/Kv) for model layers 1 to 17. The far-field values were not calibrated to the aquifer test but were assigned based on average aquifer values. The model values in the layers below layer 17 were not changed for the District H calibration because no hydrogeologic information is available for those depths in District H.

Comparison of Hydraulic Conductivity Values Lower Cape and District H Nauset Lens Model Parameters

	Lower Cape Model District H		Nauset Lens Model at District H Near Field		Nauset Lens Model at District H Far Field	
Layer	**Kh:Kv**	**Anisotropy Ratio (Kh:Kv)**	**Kh:Kv**	**Anisotropy Ratio (Kh:Kv)**	**Kh:Kv**	**Anisotropy Ratio (Kh:Kv)**
1	200:38	5.26:1	200:100	2:1	200:100	2:1
2	201:28	7.18:1	200:100	2:1	200:100	2:1
3	150:43	5:1	20:0.2 10:1 0.2:0.02	100:1 10:1 10:1	120:40	3:1
4	70:2.33	3.48:1	72:7.2	10:1	70:20	3.5:1
5	70:0.5	9.55:1	72:7.2	10:1	70:20	3.5:1
6	30:0.3	140:1	72:7.2	10:1	70:20	3.5:1
7	30:0.3	100:1	32:3.2	10:1	70:20	3.5:1
8	30:0.3	100:1	98:10	9.8:1	90:15	6:1
9	30:0.02	100:1	98:10	9.8:1	90:15	6:1
10	10:0.001	1500:1	98:10	9.8:1	90:15	6:1
11	10:0.009	1111:1	15:1.5	10:1	50:5	10:1
12	10:0.001	1000:1	50:3	16.7:1	50:3	16.7:1
13	10:0.001	1000:1	50:3	16.7:1	50:3	16.7:1
14	10:0.001	1000:1	50:3	16.7:1	50:3	16.7:1
15	10:0.001	1000:1	50:3	16.7:1	50:3	16.7:1
16	10:0.001	1000:1	50:3	16.7:1	50:3	16.7:1
17	10:0.001	1000:1	10:1	10:1	10:0.1	100:1

The near-field and far-field areas in layers 1 and 2 encompass approximately 84 and 1,095 acres, respectively and represent aquifer Zone A (Figure 8-2). The near-field areas are consistent in each layer. In layer 1, the near-field and far-field values of horizontal hydraulic conductivity are 200 feet/day with an anisotropy (Kh:Kv) of 2.

Layer 3 in the near-field represents the aquitard zone A/B and the far-field represents aquifer materials (Figure 8-2). Layer 3 is the only near-field area that is further divided into three areas of different hydraulic conductivity, including; 1) the area immediately around the pumping wells, 2) the area beneath vernal pool VP-E11, and VP-E3) the area beneath vernal pools VP-E1 and VP-E9. The sub-areas were used for a more refined calibration near vernal pool VP-E11. As described in Section 7.4 and Appendix G – Attachment 3, there was no apparent response to pumping in aquifer Zone A at vernal pools VP-E1 and VP-E9, but some response was measured near vernal pool VP-E11. The horizontal hydraulic conductivity beneath vernal pool VP-E11 is 10 feet/day with an anisotropy of 10:1. Beneath vernal pools VP-E1 and VP-E9, the horizontal hydraulic conductivity is 0.2 feet/day with an anisotropy of 10:1.

Around the pumping wells, the horizontal hydraulic conductivity is 20 feet/day with an anisotropy of 100:1. The far-field value of horizontal hydraulic conductivity in layer 3 is 120 feet/day with an anisotropy of 3:1. The layer 3 far-field area is approximately 1,177 acres.

The near-field area in layers 4 to 6 represents aquifer Zone B with a horizontal hydraulic conductivity value of 72 feet/day and an anisotropy of 10:1 (Figures 8-2 and 8-3). The far-field area of approximately 1,900 acres has a horizontal hydraulic conductivity of 70 and an anisotropy of 3.5.

Layer 7 in the near-field represents the aquitard zone B/C, whereas the far-field represents aquifer materials (Figure 8-3). The near-field value of horizontal hydraulic conductivity is 32 feet/day with an anisotropy of 10:1 and the far-field value of horizontal hydraulic conductivity is 70 feet/day with an anisotropy of 3.5:1. The layer 7 far-field area is approximately 2,000 acres.

The near-field area in layers 8 to 10 represents aquifer Zone C with a horizontal hydraulic conductivity value of 98 feet/day and anisotropy of 9.8:1 (Figures 8-3 and 8-4). The far-field area of approximately 2,000 acres has a horizontal hydraulic conductivity of 90 feet/day and an anisotropy of 6:1.

Layer 11 in the near-field represents the aquitard zone C/D and the far-field represents aquifer materials (Figure 8-4). The near-field value of horizontal hydraulic conductivity is 15 feet/day with an anisotropy of 10:1 and the far-field value of horizontal hydraulic conductivity is 50 feet/day with an anisotropy of 10:1. The layer 11 far-field area is approximately 1,625 acres.

The near- and far-field area in layers 12 to 16 represents aquifer Zone D with a horizontal hydraulic conductivity value of 50 feet/day and anisotropy of 16.7:1 (Figure 8-4). The far-field area is approximately 2,000 acres.

Layer 17 is beneath the District H aquifer and was modified from the Lower Cape model to decrease the anisotropy from 1000:1 to 10:1 in the near-field and 100:1 in the far-field (Figure 8-4). These values are not based on observations during the aquifer test but were selected to enable saltwater upconing through layer 17 in a worst-case-scenario assuming that high concentrations of TDS do occur just below aquifer Zone D.

The values of aquifer specific storage used in the District H near-field areas are between $1x10^{-3}$ feet-1and $2x10^{-5}$ feet-1, which is within the range calculated from the aquifer test analysis in Section 4.4. The specific yield utilized in the model is 0.25, which is the same as that used in the Lower Cape model (Masterson 2004).

Two versions of the Nauset Lens model were developed for simulating pumping in District H; the aquifer test calibration model and the long-term saltwater upconing model. These two models are identical except for the discretization of model grid and simulation time. The aquifer test model grid telescopes to a finely discretized area of 26.5 x 17.6 feet around each pumping well cell. The long-term saltwater upconing simulations were performed using a single pumping center located in the center of the well field. This simplification was necessary in order to minimize the number of grid cells and also maintain a fine discretization (26.5 x 17.6 feet) around the pumping well.

The long-term simulation also employed a technique to expedite the simulation time (which could take weeks to months) to simulate 100 years of pumping. This technique uses an enhanced porosity value in cells very near the pumping well cell to accelerate the transport calculation by increasing the internally calculated time step size (Zhang et al. 2011). Under pumping conditions, the velocity of the groundwater adjacent to the pumping well cell is much faster than the average groundwater velocity elsewhere in the model. The internally calculated time-step size is based on the maximum groundwater velocity, regardless of whether or not solute transport occurs in those cells. The porosity in cells in and around the pumping cells was increased to values of 200 percent which had no discernible effect on the transport results. The accelerated 100-year model simulations took approximately 10 days to complete.

The modifications to the Nauset Lens model described in the District G Pump Test Report (EPG 2012b) also apply to the SEAWAT model developed for the District H Source Final Report. Those modifications include:

1. The grid cells containing Hatches Creek were refined in the Nauset Lens model compared with the Lower Cape model so that the simulated effects of pumping from the District G location could be represented more precisely

2. The conductance values of the Hatches Creek drain cells and all drain cells north of District G were reduced to one-third of the values in the Lower Cape model to raise simulated groundwater levels in the vicinity of District G.

3. In layer 1, hydraulic conductivity was lowered from 200 feet/day to 150 feet/day, and in layers 2 and 3, the eastern half of the Nauset Lens model hydraulic conductivity was lowered from 125 feet/day to 80 feet/day. This was done to raise overall groundwater levels in the center of the lens to better represent the measured water levels at the NRHS, District G, and District H sites.

Figure 8-5 shows the water-level contours for layer 1 (water table) for the calibrated Nauset Lens model compared with the Nauset Lens aquifer portion of the U.S. Geological Survey Lower Cape model. While the water levels are slightly higher in the central portion of the Nauset Lens model than in the Lower Cape model, the shape of the freshwater lens is nearly identical, indicating that the extracted and refined

Nauset Lens model accurately reproduces the key properties, features and water levels of that portion of the U.S. Geological Survey Lower Cape model from which it was created. Additionally, the Nauset Lens model more accurately depicts measured groundwater levels at the NRHS, District G, and District H sites measured by EPG from 2009 to 2011.

8.3 Model Limitations and Assumptions

While previous models of Cape Cod were applied with success for their intended purposes, there are fewer limitations with the Nauset Lens models applied in the District H project than with any model previously used to simulate pumping in the Nauset Lens aquifer (compare for example models reported by Reilly and Goodman 1985; Guswa and LeBlanc 1985; Martin 1993; McLane 2004a, b; and Masterson 2004). With regard to the limitations of the Lower Cape model on which the District H project Nauset Lens model is based, Masterson (2004) stated:

> "In this investigation, the assumptions about the distribution of aquifer properties throughout the flow lens are based on limited field data augmented by the relation between the regional depositional model of the glacial material and the model-simulated hydraulic-conductivity values. These results underscore the importance of developing a better understanding of the hydraulic properties of the subsurface materials through (1) well-designed aquifer tests, (2) detailed characterization of the lithology through the vertical extent of the aquifer down to the freshwater/saltwater interface, and (3) measurements of the pre-pumping depth to the freshwater/saltwater interface, prior to developing large-capacity pumping wells at the proposed well sites."

The development of the Nauset Lens model, and in particular, the calibration of the model to the District H aquifer test and site-specific data address, to a large degree, these limitations identified by the original model developer.

The MODFLOW and MT3D models incorporated into SEAWAT require the use of simplifying assumptions. Basic modeling assumptions are stated in the SEAWAT manual (Guo and Langevin 2002) are as follows:

> "The development presented here is based on the usual assumptions that Darcy's law is valid (laminar flow); the standard expression for specific storage in a confined aquifer is applicable; the diffusive approach to dispersive transport based on Fick's law can be applied; and isothermal conditions prevail. The porous medium is assumed to be fully saturated with water. A single, fully miscible liquid phase of very small compressibility also is assumed."

In addition to the specific assumptions used in the development of the Nauset Lens model is the underlying assumption that the construction and calibration of the Lower Cape model on which the

Nauset Lens model is based represents the most complete representation of groundwater flow on the Lower Cape, to date. The U.S. Geological Survey documentation of data collection and research on Cape Cod indicates that this is an accurate assumption.

The Nauset Lens model was refined and calibrated with site-specific data only in the areas of the District G, NRHS, and District H sites. Therefore, the improvements over the original Lower Cape model do not extend across the entire model.

8.4 Model Calibration to Aquifer Test Data

The Nauset Lens model hydraulic conductivity was calibrated in the area of the District H site using pumping rates and drawdown data obtained from two aquifer tests performed in December 2010 and described in Sections 3 and 4. Because the aquifer tests were conducted across a relatively small portion of the Nauset Lens aquifer, only a limited portion of the Nauset Lens model was recalibrated using the District H aquifer test. The aquifer tests conducted in the NRHS and District G well fields were used to calibrate the model in those areas (EPG 2011b; 2012b). Beyond the far-field area, the majority of the model parameters were not changed from those in the U.S. Geological Survey Lower Cape model.

Aquifer test analyses performed using MLU and described in Section 3.3 were used as a guide to calibration and as a starting value for using the program PEST (Doherty 2010), a model calibration tool. The final SEAWAT calibrated values are similar to the range of aquifer parameters estimated from the MLU analysis results (Section 6.3). The following table shows the District H MLU and Nauset Lens near-field model values of hydraulic conductivity and storage. Note that the storage values in this table are in units of specific storage (ft^{-1}), whereas the values of storage in Section 6.3 and Appendix G – Attachment 2, Table A2-11 represent storativity (unitless).

Comparison of Calibrated Values of Hydraulic Conductivity and Storage for MLU and SEAWAT

MLU					SEAWAT								
						Nearfield				Farfield			
Zone	Kh (ft/d)	Kv (ft/d)	Kh/Kv	Ss (ft^{-1})	Layer	Kh (ft/d)	Kv (ft/d)	Kh/Kv	Ss (ft^{-1})	Kh (ft/d)	Kv (ft/d)	Kh/Kv	Ss (ft^{-1})
A	150	75	2	6.7×10^{-3}- 3.3×10^{-3}	1 2	200	100	2	1.0×10^{-3} 1.0×10^{-4}	200	100	2	1.0×10^{-5} 5.0×10^{-5}
A/B	1-2	0.07- 0.25	8-15	2.0×10^{-4}- 3.0×10^{-4}	3	0.20 10	0.02 1.0	10 10	5.0×10^{-5}	120	40	3	5.0×10^{-5}
B	100- 230	3.3- 11.5	9-70	3.0×10^{-5}- 2.0×10^{-7}	4 5 6	72	7.2	10	1.0×10^{-4}	70	20	3.5	5.0×10^{-5}
B/C	50	2.5- 3.9	13-20	3.0×10^{-6}- 6.0×10^{-5}	7	32	3.2	10	2.0×10^{-5}	70	20	3.5	5.0×10^{-5}
C	75- 160	6.4- 11.4	7-25	6.0×10^{-7}- 3.0×10^{-6}	8 9 10	98	10	9.8	2.0×10^{-5}	90	15	6	5.0×10^{-5}
C/D	10	0.4	25	5.0×10^{-6}- 9.0×10^{-6}	11	15	1.5	10	2.0×10^{-5}	50	5	10	5.0×10^{-5}
D	20- 40	0.4- 0.6	35-100	8×10^{-7}- 1.6×10^{-5}	12 13 14 15 16	50	3	10	2.0×10^{-5}	50	3	16.7	5.0×10^{-5}
Below MLU	--	--	--	--	17	10	0.01	1000	5.0×10^{-5}	10	0.1	100	5.0×10^{-5}

The calibration simulations were performed using observed drawdown measurements obtained from the TPW-3B and TPW-2C aquifer tests. For the test at TPW-3B, the drawdown represents the difference in groundwater levels prior to pumping on December 6, 2010 and after five days of pumping on December 11, 2010. For the test at TPW-2C, drawdown represents the difference in groundwater levels after 14 days and 15 hours of simulation including pumping and recovery from the test at TPW-3B. The reason the drawdown was calculated in this way is because the a portion of the model calibration was performed using the program PEST (Doherty 2010) which more easily represents drawdown as the difference in water levels from time =0 and not from the beginning of each pumping test. The model simulation includes both pumping tests recovery periods. Drawdown was preferred over observed water level elevation for local aquifer parameter calibration purposes because the water levels measured in December 2010 are higher than the average annual non-pumping water table in the Nauset Lens model, and therefore do not provide representative long-term water level calibration targets. The two tables below show the observed and simulated drawdown and water level elevations for the aquifer test at TPW-3B and TPW-2C.

TPW-3B Aquifer Test Observed and Simulated Drawdown and Water Levels (December 6 and December 11, 2010)

Well ID	12/11/2010 Observed Drawdown (ft)	12/11/2010 Simulated Drawdown (ft)	Observed 12/06/2010 Water Level (ft NAVD88)	Simulated 12/06/2010 Water Level (ft NAVD88)	Observed 12/11/2010 Water Level (ft NAVD88)	Simulated 12/11/2010 Water Level (ft NAVD88)
VP-E11C	0.38	0.40	8.37	8.67	7.99	8.27
OW-1A	0.11	0.50	9.48	9.49	9.37	8.99
OW-1B	7.48*	6.81	8.23*	9.26	0.75*	2.45
OW-1C	2.92	2.70	8.16*	9.24	5.24*	6.53
OW-1D	1.36*	1.15	7.73*	9.19	6.37*	8.03
OW-2A	0.35	0.58	9.59	9.57	9.24	9.00
OW-2B	6.90*	6.73	8.26*	9.39	1.36*	2.66
OW-2C1	2.73*	2.89	8.13*	9.38	5.40*	6.49
OW-2C2	2.71*	2.86	8.14*	9.36	5.43*	6.50
OW-2D	1.45*	1.13	7.82*	9.30	6.37*	8.17
OW-3A	0.36	0.60	9.52	9.52	9.16	8.92
OW-3B1	11.32*	39.22^	8.22*	9.32	-3.10*	-29.91
OW-3B2	13.10*	85.57^	8.22*	9.30	-4.88*	-76.29
OW-3C	2.83*	3.19	8.11*	9.30	5.28*	6.10
OW-4B	0.41	1.47	8.85	9.01	8.44	7.69
OW-4C	2.85*	1.33	8.11*	9.01	5.26*	7.68

*Water level is corrected for tidal influence
^Value not used for calibration statistics

TPW-2C Aquifer Test Observed and Simulated Drawdown and Water Levels (December 16 and December 20, 2010)

Well ID	12/20/2010 ++Observed Drawdown (ft)	12/20/2010 ++Simulated Drawdown (ft)	Observed 12/16/2010 Water Level (ft NAVD88)	Simulated 12/16/2010 Water Level (ft NAVD88)	Observed 12/20/2010 Water Level (ft NAVD88)	Simulated 12/20/2010 Water Level (ft NAVD88)
OW-1B	2.53*	2.55	8.17*	9.06	5.70*	6.71
OW-1C	3.77*	3.04	8.11*	9.05	4.39*	6.19
OW-1D	1.33*	1.52	7.68*	9.01	6.40*	7.67
OW-2B	2.71*	3.03	8.19*	9.17	5.54*	6.36
OW-2C1	9.89*	22.17^	8.09*	9.18	-1.75*	-12.79
OW-2C2	14.88*	40.98^	8.09*	9.16	-6.74*	-31.60
OW-2D	1.50*	1.65	7.72*	9.12	6.33*	7.65
OW-3B1	2.57*	3.07	8.24*	9.11	5.65*	6.25
OW-3B2	2.60*	2.99	8.09*	9.09	5.62*	6.31
OW-3C	5.08*	6.30	8.08*	9.10	3.04*	2.99
OW-4B	0.14*	1.19	8.89	8.84	8.71	7.80
OW-4C	2.50*	1.20	8.05*	8.84	5.61*	7.81

*Water level is corrected for tidal influence
++Drawdown is the difference between water levels on 12/06/10 and 12/20/10
^Value not used for calibration statistics

The model simulation period was 31 days, representing the period from December 5 to December January 5, 2011. This period includes one day prior to the test, five days of pumping at TPW-3B (December 6 to 11, 2010), the five-day period after the TPW-3B test (December 11 to 16, 2010), the 5 days of pumping at TPW-2C (December 16 to 21, 2010), and the five-day period after the TPW-2C test. The simulation was separated into 20 stress periods of various lengths, with shorter stress periods assigned during the initial hours of the pump tests, and longer stress periods assigned during the recovery period. Recharge was maintained at the average rate of 24 inches/year). A separate aquifer test simulation was created with pumping test effluent added to the model at the discharge location approximately 1,650 feet from the pumping wells (Figure 5-8).

For three wells completed in aquifer Zone A near vernal pools VP-E1 and VP-E9 (OW-4A, VP-E1C, and VP-E9C) any drawdown that occurred was so small that it was obscured by the natural trends in groundwater levels. In fact, water levels in the aquifer Zone A generally rose during the test period, likely due to seasonal recharge (see Appendix G – Attachment 3). Therefore, the drawdown in the aquifer Zone A wells was not used for calibration except for VP-E11C and OW-1A, OW-2A, and OW-3A during the TPW-3B test, where some drawdown was observed.

Simulated drawdown for a 21-day period during the pumping tests and subsequent recovery period are plotted with measured drawdown values for 16 observation wells near the pumping well; VP-E11, OW-1A, OW-1B, OW-1C, OW-1D, OW-2A, OW-2B, OW-2C1, OW-2C2, OW-2D, OW-3A, OW-3B1, OW-3B2, OW-3C, OW-4B, and OW-4C (Figures 8-6 to 8-11).

Simulated drawdown values match measured values very well, with the exception of wells OW-3B1 and OW-3B2 during the test in TPW-3B (Figure 8-8). Similarly, the simulated drawdown values in OW-2C1 and OW-2C2 (Figure 8-10) did not match well during the TPW-2C test. This is due to the wells' proximity to the pumping wells resulting in an over-estimation of drawdown. The pumping well cells are 26.5 x 17.6 feet. Typically, a finite-difference model does not simulate the gradient near the pumping well cell accurately due to the large size of the well cell (Anderson and Woessner 1992). Therefore the simulated values for OW-3B1 and OW-3B2 were not used to calculate the calibration statistics for the TPW-3B test and simulated values for OW-2C1 and OW-2C2 were not used to calculate calibration statistics for the TPW-2C test.

Simulated values of drawdown at the end of pumping for the TPW-3B five-day test period are compared against drawdown values measured at the corresponding time (Figure 8-12) for 16 well locations. When the measured and simulated water levels are similar, they plot close to the diagonal line (1:1 line). Similarly, graphs in Figure 8-13 are used to compare simulated versus measured drawdown values at the end of pumping for the TPW-2C five-day test period. Figures 8-12 and 8-13 show good agreement between modeled and measured values of drawdown, indicating a good calibration. Note that for the wells in close proximity to the pumping wells listed above the differences are large. However, those large differences were not used in the calculation of calibration statistics.

Mean Absolute Error (MAE) and Root Mean Square Error (RMSE) statistics, which are considered to be good indicators of model calibration (Anderson and Woessner 1992), were also calculated for the data displayed in Figures 8-12 and 8-13. MAE and RMSE are statistical values comparing the difference (residual) between the measured and simulated water levels (Anderson and Woessner 1992); i.e. statistical measures of the "distance" between model calculated points and the 1:1 line in Figures 8-12 and 8-13. MAE is simply the average of the absolute value of the residuals, and RMSE is the square root of the sum of the residual values squared. The MAE value of 0.41 feet and the RMSE value of 0.57 feet for the five-day test at TPW-3B become a MAE of 0.26 feet and RMSE of 0.30 feet when values for well cluster 4 are not used in the calculation (see Appendix G – Attachment 2). Similarly, the MAE value of 0.58 feet and RMSE value of 0.73 feet for the five-day test at TPW-2C become a MAE of 0.44 feet and

RMSE of 0.57 feet when well cluster 4 is excluded from the calibration. The calibration of the Nauset Lens model used in analyzing the District H aquifer test is considered very good.

From an analysis of the water level data, it was determined that there was no discernible rise in water levels attributable to the re-infiltration of discharge effluent during the aquifer test. Application of the discharge effluent to the model resulted in very small differences in drawdown for some wells. The MAE and RMSE under re-infiltration conditions were 0.26 feet and 0.30 feet, respectively for the TPW-3B test.

A check of mass balance in the calibrated Nauset Lens model indicates that the mass balance error is very low (In-out = 0 percent for solute transport and groundwater flow). This further confirms that the model is operating properly for its intended use in this project.

8.5 Model Sensitivity

The Nauset Lens model was not subjected to a complete aquifer parameter sensitivity test following the well field area refinements and calibration check discussed above, as this model had been well tested during its development by the U.S. Geological Survey (Masterson 2004). However, sensitivity testing was performed for dispersivity (in the vertical direction from the SWI to the well screens) and for transient recharge, as discussed in the sections below.

In addition, previous testing of the Pamet lens SEAWAT model (EPG 2011a) demonstrated that concentrations of TDS in model cells representing and surrounding the pumping well were somewhat sensitive to the grid cell size. Although further sensitivity testing of this parameter was not performed, the grid cell sizes representing the pumping wells were minimized for the Nauset Lens model.

8.5.1 Sensitivity to Applied Vertical Dispersivity

During the aquifer test, no significant increase in TDS was observed in the Zone D wells (OW-1D and OW-2D) so no dispersivity values could be estimated. However vertical dispersivity values of 1 and 5 feet were selected for sensitivity testing to demonstrate dispersivity effects on TDS transport. The model sensitivity to values of vertical dispersivity was tested in long-term simulations (100 years). For these simulations, vertical dispersivity values of 1 feet and 5 feet were compared to simulations with no dispersivity. In simulations with specified vertical dispersivity, a very small value of horizontal dispersivity ($1x10^{-6}$ feet) was used. Applied vertical dispersivity increases the thickness of the transition zone separating freshwater from underlying saltwater, even under non-pumping conditions. Larger vertical dispersivity values result in faster transport of TDS concentrations to the well and higher concentrations in the well at a given time after pumping begins. For example, without applied dispersion, the arrival of small concentrations (less than 1 mg/L) of TDS occurs after approximately 60 years, whereas with dispersivity = 1 feet TDS concentrations arrive after approximately 20 years; and with dispersivity = 5 feet TDS concentrations arrive after approximately 3 years.

The actual value of dispersivity at the District H site has not been measured or estimated. In fact, the presence of seawater concentrations beneath District H has not been established. Long-term monitoring of TDS concentrations under pumping conditions, as recommended in Section 12, can be used to estimate actual values of vertical dispersivity at the District H site.

8.5.2 Monthly Recharge Estimates Used to Simulate Seasonal Water Levels

To demonstrate that the Nauset Lens model better represents conditions across proposed well fields, the calibrated model was used to simulate long-term water level trends. A transient recharge model was constructed using estimated monthly recharge values described below. The model results compare well with measured water levels in the U.S. Geological Survey well EGW-36, and the long-term water levels collected in District G wells G-OW-7 and G-OW-8 and District H well OW-1A.

As described in Section 5, seasonally variable recharge has an effect on the surface and groundwater levels in Lower Cape Cod (LeBlanc et al. 1986). Seasonal recharge rates for the Hunt–Annaquatucket–Pettaquamscutt Stream-Aquifer System in Rhode Island were estimated by Barlow and Dickerman (2001) and were used by Walter and Masterson (2003) to construct a transient recharge simulation for a groundwater flow model of western Cape Cod. A similar configuration of monthly recharge rates was calculated for the Nauset Lens model based on the fraction of annual recharge for each month, which was obtained from Figure 10A of Barlow and Dickerman (2001). This was done by dividing the amount of recharge reported for each month by the total recharge for the year. The following table shows the monthly fraction of recharge reported by Barlow and Dickerman (2001). The value of monthly recharge for the Nauset Lens model was calculated by multiplying the average annual recharge rate of 24 inches/year (Masterson 2004) by the monthly fraction shown in the table below.

Monthly Recharge for Nauset Lens Model

Month	Land Surface Recharge (inches/Month)	Fraction of Average Annual Recharge
January	2.8	0.118
February	2.8	0.118
March	4.0	0.165
April	3.4	0.142
May	2.5	0.102
June	1.3	0.055
July	0.7	0.030
August	0.7	0.030
September	0.5	0.022
October	0.8	0.033
November	1.9	0.079
December	2.6	0.106
Total	24.0	1.0

A plot showing the percent difference between the fractional monthly recharge and the average monthly recharge of 2 inches (Figure 8-14) demonstrates that the "average" monthly recharge might only represent the average monthly November recharge (1.9 inches), but is either greater or less than the monthly recharge for the remainder of the year. For that reason, it is more reasonable to compare the actual measured groundwater levels with simulated groundwater levels that represent a transient recharge. The transient recharge Nauset Lens model simulated 10 years of transient conditions so that the starting groundwater levels would have negligible effect on the latter years in the simulation.

A comparison of simulated groundwater levels at the District H well field for a 2.5-year period starting in June 2009 with the long-term groundwater levels in EGW-36 and OW-1A shows a similar seasonal trend (Figure 8-15). Groundwater levels in OW-1A are shown for the period between April 2010 and December 2011. The transient recharge model represents very closely the timing and magnitude (2.5 feet) of the observed seasonal groundwater level fluctuation, which is 3.4 feet in the vicinity of District H, and a long-term average of 2.4 feet in EGW-36.

In addition, a comparison of simulated and observed groundwater levels is presented for the District G area. Figure 8-16 is a graph showing the simulated groundwater levels in District G and the observed water levels in District G wells GOW-7 and G-OW8 for the period between July 2010 and May 2011. The groundwater level for EGW-36 is also shown to illustrate that the water level elevation in District H is lower than at EGW-36 or District G. Similarly, the simulated District G groundwater levels closely represent the timing and magnitude (2.5 feet) of the observed seasonal water groundwater level fluctuation which was approximately 2.2 feet in District G.

The Nauset Lens model used to generate the Zone II delineation and the Area of Influence maps for this report was calibrated in the areas of three well fields to (District G, NRHS, and District H) to four aquifer tests. Furthermore, the Nauset Lens model represents the seasonal long-term groundwater fluctuations under conditions of transient recharge.

9 APPROVABLE YIELD ANALYSIS

The Massachusetts Drinking Water Program Guidelines (Chapter 4, Section 4.3.1.5) state that, for a pumping test conducted on the well that will be used as the final production well, which was the case for both TPW-3B and TPW-2C at the District H site, the calculated approvable yield will be the rate at which the pumping test was conducted, provided that a 5-foot safety margin exists when the applicable stabilization criteria is met (as discussed in Chapter 4, Section 4.3.1.4.5.c). The calculated approvable yield for permitting purposes of 1,310,000 gpd represents the pumping rate (910 gpm) for the lowest constant-rate aquifer test in December 2010.

For permitting purposes, an analysis was performed to examine the response of the higher-density saltwater zone beneath the District H well field, and possible TDS concentration impacts in discharged water. Two approvable yield simulations were performed (for TPW-3B and TPW-2C separately), and one simulation was performed using a combined pumping rate of 1,000,000 gpd with wells TPW-3B and TPW-2C each pumping simultaneously at 500,000 gpd. This represents the anticipated average daily demand (annual basis) of Eastham's Town-wide water system at build-out. It is emphasized that actual withdrawal rates at District H are expected to be significantly less than this, likely on the order of 250,000 – 500,000 gpd, when District H is used in conjunction with the other two well fields at District G and Nauset Regional High School.

The resulting concentrations represent the contribution to TDS from the freshwater/saltwater transition zone and do not account for dissolved solids (e.g. dissolved iron and calcium) already present in the freshwater aquifer.

The Nauset Lens SEAWAT model was used to perform the analyses. Model simulations were performed at the constant rate of 1,310,000 gpd in each well to examine changes in TDS concentrations in the aquifer zone beneath the supply wells and in the discharged groundwater. After 100 years of pumping, TDS concentrations in TPW-3B are 42 mg/L and 852 mg/L in the model cell below and to the east of the pumping well cell. In TPW-2C, after 100 years of pumping, TDS concentrations in the well are 148 mg/L and 5,464 mg/L in the model cell below and to the east of the pumping well. TPW-2C is much closer to the freshwater/saltwater transition zone and, as a result, the concentrations after 100 years in TPW-2C are higher than in TPW-3B. These simulations do not represent actual anticipated pumping conditions but demonstrate that pumping at the approvable yield rate for a very long time will not result in TDS concentrations over the MCL for TDS (500 mg/L) and chloride (250 mg/L) from the potential saltwater zone beneath District H. Dilution from the abundant freshwater contribution to the wells is sufficient to keep the TDS concentrations from deteriorating water quality in the pumping wells.

Model simulations were also performed at the constant rate of 1,000,000 gpd (500,000 gpd from TPW-3B and 500,000 gpd from TPW-2C) for 100 years. This pumping scenario resulted in no significant changes in TDS concentrations in model discharges from the wells.

Under conditions of no applied dispersivity, upconing of the SWI does not occur when the pumping rates are 500,000 gpd in each well. The Nauset Lens model does indicate lateral movement inland of the SWI by approximately 1,000 feet, but this does not encroach on the well field. The actual location of the SWI along the coastline is not known but may be farther from the well field than is represented in the model. Concentrations of 1 mg/L TDS remain at a distance of approximately 100 feet below the TWP-2C well screen and within aquifer Zone D.

Vertical aquifer dispersivity was added to the model to examine its effect on the transport of TDS from the transition zone to the model well screen elevation. A dispersivity value of 1 foot was applied in the vertical direction. This value is within the range of values applied by the U.S. Geological Survey in a previous modeling study of saltwater upconing for the Lower Cape Cod aquifers (Masterson 2004). Results of this sensitivity scenario indicate that concentrations in the pumping wells are 1 and 43 mg/L in TPW-3B and TPW-2C, respectively after 100 years of pumping.

Based upon the long-term simulations and TDS concentration analyses, for a scenario in which the well field is operated at a continuous rate equal to the average annual rate for 100 years, water quality is likely to remain below the secondary drinking water standards for TDS and chloride.

10 ZONE II DELINEATION

Zone II refers to the area designated for protection of groundwater supply to a well. In the case of the District H well field, the groundwater supply is derived entirely from recharge of precipitation and there are no contributing streams or surface water bodies that supply groundwater to the well field. The Zone II and Area of Influence were estimated using the Zone II SEAWAT model as described below.

10.1 Modeling Method

The Zone II for the District H well field was developed using numerical modeling methods. The groundwater modeling code used in this analysis is SEAWAT (Guo and Langevin 2002). SEAWAT is a three-dimensional density-dependent groundwater flow and transport model developed by the U.S. Geological Survey, the validation of which is presented in the SEAWAT manual (Guo and Langevin 2002).

10.2 Conceptual Model of the Aquifer

The conceptual model of the Nauset freshwater lens is described in Section 5 of this report. In summary, the aquifer is composed of stratified glacial sand, silt, and clay materials (Guswa and LeBlanc 1985) which form four aquifer zones separated by three leaky aquitard zones in the vicinity of the District H site. The aquifer occurs as a lens of fresh water atop saltwater which, at the District H site is at least approximately 360 feet thick. The highest elevation of the water table in the freshwater lens is located upgradient and approximately 1.2 miles to the northwest of the District H site. Precipitation is the only source of recharge to the freshwater lens and the center of the lens. Groundwater flows radially outward from the center of the lens toward the coastlines (Figure 8-5). The surface water features influenced by the wells are the vernal pools, the Atlantic Ocean, Nauset Bay, Moll Pond and Minister Pond. Other surface water features on the Nauset Lens aquifer are beyond the influence of the District H pumping wells (Figure 5-4).

10.3 Data Collection

The site-specific data used to calibrate the Zone II model to the December 2010 aquifer tests are described in Section 4. These data include precipitation amounts during the test period, long-term water level trends prior to the test, lithologic data, well completion data, and aquifer test data.

The U.S. Geological Survey reports (Guswa and Le Blanc 1985; Oldale and Barlow 1986; LeBlanc et al. 1986; Martin 1993; and Masterson 2004) contain much of the information used by Masterson (2004) to construct the SEAWAT model of Lower Cape Cod.

10.4 Model Design

The Zone II model for the District H site was extracted from the U.S. Geological Survey's SEAWAT model of Lower Cape Cod (Masterson 2004) as discussed in Section 8.2 above. The most significant modifications to the model were made to grid dimensions and aquifer properties in the vicinity of the three proposed Eastham well field sites to calibrate the model to measured drawdown, which include:

1. TMR of the U.S. Geological Survey Lower Cape model to produce the focused and more efficient Nauset Lens model as described in Section 8.2;

2. Northern boundary set to constant head based on the quasi-steady-state water levels from the Lower Cape model (Masterson 2004) as described in Section 8.2;

3. Refinement of model grid size as described in Section 8.2;

4. Reduction of creek bed conductance in Hatches Creek drain cells as described in Section 8.2;

5. Adjustment of horizontal and vertical hydraulic conductivities in and surrounding District G, District H, and NRHS to match aquifer tests performed in those areas described in Section 8.2 and in EPG Source Final Reports (2011a; 2012b);

6. Modification of hydraulic conductivity values in layers 1 to 3 across portions of the model to raise overall water levels; and

7. Adjustment of the layer thicknesses as described in Section 8.2.

Because the performance of the Nauset Lens model very closely coincides with the performance of the U.S. Geological Survey Lower Cape model, documentation of the Lower Cape model (Masterson 2004) is relied on as the documentation describing the construction of the Nauset Lens model and is included in Appendix J to this report.

10.5 Model Input Parameters

The Zone II model input parameters (recharge, initial heads, initial concentrations, general head boundaries, constant head, constant concentration) are essentially unchanged from those of the U.S. Geological Survey model of the Lower Cape (Masterson 2004) except in District H were the SWI elevation was lowered and along the northern model boundary where constant head cells were carefully transferred from the Lower Cape model to the Nauset Lens model to represent the boundaries of the Nauset Lens aquifer along Black Fish Creek. The heads in these constant head cells are equivalent to the water levels calculated by the Lower Cape model in quasi-steady-state. Therefore, the overall structure of the Nauset Lens model is essentially identical to the USGS Lower Cape model. In the vicinity of the District H, NRHS, and District G well fields, the hydraulic conductivity and storativity values have been modified as described in Section 8.2 and the table in Section 8.2 showing the comparison of hydraulic conductivity values for the Lower Cape and District H Nauset Lens Model Parameters, and in the EPG Source Final Reports for District G and NRHS (EPG 2011a, EPG 2012b).

10.6 Model Calibration

The calibration of the U.S. Geological Survey Lower Cape model is discussed in the Appendix of the U.S. Geological Survey report presented herein as Appendix J. However, as noted in Section 4.4 of this report, the model was further calibrated to the two five-day aquifer tests conducted at the District H site in December 2010. The calibration statistics are presented in Figures 8-12 and 8-13.

10.7 Model Verification

The verification of the U.S. Geological Survey Lower Cape model is discussed in the Appendix of the U.S. Geological Survey report presented herein as Appendix J. The model results were compared to various actual pumping conditions from 1907 until 2002 (Masterson 2004). It was not considered necessary to make the same simulations as the U.S. Geological Survey for model verification.

10.8 Sensitivity and Limitations of the Model

The sensitivity of the U.S. Geological Survey Lower Cape model is discussed in the Appendix of the U.S. Geological Survey report presented herein as Appendix J. Sensitivity of the Nauset Lens model to changes in saltwater transport was tested as described in Sections 8.5 and 9 above. The saltwater transport results are sensitive to values of vertical dispersivity. These parameters, however, have no significant effect on the size of the Zone II or Area of Influence under a pumping rate of 1,310,000 gpd, mainly because the calculated drawdown at the water table over 180 days is not affected by long-term saltwater transport.

The groundwater flow portion of the Nauset Lens model is sensitive to values of recharge. Monthly recharge was approximated and applied to a 10-year simulation described in Section 8.5. The long-term annual amount of recharge is well documented (Le Blanc et al. 1986; Martin 1993; Masterson et al. 1997) and there is no reason to change the values of recharge in quasi-steady state simulations for long-term saltwater transport analyses.

The Lower Cape model was constructed for the purpose of simulating the movement of the freshwater/saltwater transition zone under various pumping scenarios and with rises in sea level over time (Masterson 2004). This model is robust, has model boundaries that approximate the actual watershed boundaries, and has been tested under conditions that go beyond a Zone II analysis (Masterson 2004). For use in calculating a Zone II there are no apparent limitations in this model.

10.9 Zone II Area

The Zone II model was used to simulate the conditions under the prescribed 180-drought (no recharge) and approvable pumping rate of 1,310,000 gpd in separate simulations for TPW-3B and TPW-2C (Figures 10-1 and 10-2). The Zone II boundaries were determined using the particle tracking program MODPATH (Pollock 1994). MODPATH uses the output heads and budget information from MODFLOW to calculate the advective particle pathlines. The advective particle pathlines used to generate the Zone II areas are included in Figures 10-3 and 10-4.

For the purposes of generating a zone of contribution at the land surface for Zone II delineation using water levels from the 180-day, constant-pumping at 1,310,000 gpd simulation, particles were placed at the water table and tracked for 5,000 years until the particles stopped at a model boundary (e.g. a groundwater divide or coastal discharge location) or were extracted at the pumping well. This method is superior to the method of backtracking particles from the well to identify the zone of contribution, as difficulties in establishing the proper number of and placement of particles near the well screen may underestimate the complete area of the zone of contribution. The analysis resulted in the identification of a swarm of particles over an area at the water table that was captured by the District H pumping wells. This area is much larger and extends across the Nauset Lens aquifer much farther than an area that would actually contribute groundwater to the District H pumping wells under normal recharge conditions. As required under DEP, March 2008, Chapter 4.5.2.3(a) and (b), Figures 10-5 and 10-6 are maps showing the Zone II for TPW-3B and TPW-2C, respectively, on a USGS topographic map of scale 1:25,000, with the required map title block. Figure 10-7 is a USGS topographic map showing both the TPW-3B and TPW-2C Zone IIs.

A water budget analysis was performed that compares the recharge rate against the proposed volume of groundwater withdrawal for the District H well site. Detailed calculations for these analyses are provided in Appendix K.

Assuming an average recharge rate of 24-inches per year (average recharge), the calculated volume of recharge associated with the District H TPW-3B Zone II area would be 60,630,000 gallons per year. Assuming a pumping rate of 1.31 MGD, the calculated volume of water withdrawal would be 63,919,524 gallons per year. As indicated in Appendix K, the ratio of annual recharge within the District H TPW-3B wellfield Zone II to annual maximum pumping is 0.95. The calculated volume of recharge associated with the District H TPW-2C Zone II area would be 57,010,020 gallons per year. Assuming a pumping rate of 1.31 MGD, the calculated volume of water withdrawal would be 63,919,524 gallons per year. Therefore, the ratio of annual recharge within the District H TPW-3C wellfield Zone II to annual maximum pumping is 0.89.

10.10 AREA OF INFLUENCE

The areas of influence of the pumping wells are shown in Figures 10-8 and 10-9. This area is defined by the 0.1 foot drawdown line simulated by the Zone II model when the District H wells are pumping under normal aquifer recharge conditions at a rate of 1,310,000 gpd for 100 years. This is a sufficient amount of time to demonstrate steady-state conditions at the water table. This area extends 8,800 feet to the north, 6,900 feet to the south, 4,400 feet to the east and 5,600 feet to the west of the District H site for TPW-3B. The Area of Influence for TPW-2C extends 7,700 feet to the north, 6,900 feet to the south, 4,400 feet to the east and 4,600 feet to the west of the District H site for TPW-3B. The only surface water bodies within the area defined by the 0.1 foot drawdown contour line are the vernal pools Moll Pond and Minister Pond.

11 SITE CHARACTERIZATION

11.1 Zone 1

The Zone I's, being the land within a 400 feet radius of District H TPW-2C and TPW-3B, are under the care and control of the Town of Eastham and the CCNS. The Zone I areas for these two wells are shown on Figures 1-4 and 1-5, and is comprised of three parcels. The production wells District H TPW-2C and TPW-3B are located on a parcel owned by the Town of Eastham (Map 9 Lot 419). The Zone 1 to the north and west are located within a parcel owned by the CCNS (Map 9 Lot 418). And the Zone I to the southeast is located within a parcel owned by the CCNS (Map 9 Lot 421). CCNS property uses are consistent with those for Zone I. A letter from the NPS regarding the public water supply Zone I property restrictions and CCNS property is included in Appendix B.

11.2 Land Uses and Potential Sources of Contamination in Zone II

11.2.1 Land Uses

Land use within the Zone II's for TPW-3B and TPW-2C were determined through the MassGIS databases and information compiled by the Town of Eastham, including the report The Town of Eastham – Local Comprehensive Plan (LCP), Third Edition 2010. Maps showing the land uses within the Zone II's for TPW-3B and TPW-2C are included as Figures 7-1 and 7-2. Figure 7-3 shows land uses within both the TPW-3B and TPW-2C Zone II's. As shown on these figures, land use within the Zone II's for District H TPW-2B and TPW-3C wells are comprised of predominately forested and residential use, with some recreational, commercial, and industrial uses. Other minor land uses within the Zone II include: non-forested wetlands, portions of the NRHS property, and the northern portions of the closed Town of Eastham Landfill site. Residential uses within the Zone II are predominately medium density residential properties, with some low and very low density residential properties and a few multi-family residential properties.

11.2.2 Potential Sources of Contamination

11.2.2.1 DEP List of Hazardous Waste Sites

The DEP list of waste sites in Eastham has been reviewed (last updated January 22, 2013) and the majority of the Zone II Area has been visited by Environmental Partners Group and representatives of DEP on field visits conducted throughout the hydrogeologic investigations and aquifer pump test activities. There are two open Bureau of Waste Site Cleanup (BWSC) reported releases within the Zone IIs for the TPW-3B and TPW-2C wells. These are the National Seashore Ranger Station located at 1050 Nauset Road and the Eastham Closed Landfill located on Old Orchard Road. Following is a summary of the status of these releases:

1. National Seashore Ranger Station site just touches the southeast corner of the Zone IIs for wells TPW-3B and TPW-2C. A release from an above ground storage tank (AST) fuel line was reported on February 14, 1996, which included a release of #2 fuel oil, 2-methylnaphthalene, and naphthalene. According to the DEP Online Sites Database, non-aqueous phase liquids (NAPL) fuel oil was detected onsite, contaminated soils were removed from the site, an SVE system installed and the area treated with chemical oxidation. This site is listed as in Phase V Operation, Maintenance and/or Monitoring.

2. Eastham Landfill, see Section 11.2.2.2 below.

11.2.2.2 Solid Waste Facilities – Eastham Landfill

The Eastham landfill is located on Old Orchard Road and was operated from 1937 to 1993. The landfill was capped and closed in 1998. Post-closure monitoring has been performed for the landfill by Bennett Environmental Associates, Inc. (Bennett).

The northern portion of the landfill property is located within the Zone II for TPW-3B and TPW-C. The northern portion of the property is occupied by the Department of Public Works and portions of the Town's solid waste and recycling transfer station; the landfill occupies the southern area of the property. Figure 11-4 shows the location of the landfill with respect to the Zone II area for the District H wells, and particle tracking pathlines depicting the groundwater flow directions from the landfill using the updated USGS MODFLOW groundwater model. Based on this modeling, groundwater flow is predominantly to the southeast of the landfill toward Salt Pond Bay area of Nauset Marsh, and most importantly it shows that District H is outside the predicted groundwater discharge zone for the landfill.

There are two circumstances of groundwater impacts in the area of the landfill that are attributed, at least in part, to the landfill: the presence of vinyl chloride and 1,4-dioxane. These are discussed below.

Vinyl chloride in Groundwater

In March 2004, vinyl chloride was detected in a private well at 325 Schoolhouse Road at concentrations that exceed the MCL for vinyl chloride (VC) of 2 µg/L. The 325 Schoolhouse Road property was issued

RTN#4-18278. As part of the Immediate Response Action (IRA) under the Massachusetts Contingency Plan (MCP), a water quality survey was conducted across a 167 acre area and included 237 residential properties located downgradient of the Eastham Landfill. This area was designated the "Molls Pond Study Area." Further investigations identified trace concentration of VC and dichloroethene (DCE), below 50% of the promulgated standards, in five private wells near the 325 Schoolhouse Road property. These additional properties were located on Knowles Street and Alston Avenue. The site geology at these properties consists of sand and gravel from the ground surface to a depth of 60 feet bgs, with depth to groundwater of 45 feet bgs. This is underlain by silts and clays to a depth of 140 feet bgs, with a deeper aquifer below 140 feet bgs. All of the properties with VC or DCE contamination had well depths greater than 150 feet bgs. A deeper well was installed at the 325 Schoolhouse Road property to a depth of 219 feet bgs. Water quality samples from this well detected VC at 2 µg/L as well as other low-level VOCs.

An "area of significant impact" was identified in a 1,000 foot by 1,000 foot area in close proximity to the 325 Schoolhouse Road property and restricted to the deep aquifer between 150-225 feet bgs. Those properties with measurable concentrations of VC and DCE were provided bottled water, where authorized by the homeowner, by the Town of Eastham. A point of entry granular activated activated carbon filtration water treatment system was installed at the 325 Schoolhouse Road property. Groundwater flow in the vicinity of the Eastham Landfill is towards the south-southeast, Salt Pond Bay area. The landfill was attributed to be the source of the VC and DCE. Influent water samples were collected at the 325 Schoolhouse Road property on a quarterly basis. On June 2, 2009 Bennett Environmental Associates (Bennett) submitted a Class A-2 Response Action Outcome (RAO) for the 325 Schoolhouse Road site after the vinyl chloride concentrations at the influent to activated carbon system were reported as less than the GW-1 standard of 2.0 ppb for ten consecutive quarterly rounds of sampling.

The 325 Schoolhouse Road property and 5 nearby properties where VOCs were detected in their private wells are all located outside and to the south-southwest of the Zone IIs for TPW-3B and TPW-2C and therefore, would not impact water quality at the District H production wells.

1,4-Dioxane in Groundwater

As part of the fall 2012 post-closure monitoring of the landfill, samples collected from the groundwater monitoring wells comprising the monitoring network (which consists of wells at the landfill perimeter, monitoring wells located outside the landfill boundaries, and a series of private wells in the vicinity of the landfill) were analyzed for 1,4-dioxane. One of the landfill monitoring wells, MW-3D, which is located at the southeast corner of the landfill property, had a detection of 1,4-dioxane at 4.3 parts per billion, which exceeds the Massachusetts Contingency Plan RCGW-1 Standard of 3 µg/L.

Because this well is located within 500 feet of a private water supply well, DEP was notified of this result and DEP subsequently issued a Notice of Responsibility to the Town on November 28, 2012 that required the Town to prepare an Immediate Response Action (IRA) Plan. The objective of the IRA plan is to sample additional private residential wells surrounding the landfill to better define the nature and extent of the presence of 1,4-dioxane. The IRA Plan was submitted to DEP by the Town's Licensed Site Professional, Bennett Associates, on January 11, 2013. DEP issued a conditional approval to conduct the response action on January 30, 2013. The tasks to be performed as part of this response action are:

1. Continued groundwater monitoring and private water supply well testing to identify whether there are additional wells impacted by 1,4-dioxane. A "study area" in the neighborhood area southeast of the landfill was identified, and the residents within this area were contacted to request that the Town be allowed to sample their water. Approximately 88 properties comprised this initial study area, and as of the end of March 2013 approximately 58 of residents were tested for both 1,4-dioxane and volatile organic compounds.

2. For properties where the analytical results were greater than 1.5 µg/L, being 50% of the GW-1 Standard, bottle water is being provided by the Town and the Town is evaluating water supply alternatives for these residences. As of the end of March 2013, nine residential properties met this condition and were being provided with bottled water.

3. The vertical and horizontal extent of the 1,4-dioxane in groundwater is to be characterized further by correlating the analytical results with well construction logs, where available, of each property.

The Town, through Bennett Associates, issued an Immediate Response Action Status Report and Quarterly Landfill Monitoring Report on March 29, 2013 that summarized the status of these IRA activities through March 22, 2013. Because the sampling of the 86 properties performed as part of the first phase of these IRA activities did not adequately confirm the horizontal extent of the 1,4-dioxane plume, a second phase of residential well sampling that expands the Study Area by approximately 130 additional properties is being performed during April and May 2013.

The results of this sampling program are to be provided to DEP in the next quarterly progress report, to be submitted to DEP before the end of June 2013. It is anticipated that these IRA activities will likely lead to additional sampling and field activities to further define the nature and extent of the 1,4-dioxane, and could include sampling of additional private wells beyond the geographic extent of the Study Area, sampling of wells in other areas of the Town in attempt to document “background” conditions, and potentially the installation of test borings and monitoring wells to further define the subsurface geology and hydrogeologic characteristics where 1,4-dioxane has been confirmed to be present.

1,4-Dioxane Sampling of Public Water Supply Wells at District G, NRHS and District H

In response to these detections of 1,4-dioxane in groundwater in the vicinity of the landfill, the public water supply wells proposed to be developed by the Town, consisting of District G, Nauset Regional High School, and District H were sampled on January 17, 2013 and analyzed for 1,4-dioxane in accordance with EPA Method 522.1, which has a method reporting limit of 0.2 ppb and a method detection limit of 0.041 ppb. At each well field the closest offset well to each of the production wells was sampled because most of the production wells are welded shut. The results of this sampling are summarized below, and the analytical reports are provided in Appendix L.

Table 11.1 Analytical results of sampling for 1,4-dioxane in proposed public water supply wells at District G, Nauset Regional High School and District H.

Well Field	*Well Designation*	*Current MCP GW-1 Cleanup Standard (ppb)*	*Potential Revised MCP GW-1 Cleanup Standard (ppb)*	*Result (ppb)*
District G	OW-8	3.0	0.3	No Detection
NRHS	OW-1A	3.0	0.3	No Detection
District H	OW-3B (Zone B)	3.0	0.3	0.071 (J)
District H	OW-3B duplicate	3.0	0.3	0.080 (J)
District H	OW-2C (Zone C)	3.0	0.3	0.045 (J)

Notes: (J) qualifier means that the analytical result is below the Reporting Limit, but greater than the Method Detection Limit and is therefore an approximate (estimated) value.

The wells at District G and the Nauset Regional High School had no detections of 1,4-Dioxane. At District H, the well screened in the Zone B aquifer had a detection of 0.071 ppb and a duplicate sample from the same well had a concentration of 0.081 ppb; the well screened in the Zone C aquifer had a detection of 0.045 ppb. These detections are below the Method Reporting Limit of 0.2 ppb, and therefore cannot be verified and are estimates.

The cleanup standard for 1,4-dioxane under the Massachusetts Contingency Plan (GW-1) is 3.0 ppb. It is the understanding of DEP’s Bureau of Waste Site Cleanup the this GW-1 cleanup standard will be lowered to 0.3 ppb within the next several months to be consistent with EPA's Office of Research and Standards. The analytical results of sampling at each of the proposed public water supply locations are either non-detect or a minimum of an order of magnitude lower than the potentially revised standard of 0.3 ppb, and therefore the wells are suitable for public water supply purposes.

The regional MODFLOW groundwater model was used to provide particle tracking that describes the direction of groundwater flow from the landfill, shown in Figure 11-1. District H is located to the northeast of the landfill area and the particle tracking shows that groundwater emanating from the landfill area flows generally to the southeast and does not intersect the District H property. For this reason the source of the trace concentrations of 1,4-dioxane detected at the Zone B and Zone C wells from samples collected in the January 2013 sampling event is not known at this time. The objective of the ongoing IRA investigations by the Town will provide definition on the horizontal and vertical extent of the 1,4-dioxane in groundwater and what the likely sources are.

11.2.3 Underground Storage Tanks

Underground Storage Tanks (USTs) and buried on-site domestic fuel tanks are a potential contamination source to groundwater (LCP, 2010). The Massachusetts GIS database shows that there is a UST at the Eastham Department of Public Works (DPW) property on Old Orchard Road. This UST has been removed by the Town and no longer exists.

11.2.4 Onsite Septic Systems

According to the LCP, 2010, the most common potential contamination sources for domestic water supply wells in Eastham are the on-site sewage disposal systems on the same or adjacent lots to the residential water supply wells. Evaluations completed by the MEP identify individual on-site septic systems as the largest source of nitrogen and phosphorus to the groundwater. Long-term nitrate sampling data has been collected for the Town of Eastham for the past fifteen years. These data indicate a continued decline in drinking water quality, with increasing nitrogen concentrations.

It is generally accepted by the DEP, the Cape Cod Commission and the Barnstable County Health Department that water that has greater than 2 ppm nitrate is being impacted by septic system discharges. Figure 11-5 provides a summary of the residential well sampling program between 2002 through 2012 where detections of nitrate were greater than 2 parts per million. Properties in Eastham that have greater than 2 ppm nitrate occur in all areas of the Town; it is not limited to a single area of the community. As of 2011 greater than 40% of the properties in Eastham had well water with nitrate concentrations greater than 2 ppm, as shown in Figure 11-6, and this percentage is progressively increasing with time.

11.3 Potential Impacts on Sensitive Receptors

District H TPW-3B and TPW-2C and their Zone I and Zone IIs are located within an area designated as Protected Open Space, which is the NPS Cape Cod National Seashore. The District H and surrounding area are listed as an Area of Critical Environmental Concern and Estimate Habitat of Rare Wetland Wildlife. The Cape Cod National Seashore has been consulted and MassGIS mapping has been reviewed to determine whether any wetland resource areas exist within the proposed Zone II area. Several vernal pools are located within the Zone IIs for TPW-3B and TPW-2C, including NPS designated vernal pools VP-1, VP-5, VP-9 and VP-11.

An extensive water level monitoring program and groundwater modeling was implemented as part of the aquifer performance tests performed at District H, to evaluate potential production well pumping effects to nearby vernal pools. These results are summarized in detail in Section 7. This study included monitoring of three vernal pools during three aquifer performance tests. No measureable decline was observed in vernal pools VP-E1 or VP-E9. A measurable decline in water levels within the vernal pools was only observed in vernal pool VP-11. The vernal pool VP-E11 model results indicated that the groundwater level declines in the vicinity of the vernal pool caused by future District H pumping is not anticipated to cause a significant change in the seasonal water elevations in the pool. As discussed in Section 12, a monitoring program is proposed for the vernal pools to confirm the results of the SEAWAT model as it relates to water level drawdown at nearby vernal pools and vernal pool stage levels as predicted by the vernal pool model under actual operating conditions of the wellfield

The project area is located within an area mapped by the Massachusetts Natural Heritage and Endangered Species program (NHESP) as a Priority Habitat of Rare Species and Estimated Habitat of Rare Wildlife. Use of the public water supply well NRHS TPW-1 will not have any effect on rare species. As part of the construction activities associated with developing the well field, the Town will file a Massachusetts Endangered Species Act (MESA) Project Review form with the NHESP. If mitigative measures are required by NHESP after their review of the MESA form, all work would be conducted according to a plan filed with the NHESP, which would be approved in advance by that program prior to the commencement of construction work. This will ensure that the proposed project will not result in a prohibited “take” of state-listed rare species. Consequently, the project would be in compliance with the Cape Cod Commission’s Regional Policy Plan, meeting the Minimum Performance Standard (MPS) as described in Section 2.4.1.4 of the Regional Policy Plan. This regulation, adopted by the Cape Cod Commission, deals with developments of regional impact proposed within critical wildlife and plant habitat areas. These proposed developments are reviewed by the National Heritage Program. The mitigative measures, if needed, may consist of relocating species or required host plants that are encountered during the construction activities, and would be performed by state-certified specialists.

12 GROUNDWATER MONITORING PROGRAM

Three monitoring programs are proposed to be implemented at District H that have the following objectives:

1. Salt water interface monitoring to confirm conditions predicted by the SEAWAT groundwater modeling under actual operating conditions of the well field.

2. Water level monitoring in select vernal pools and monitoring wells to confirm the vernal pool modeling predictions under actual operating conditions of the well field.

3. Water quality monitoring of sentinel wells to District H.

The proposed monitoring programs are discussed in detail below.

12.1 Salt Water Interface Monitoring

12.1.1 General Plan Information

A salt water interface monitoring program will be implemented to confirm the water quality conditions predicted by the SEAWAT groundwater modeling under actual operating conditions of the well field. The goal of the monitoring is to ensure that water quality in the Zone B and Zone C aquifers is not being influenced by transition zone effects under pumping conditions. Groundwater modeling indicates that if these transition zone effects were to occur increases in sodium, chloride and TDS concentrations would first be observed in the Zone D aquifer prior to the other, shallower aquifer zones being affected. A series of observation wells will be monitored to confirm conditions in the Zone D aquifer. The monitoring will be initiated prior to pumping operations for the collection of background data (i.e., pre-pumping conditions), and a semi-annual schedule of monitoring is proposed for the long-term monitoring plan.

Water levels in the Zone A (water table), Zone B (shallow aquifer), Zone C (intermediate aquifer), and Zone D (deep aquifer) of well clusters OW-1 and OW-2 and in the Zone C well of well clusters OW-3 and OW-4 will be monitored hourly with data logging pressure transducers. Manual water-level measurement will be taken semi-annually immediately prior to downloading the data logger data. The data will be adjusted to NGVD, plotted on graphs (water levels vs. time) and evaluated against model-predicted water levels.

Water quality in the Zone C and Zone D wells of clusters OW-1 and OW-2 and will be monitored on a semi-annual basis. A submersible pump will be deployed in the Zone C and Zone D wells for purging a minimum of 3 well volumes prior to sampling for field parameters (temperature, specific conductance, and pH) and laboratory parameters (sodium, chloride, sulfate, TDS, iron, and manganese). Trends of the collected water quality data will be evaluated bi-annually (every two years), and if transition zone effects are being observed recommendations will be developed on whether monitoring of additional observation wells, such as the Zone C well of clusters OW-3 and OW-4 or observation wells screened in the Zone B aquifer, should be added to the monitoring program. Recommendations will also be developed on the frequency of monitoring and the field and laboratory parameters being sampled.

Data from this monitoring program will be used to assess potential changes in water quality, and to revise and update as necessary the groundwater model that was used in the analysis of approvable yield after a sufficiently long record of water quality data has been developed. Water quality data trends, along with other operational and hydrologic factors, will be evaluated from time to time as a basis for implementing any required modifications to well field operational practices.

The monitoring will begin after the permit is issued and before pumping operations start (for municipal supply) to allow for the collection of baseline data (i.e., pre-pumping conditions) and to allow for the comparison of background water quality to water quality during municipal pumping operations. Once the well field has been placed in operation, monitoring of hydrologic, operational, and water quality data will be performed in accordance with the schedules outlined in the sections below.

12.1.2 Monitoring Network

The monitoring network will consist of wells OW-1A, TPW-1B (or OW-1B), OW-1C, OW-1D, OW-2A, OW-2B, OW-2C1, OW-2D, OW-4A, OW-4B and OW-4C at the District H site. Together, these wells will provide data on the shallow, intermediate and deep zones of the aquifer.

12.1.3 Water Level and Rainfall Data Collection

Water levels in the Zone A, Zone B, Zone C, and Zone D wells of the OW-1 and OW-2 clusters and Zone A, Zone B, and Zone C wells of the OW-4 cluster will be monitored with data logging pressure transducers. The data loggers will be programmed to collect a water level and water temperature reading once per hour. The water level and temperature data collection will begin approximately two quarters before pumping of the District H wells is initiated.

The data loggers will be downloaded semi-annually (i.e., March and September). A manual water-level measurement will be taken semi-annually just prior to downloading the data logger. The data logger clocks will be checked and reset to Coordinated Universal Time (UTC) if necessary.

Rainfall data will be downloaded semi-annually from the National Park Service rain gauge in Truro (or other nearby rain gauge station).

12.1.4 Water Quality Data Collection

Water quality in the Zone C and Zone D observation wells of the OW-1 and OW-2 clusters will be monitored. A submersible pump will be deployed in the Zone B and Zone C wells for purging until stabilization of the field parameters occurs (typically three well volumes) prior to sampling for field parameters (temperature, specific conductance, and pH) and laboratory parameters (sodium, chloride, sulfate, TDS, iron, and manganese).

Base-line water quality data from the Zone B and Zone C wells of the OW-1 and OW-2 well clusters will be collected quarterly beginning approximately two quarters prior to the District H production wells going on-line (i.e., two sets of samples will be collected approximately 6 months and 3 months prior to the District H production wells going on-line).

After the production wells are on-line and are a fully functional part of the water distribution system, water quality from the production wells and monitoring wells will be monitored semi-annually in March, and September.

12.1.5 Data Evaluation and Reporting

Water quality data will be compiled in tabular form. Water level data will be adjusted to NGVD and plotted on graphs of water-level elevations vs. time. Graphs of pumping rates, rainfall, and all water quality data over time will also be compiled.

The analyses of the water quality sampling will be summarized in a data information report once every two years. The report will provide a presentation and discussion of the monitoring data collected over that period, together with an evaluation of the monitoring program including monitoring schedule, frequency of data collection, field and laboratory water quality parameters, and adequacy of the number and location of monitoring points.

Every five years, the monitoring data will be compared to water quality and head distributions computed using the most current version of the Nauset lens model. The results of the comparison can be used to modify or update the model.

12.2 Vernal Pool Monitoring

The goal of the vernal pool monitoring program is to confirm, under actual operating conditions of the wellfield, the results of the SEAWAT model as it relates to water level drawdown at nearby vernal pools and vernal pool stage levels as predicted by the vernal pool model. As summarized in Sections 8.4 and 8.5, the vernal pool model shows that normal pumping conditions at District H would have a very small effect on the vernal pool stage (average drop of 2.5 inches), based on monitoring data collected from December 2010 to December 2011. The model was based on a SEAWAT calculated groundwater level decline of approximately 7.4 inches in the vicinity of vernal pool VP-E11, in response to a pumping rate of 0.5 MGD at TPW-3B.

A series of vernal pools and observation wells will be monitored to confirm that the effects to vernal pool water levels from production well pumping are consistent with those predicted in the vernal pool model. The vernal pool monitoring plan will include the following four components:

1. Vernal pool water level monitoring
2. Observation well water level monitoring
3. Precipitation monitoring
4. Progress meetings

The monitoring will be initiated prior to pumping operations for the collection of background data (i.e., pre-pumping conditions), and a semi-annual schedule of monitoring is proposed for the long-term monitoring plan.

Water level measurements will be performed at the following locations:

- Within the vernal pool and in a piezometer installed within the water table beneath the vernal pool at vernal pool locations VP-E1, VP-E9, VP-E11, VP-E6, and VP-E5 or VP-E5a
- Observation wells screened in the Zone A (water table), Zone B (shallow aquifer), and Zone C (intermediate aquifer) aquifers of well clusters OW-1, OW-2, OW-3 and OW-4.

Water levels will be collected hourly with data logging pressure transducers. Manual water-level measurements will be taken each quarter just prior to downloading the data loggers. The data will be adjusted to NGVD, plotted on graphs (water levels vs. time) and evaluated against model-predicted water levels. The frequency of monitoring and the monitoring network will be evaluated on an biennial basis.

After a sufficiently long record of water level measurements has been developed, measured pumping effects on water levels and vernal pool stage levels will be compared with those predicted in the vernal pool model, to revise and update as necessary the SEAWAT and vernal pool model. Water level data trends, along with other operational and hydrologic factors, will be evaluated from time to time as a basis for implementing any required modifications to well field operational practices.

The monitoring will begin after the permit is issued and a minimum of six months before pumping begins (for municipal supply) to allow for the collection of baseline data (i.e., pre-pumping conditions) and to allow for the comparison of background water levels to water levels during municipal pumping operations. Once the well field has been placed in operation, water level monitoring will be performed in accordance with the schedules outlined in the sections below.

12.2.1 Monitoring Network

The water level monitoring network will include vernal pools and observation wells.

The vernal pool water level monitoring network will include the vernal pools located closest to production wells TPW-3B and TPW-2C, including VP-E1, VP-E9, VP-E11 and either VP-E5 or VP-E5a. The selection of vernal pool VP-E5 or VP-E5a will be based on discussions with the NPS personnel. Water levels will also be collected from one background vernal pool, VP-E6. At a minimum, water levels will be monitored within the vernal pool and from a piezometer installed in the water table beneath the vernal pool (5 surface water and 5 water table locations total).

Observation well water level monitoring will be performed in wells screened within the Zone A (water table aquifer) and Zones B and C pumping zone aquifers at observation well clusters OW-1, OW-2, OW-3 and OW-4 (12 wells total).

12.2.2 Water Level and Rainfall Data Collection

Water levels will be monitored with data logging pressure transducers in the Zone A, Zone B, and Zone C of the OW-1, OW-2, OW-3, and OW-4 clusters and within the vernal pool and the water table beneath the vernal pool at vernal pools VP-E1, VP-E9, VP-E11, VP-E5 or VP-E5a, and VP-E6. The data loggers will be programmed to collect a water level and water temperature reading once per hour. The water level and temperature data collection will begin at least one year before pumping of the District H wells is initiated.

An Onset rain gauge (or equivalent) will be set up at the Town of Eastham DPW property located approximately 4,700 feet west of the TPW-3B and TPW-2C production wells. This rain gauge will be maintained and operated for at least two years after the District H production wells are brought on-line. After two years, the option will be reviewed to discontinue operation of the rain gauge, at which time precipitation data will be obtained from either the NPS rain gauge in Truro or the Chatham rain gauge.

The data loggers and Onset rain gauge will be downloaded semi-annually (i.e., March and September). A manual water-level measurement will be taken at each observation wells, vernal pool and piezometer monitoring location each quarter just prior to downloading the data logger. The data logger clocks will be checked and reset to Coordinated Universal Time (UTC) if necessary.

13.2.3 Data Evaluation and Reporting

All water level measurements will be adjusted to NGVD and plotted on graphs of water-level elevations vs. time. Graphs of pumping rates and rainfall will also be compiled.

The information will be summarized in a data information report once every two years. The report will provide a presentation and discussion of the monitoring data collected over that period, together with an evaluation of the monitoring program including monitoring schedule, frequency of data collection, and adequacy of the number and location of monitoring points.

Every five years, the data will be compared to predicted water levels computed using the using the SEAWAT and vernal pool model. The results of the comparison can be used by the Town of Eastham to modify or update the model and, if appropriate, modify well field operations.

12.3 Sentinel Well Water Quality Monitoring

As indicated in *Chapter 4 – Groundwater Supply Development and Source Approval Process Section 4.6.2,* land uses that may prompt the need for monitoring at public water supply wells are if the water supply is in the vicinity of industrial/commercial areas, unsewered and densely populated residential areas, or areas in which groundwater contamination has been detected. Section 11 describes groundwater impacts resulting from the landfill, including historic detections of vinyl chloride and recent detections of 1,4-dioxane.

For this reason, a sentinel monitoring wells screened in the Zone B and Zone C aquifer is warranted. These monitoring wells will provide early-on indications of whether impaired water quality conditions exist upgradient of the productions wells. These monitoring wells are to be located at the western edge of the District H property adjacent to Nauset Road, at a location to be selected by the Town after the Source Approval permit is received by the Town. One monitoring well couplet is proposed at this time, however additional wells at locations between this sentinel well and the production wells can be added over time if the evaluation of water quality trends identify this need.

The wells are to be sampled for nitrate, VOCs (Method 524.2) and 1,4-doxane (Method 522.1 Modified) together with standard field paramaters of pH, specific conductivity and temeperature, on a semi-annual basis.

The sentinel water quality analyses will be summarized in a data information report once every two years. The report will provide a presentation and discussion of the monitoring data collected over that period, together with an evaluation of the monitoring program including monitoring schedule, frequency of data collection, field and laboratory water quality parameters, and adequacy of the number and location of monitoring points.

13 WELLHEAD PROTECTION PLAN

The Town of Eastham has designated two potential sites for development of municipal water supply wells. These sites are the Water Resource Protection Zoning District “G” (District G) and Well-field Protection Zoning District “H” (District H). District H is designated by Eastham Zone Bylaws as “An open space area designed to protect the public health by preventing the contamination of the ground and surface water resources in a test wellfield area demonstrated to be capable of providing a portion of the potential public water supply for the Town of Eastham.”

Prior to bringing the District H well field online, the Wellhead Protection Zoning and Non-zoning Controls as outlined in 310 CMR 22.21(2) will be addressed and implemented by the Town of Eastham.

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Tables

Table 3-1. Well Construction Details and Coordinates
Observation Wells and Test Production Well
District H Aquifer Performance Test
Eastham, MA

Well ID	Well Diam. inches	Date Drilled	COAST. SURV. DATA (1)					UPDATED COAST. SURV. DATA (1)			Distance from TPW-3B (feet)	Distance from TPW-2C (feet)
			NORTHING	EASTING	TOP OF CASING EL.	TOP OF PVC EL.	GROUND EL.	TOP OF CASING EL.	TOP OF PVC EL.	GROUND EL.		
District H												
OW-1A	1	3-Mar-2006	2774915.334	1074661.318	37.55	36.92	35.68				147	287
OW-1B	4	28-Feb - 1-Mar-2006	2774920.162	1074661.029	37.25	36.84	35.80				143	282
OW-1C	6/4	17-26-Aug-2009	2774903.080	1074665.591	38.34	37.60	35.52				160	300
OW-1D	4	27-Aug-2 Sept-2009	2774910.694	1074665.690	38.00	37.73	36.03				153	293
TPW-1B	6	3-4-Mar-2006	2774904.642	1074657.946	38.13	36.94	36.23				157	295
OW-2A		7-Sep-2010	2775182.322	1074539.986	39.40	39.22	36.84				147	11
OW-2B		8-Sep-2010	2775189.843	1074532.056	40.70	40.55	38.22				158	17
OW-2C1	4	29-30-Jun-2010	2775158.910	1074522.470	39.69	39.52	36.80				138	19
OW-2C2		1-Sep-2010	2775178.953	1074536.533	39.35	39.09	36.97				146	6
OW-2D	4	8-10-Sep-2010	2775191.428	1074537.184	40.41	40.14	38.01				156	19
TPW-2C	12	16-Nov - 8 Dec-2010	2775172.996	1074535.099	37.57		36.69				142	
OW-3A			2775063.189	1074607.760	29.78	29.47	27.33				10	132
OW-3B1	4	7-8 Jul-2010	2775077.024	1074601.963	29.59	29.27	27.07				25	117
OW-3B2			2775055.607	1074616.342	29.71	29.47	27.43				4	143
OW-3C	4	30-Jun - 7-Jul-2010	2775070.645	1074604.212	29.54	29.21	27.09				18	123
TPW-3B	12		2775054.550	1074612.780	28.65		27.37					142
OW-4A		15-Sep-2010	2774498.690	1074905.537	19.83	19.60	17.20	17.84	17.61	17.14	628	769
OW-4B		14-Sep-2010	2774493.505	1074906.614	19.33	19.12	16.65	17.34	17.32	16.67	633	774
OW-4C	4	13-14-Sep-2010	2774487.501	1074907.828	18.78	18.66	16.28	16.94	16.86	16.86	639	780
VPE-9 3"	3		2774445.099	1074871.298	17.27	17.33					662	802
VPE-9 C-1			2774453.680	1074815.863	18.38	18.07					634	772
2011 Phase 2 Vernal Pool Dataloggers												
VP-E1A	1.5		2774211.456	1074405.520	12.68	12.59	12.60	12.62	12.53		868	970
VP-E1B	1.5		2774211.315	1074405.510	12.68			12.62			868	970
VP-E1C	1.5		2774213.504	1074406.140	12.75						866	968
VP-E9A	1.5		2774426.319	1074943.645	12.48	12.36	12.31				710	851
VP-E9B	1.5		2774426.342	1074943.502	12.48						710	851
VP-E9C	1		2774440.929	1074939.861	11.91						695	837
VP-E11A	1.5		2775288.013	1075243.156	12.03	11.86	11.86				672	717
VP-E11B	1.5		2775288.316	1075243.138	12.03						672	717
VP-E11C	1.5		2775289.377	1075243.776	11.90						673	718
EGW-36	2?		2776676.083	1072778.022	54.04	53.94	FLUSH				2,449	2,312
2009-2010 Phase 1 Vernal Pool Dataloggers												
VP-E1SG	n/a		2774216.356	1074406.927		12.82					863	965
VP-E2SG			2774862.693	1075698.906		11.55					1,103	1,204
VP-E9tall	n/a		2774372.592	1074982.882		12.98					776	917
NRHS												
Background Regional Water Level Data												
OW-1A	4	Sep-09	2779685.60	1073485.79	66.13	65.18	63.40				4,766	4,633
District G												
Background Regional Water Level Data												
OW-7	4	18-25-Sept-2009	2781697.85	1069781.51	46.06	45.69	44.31				8,214	8,073
OW-8	4	30-Aug-2010	2781715.36	1069805.57	46.67	46.49	43.96				8,214	8,073

Table 3-1. Well Construction Details and Coordinates
Observation Wells and Test Production Well
District H Aquifer Performance Test
Eastham, MA

Well ID	GROUND EL	Boring TD ft. bgs.	Bottom Screen ft. bgs.	Top Screen ft. bgs.	Boring TD Elev. (ft)	Elev. Screen Bottom Elev. (ft)	Elev. Screen Top Elev. (ft)	Well Construction (feet bgs) Sand	Transition Sand	Bentonite	CB Grout	Natural Backfill	Neat Cement
District H													
OW-1A	35.68	38.5	38.5	31.5	-2.82	-2.82	4.18				26-3	38.5-26	3-0
OW-1B	35.80	119.5	119.5	109.5	-83.70	-83.82	-73.82	120-104			104-4		3-0
OW-1C	35.52	219	217	207	-183.48	-181.32	-171.32	219-205	205-204	204-202	202-3		3-0
OW-1D	36.03	400	349	346	-363.97	-313.32	-310.32	352-344	344-343	343-342	342-3		3-0
TPW-1B	16.23	116.5	116.5	106.5	-100.27	-80.82	-70.82	117-96			96-3		3-0
				35-40 slot									
OW-2A	36.84	38	36	26	-1.16	-0.32	9.68	38-24		24-14		14-10	Oct-00
OW-2B	38.22	108	104	94	-69.78	-68.32	-58.32	106-92		92-82	82-10		10-0
OW-2C1	36.80	219	203.5	183.5	-182.20	-167.82	-147.82	205-181	181-179	179-169	169-10		10-0
OW-2C2	36.97	227	196	186	-190.03	-160.32	-150.32	197-183		183-173	173-10		10-0
OW-2D	38.01	357	353	348	-318.99	-317.32	-312.32	353-345		345-335	335-10		10-0
TPW-2C	36.69	220	205	185	-183.31	-169.32	-149.32	206.5-183	183-182	182-172	172-20		20-10
				50 slot #2 Gravel						210-206.5			
OW-3A	27.33	26	24	14	1.33	11.68	21.68	26-12		12-10			10-0
OW-3B1	27.07	103	101	91	-75.93	-65.32	-55.32	103-89		89-79	79-10		10-0
OW-3B2	27.43	108	104	94	-80.57	-68.32	-58.32	105-92		92-82	82-10		10-0
OW-3C	27.09	220	195	185	-192.91	-159.32	-149.32	198-179		179-169	169-10		10-0
TPW-3B	27.37	112	103	93	-84.63	-67.32	-57.32	104-91	91-90	90-80	80-20	112-104	20-10
				80 slot #4 Gravel						109-108			
OW-4A	17.20	16	15	5	1.20	20.68	30.68	16-4		4-2			2-0
OW-4B	16.65	92	90	80	-75.35	-54.32	-44.32	92-78		78-68	68-10		10-0
OW-4C	16.28	218	194	184	-201.72	-158.32	-148.32	196-182		182-172	172-10		10-0
VPE-9 3"													
VPE-9 C-1													
2011 Phase 2 Vernal Pool Dataloggers													
VP-E1A*	12.60	3.1			9.58	9.58							
VP-E1B*		6.13			6.55	6.55							
VP-E1C*		12.26			0.49	0.49							
VP-E9A*	12.31	3.7			8.78	8.78							
VP-E9B*		6.2			6.28	6.28							
VP-E9C*		10.09			1.82	1.82							
VP-E11A*	11.86	3.2			8.83	8.83							
VP-E11B*		6.2			5.83	5.83							
VP-E11C*		12.25			-0.35	-0.35							
EGW-36	FLUSH												
2009-2010 Phase 1 Vernal Pool Dataloggers													
VP-E1SG													
VP-E2SG													
VP-E9tall													
NRHS													
Background Regional Water Level Data													
OW-1A	63.40	88	87	77	-24.60			88-45		45-41		41-3	3-0
District G													
Background Regional Water Level Data													
OW-7	44.31	98	96	86	-53.69			98-70		70-68	68-13		13-0
OW-8	43.96	98	89.5	79.5	-54.04			90.5-77.5		77.5-67.5		67.5-10	10-0

Notes:

Wells in **BOLD** are wells installed under Phase 2 in June -September 2010

(1) **VERTICAL DATUM : NAVD88**
HORIZONTAL COORDINATE SYSTEM : NAD83

* Value measured from top of pipe (not ground surface) with water level tape, not surveyed.

OW-4 Cluster Wells Cut down on April 19, 2011, after this date use Updated Coastal Survey Data

VP-E1A and VP-E1B Piezometers moved on 4/4/11;

Table 4-1
Summary of District H Pump Test Results

				Combined APT	
		TPW-3B Dec. 6-11, 2010	**TPW-2C Dec. 16-12, 2010**	**TPW-3B Mar. 22-28, 2011**	**TPW-2C Mar. 22-28, 2011**
Total Depth of Well	ft. bgs	108	210	108	210
Length of Well Screen	feet	10	20	10	20
Length of Bottom Sump	feet	5	5	5	5
Top Well Screen	ft. bgs	93	185	93	185
Top Well Screen	ft. TOC	95.09	187.06	95.09	187.06
Pre-Test Static Water Level	ft. TOC	21.28	30.54	20.33	29.82
Pre-Test Static Water Level	ft. bgs	19.19	28.48	18.24	27.76
Total Available Water Above Well Screen	feet	73.81	156.52	74.76	157.24
Available Water with 5-foot Buffer	feet	68.81	151.52	69.76	152.24
Minimum Flow Rate-Instantaneous	gpm	913	915	703	708
Maximum Flow Rate-Instantaneous	gpm	948	935	769	755
Minimum Flow Rate-Totalizer	gpm	909	911	703	712
Maximum Flow Rate-Totalizer	gpm	912	919	728	730
Average Flow Rate Totalizer	gpm	910	916	716.4	722.7
Background Water Levels		Rising	Rising	Rising	Flat
Maximum DTW (last 36-hours)	ft. TOC	38.86	59.94	35.72	54.20
Maximum Drawdown (last 36-hours)	feet	17.58	29.40	15.39	24.38
Specific Capacity	gpm/ft	51.76	31.16	46.55	29.64
Available Water Above Screen at End of Test	feet	56.23	127.12	59.37	132.86
180-Day Extension Drawdown	feet	17.75	29.24	15.63	25.31
180-Day Extension Water Level	feet TOC	39.03	59.78	35.96	55.13
10% of Available Water	feet	7.38	15.65	7.48	15.72
Top Well Screen less 10% of available water	feet TOC	87.71	171.408	87.61	171.34
Available Water Above Well Screen at 180-day Extension	feet	56.06	127.28	59.13	131.93

Table 4-2: Aquifer Test Water Quality Results
District H TPW-3B and TPW-2C Testing

Field Analytical Results

District H - TPW-3B

5 Day Aquifer Performance Test

Date	Time	pH	Specific Cond. (µmhos/cm°C)	Temp (Degrees C)	Turbidity (NTU)
12/6/2010	10:32	6.32	152.0	10.3	0.53
12/7/2010	12:35	6.36	154.5	10.3	0.32
12/8/2010	10:50	6.32	154.0	10.2	0.44
12/9/2010	14:06	6.26	153.4	10.2	0.24
12/10/2010	10:50	6.22	154.8	10.1	0.16
12/11/2010	8:10	6.26	154.4	10.1	0.08

District H - TPW-2C

5 Day Aquifer Performance Test

Date	Time	pH	Specific Cond. (µmhos/cm°C)	Temp (Degrees C)	Turbidity (NTU)
12/16/2010	11:50	5.67	132.8	10.3	0.43
12/17/2010	12:05	6.06	130.7	10.2	0.40
12/18/2010	9:40	6.08	132.0	10.1	0.41
12/19/2010	13:57	6.06	131.6	10.2	0.29
12/20/2010	8:50	6.20	126.9	10.1	0.25
12/21/2010	8:30	6.15	132.6	10.2	0.33

District H - Combined APT TPW-3B and TPW-2C

6 Day 17 hour Aquifer Performance Test

District H - TPW-3B

Date	Time	pH	Specific Cond. (µmhos/cm°C)	Temp (Degrees C)	Turbidity (NTU)
3/22/2011	15:37	6.23	143.0	10.3	0.39
3/23/2011	15:50	6.21	142.6	10.3	0.48
3/24/2011	10:30	6.22	143.2	10.2	0.52
3/25/2011	18:15	6.26	142.2	10.3	0.46
3/26/2011	14:02	6.16	139.8	10.3	0.43
3/27/2011	14:45	5.99	139.1	10.4	0.37

District H - TPW-2C

Date	Time	pH	Specific Cond. (µmhos/cm°C)	Temp (Degrees C)	Turbidity (NTU)
3/22/2011	15:45	6.25	120.4	10.4	0.36
3/23/2011	15:55	6.1	120.5	10.3	0.49
3/24/2011	10:38	6.19	120.8	10.3	0.51
3/25/2011	18:19	6.18	121.6	10.3	0.60
3/26/2011	14:06	6.19	120.5	10.3	0.51
3/27/2011	14:55	6.03	121.6	10.4	0.52
3/28/2011	14:50	6.21	121.7	10.4	0.33

Table 4-2: Aquifer Test Water Quality Results
District H TPW-3B and TPW-2C Testing

Field and Laboratory Analytical Results

District H TPW-3B

5 Day Aquifer Performance Test

Date/Time Pump Test Sample Sample ID	Massachusetts MCL or Secondary MCL	12/6/10 10:25 1 Hour TPW-3B-1Hr	12/8/10 10:20 48 Hours TPW-3B-48Hrs	12/11/10 7:10 5 Days TPW-3B-END
Total Metals (mg/l)				
Aluminum	0.05-0.2 (a)	BRL	BRL	BRL
Antimony	0.006	-	-	BRL
Arsenic	0.010	-	-	BRL
Barium	2	-	-	BRL
Beryllium	0.004	-	-	BRL
Cadmium	0.005	-	-	BRL
Calcium	NSA	5.5	5.6	5.7
Chromium	0.1	-	-	BRL
Copper	1 (a) 1.3 (b)	BRL	BRL	BRL
Iron	0.3 (a)	BRL	BRL	BRL
Lead	0.015 (b)	-	-	BRL
Magnesium	NSA	3.4	3.6	3.7
Manganese	0.05 (a)	BRL	BRL	BRL
Mercury	0.002	-	-	BRL
Nickel	0.1 (d)	-	-	BRL
Potassium	NSA	1.2	1	1.4
Selenium	0.05	-	-	BRL
Silver	0.1 (a)	0.009	BRL	BRL
Sodium	20 (d)	-	-	18
Thallium	0.002	-	-	BRL
Zinc	5 (a)	BRL	BRL	BRL
Hardness	NSA	28	29	30
Inorganic Chemistry (mg/l)				
Total Dissolved Solids	500 (a)	78	140	130
Chloride	250 (a)	24	28	25
Color, True (C.U.)	15 C.U. (a)	BRL	BRL	BRL
Fluoride	4.0	-	-	0.1
Nitrate (as Nitrogen)	10	-	-	1.4
Nitrite (as Nitrogen)	1	-	-	BRL
pH	6.5-8.5 (a)	5.9	6.6	5.8
Specific Cond.	NSA	-	-	87
Sulfate	250 (a)	6	BRL	7.4
Turbidity (N.T.U.)	5 (g)	0.3	BRL	1.1
Alkalinity, Total (as $CaCO_3$)	NSA	22	29	14
Carbon Dioxide, Total (by calculation)	NSA	-	-	34
Ammonia (as Nitrogen)	30 (g)	-	-	BRL
Odor	3 (a)	BRL	BRL	BRL
Cyanide, Total	0.2	-	-	BRL
Volatile Organic Compounds (µg/l)				
Chloroform	70 (d)	-	-	1
Perchlorate EPA Method 314.0 (µg/l)				
Perchlorate (µg/l)	2	-	-	BRL
Specific Conductance (µmhos/cm°C)	NSA	-	-	129
Microbiology				
Coliform, Total	Absent (e)	-	Absent	Absent
E. Coli	Absent	-	-	-
Radionuclides				
Radon (pCi/L)	10,000 (f)	-	-	226.6 ± 44.9 (65.0)
Gross Alpha (pCi/L)	15	-	-	0.218 ± 0.600 (1.46)
Gross Beta 4 (millirem/year)	4	-	-	o.444 ± 0.672 (1.48)
Radium-226 (pCi/L)	5 (c)	-	-	0.0872 ± 0.296 (0.641)
Radium-228 (pCi/L)	5 (c)	-	-	0.386 ± 0.382 (0.798)
Synthetic Organic Contaminanats (µg/l)				
All Analytes		-	-	BDL
Field Parameters				
pH	6.5-8.5 (a)	6.32	6.32	6.26
Specific Cond. (µmhos/cm°C)	NSA	152.0	154.0	154.4
Temp	NSA	10.3	10.2	10.1
Turbidity	5 (g)	0.53	0.44	0.08
Odor	NSA	None	None	None

NSA = No Standard Available BRL = Concentration if any is below reporting limit. - = Not Analyzed

(a) = Secondary MCLs regulate certain contaminants for aesthetic reasons, such as taste, color and odor.
These contaminants are not considered to pose a human health risk at the SMCL

(b) = Standard is an Action Level. Exceedance of Action Level in more than 10% of tap samples collected
requires public water suppliers to treat drinking water to adjust pH and prevent corrosion of pipes.

(c) = Standard is for Radium (226+228) = 5 pCi/L

(d) = Standard is a Massachusetts Drinking Water Guideline based on health risk. Guidelines are provided for certain
contaminants for which standards have not been established.

(e) = Public water suppliers may detect Total Coliform under certain conditions and not exceed the MCL for Total Coliform.

(f) = Standard is an Action for Radon. Exceedence of this guideline indicates that air sampling for Radon should be done.

(g) =USEPA Drinking Water Standards and Health Advisories (2009)

Table 4-2: Aquifer Test Water Quality Results
District H TPW-3B and TPW-2C Testing

Field and Laboratory Analytical Results

District H TPW-2C

5 Day Aquifer Performance Test

Date/Time Pump Test Sample Sample ID	Massachusetts MCL or Secondary MCL	12/16/10 10:10 1 Hour TPW-2C-1Hr	12/18/10 9:30 48 Hours TPW-2C-48Hrs	12/21/10 7:40 5 Days TPW-2C-5D
Total Metals (mg/l)				
Aluminum	0.05-0.2 (a)	BRL	BRL	BRL
Antimony	0.006	-	-	BRL
Arsenic	0.010	-	-	BRL
Barium	2	-	-	BRL
Beryllium	0.004	-	-	BRL
Cadmium	0.005	-	-	BRL
Calcium	NSA	4.2	3.9	4.0
Chromium	0.1	-	-	BRL
Copper	1 (a) 1.3 (b)	BRL	BRL	BRL
Iron	0.3 (a)	BRL	BRL	0.1
Lead	0.015 (b)	-	-	0.002
Magnesium	NSA	2.5	2.6	2.6
Manganese	0.05 (a)	BRL	BRL	BRL
Mercury	0.002	-	-	BRL
Nickel	0.1 (d)	-	-	BRL
Potassium	NSA	1	1	1
Selenium	0.05	-	-	BRL
Silver	0.1 (a)	BRL	BRL	BRL
Sodium	20 (d)	-	-	15
Thallium	0.002	-	-	BRL
Zinc	5 (a)	BRL	BRL	BRL
Hardness	NSA	21	21	not reported
Inorganic Chemistry (mg/l)				
Total Dissolved Solids	500 (a)	72	BRL	110
Chloride	250 (a)	21	22	22
Color, True (C.U.)	15 C.U. (a)	BRL	BRL	BRL
Fluoride	4.0	-	-	BRL
Nitrate (as Nitrogen)	10	-	-	0.52
Nitrite (as Nitrogen)	1	-	-	BRL
pH	6.5-8.5 (a)	5.9	5.8	5.8
Specific Cond.	NSA	-	-	100
Sulfate	250 (a)	4	6	7.0
Turbidity (N.T.U.)	5 (g)	0.4	0.3	0.2
Alkalinity, Total (as $CaCO_3$)	NSA	7	9	18
Carbon Dioxide, Total (by calculation)	NSA	-	-	34
Ammonia (as Nitrogen)	30 (g)	-	-	BRL
Odor (threshold odor numbers)	3 (a)	BRL	BRL	BRL
Cyanide, Total	0.2	-	-	BRL
Volatile Organic Compounds (µg/l)				
Chloroform	70 (d)	-	-	1
Perchlorate EPA Method 314.0 (µg/l)				
Perchlorate (µg/l)	2	-	-	BRL
Specific Conductance (µmhos/cm°C)	NSA	-	-	130
Microbiology				
Coliform, Total	Absent (e)	-	Absent	Absent
E. Coli	Absent	-	-	-
Radionuclides				
Radon (pCi/L)	10,000 (f)	-	-	-
Gross Alpha (pCi/L)	15	-	-	-0.467 ± 0.969 (6.86)
Gross Beta 4 (millirem/year)	4	-	-	-
Radium-226 (pCi/L)	5 (c)	-	-	0.5 ± 0.3
Radium-228 (pCi/L)	5 (c)	-	-	0.565 ± 0.454 (0.922)
Synthetic Organic Contaminanats (µg/l)				
All Analytes		-	-	BDL
Field Parameters				
pH	6.5-8.5 (a)	5.67	6.08	6.15
Specific Cond. (µmhos/cm°C)	NSA	132.8	132	132.6
Temp	NSA	10.3	10.1	10.2
Turbidity	5 (g)	0.43	0.41	0.33
Odor	NSA	None	None	None

Notes:
NSA = No Standard Available   BRL = Concentration if any is below reporting limit.   - = Not Analyzed
(a) = Secondary MCLs regulate certain contaminants for aesthetic reasons, such as taste, color and odor.
These contaminants are not considered to pose a human health risk at the SMCL
(b) = Standard is an Action Level. Exceedance of Action Level in more than 10% of tap samples collected
requires public water suppliers to treat drinking water to adjust pH and prevent corrosion of pipes.
(c) = Standard is for Radium (226+228) = 5 pCi/L
(d) = Standard is a Massachusetts Drinking Water Guideline based on health risk. Guidelines are provided for certain
contaminants for which standards have not been established.
(e) = Public water suppliers may detect Total Coliform under certain conditions and not exceed the MCL for Total Coliform.
(f) = Standard is an Action for Radon. Exceedence of this guideline indicates that air sampling for Radon should be done.
(g) =USEPA Drinking Water Standards and Health Advisories (2009)
(h) = Laboratory did not analyze for these parameters. Samples were collected on 3/28/11 test.
at the end of 7 days 4 hours of pumping TPW-2C at 1 million gallons per day.

Table 4-3: TPW-3B Pump Test
Summary of Manual Water Level Measurements and Flow Rates
OW-3 Cluster Wells

		H-TPW-3B					OW-3A		OW-3B1		OW-3B2		OW-3C	
Time		Totalizer (gallons)	Calculated Flow Rate (gpm)	Instant. Flow Rate (gpm)	DTW (feet below TOC)	TOC Drawdown (feet)	DTW (feet below PVC)	TOC Drawdown (feet)	DTW (feet below PVC)	TOC Drawdown (feet)	DTW (feet below PVC)	TOC Drawdown (feet)	DTW (feet below PVC)	TOC Drawdown (feet)
12/1/10 13:00					21.29		19.89	-0.06	21.13	0.01	21.31	-0.66	21.18	0.01
12/6/10 9:02		0			21.28	0	19.95	0	21.12	0	21.97	0	21.17	0
12/6/10 9:07	0:05:00	5075	1015	1015	35.6	14.32								
12/6/10 9:12	0:10:00	9810	947	962	35.7	14.42								
12/6/10 9:22	0:20:00	19330	952	930	35.9	14.62								
12/6/10 9:32	0:30:00	28362	903.2	904	36.3	15.02								
12/6/10 9:42	0:40:00	37340	897.8	917	36.73	15.45								
12/6/10 9:55	0:53:00	49253	916.4	925	37.07	15.79								
12/6/10 10:05	1:03:00	58377	912.4	907	37.15	15.87								
12/6/10 11:05	1:58:00	113186	913.5	942	37.7	16.42	19.92	-0.03	31.17	10.05	34	12.03	22.85	1.68
12/6/10 12:05	1:00:00	167902	841.8	922	37.87	16.59								
12/6/10 13:05	1:00:00	222625	912.1	948	37.96	16.68	19.94	-0.01	31.36	10.24	34.18	12.21	22.97	1.80
12/6/10 14:05	1:00:00	278257	927.2	922	38.03	16.75								
12/6/10 15:05	1:00:00	332040	896.4	931	38.1	16.82	19.94	-0.01	31.44	10.32	34.25	12.28	23.06	1.89
12/6/10 16:05	1:00:00	386694	910.9	922	38.13	16.85								
12/7/10 7:06	15:01:00	1207165	910.6	901	38.57	17.29								
12/7/10 8:05	0:59:00	1260892	910.6	904	38.6	17.32	19.97	0.02	32.06	10.94	34.83	12.86	23.68	2.51
12/7/10 9:05	1:00:00	1315523	910.5	931	38.63	17.35								
12/7/10 10:05	1:00:00	1370131	910.1	923	38.64	17.36								
12/7/10 11:05	1:00:00	1424785	910.9	934	38.62	17.34	19.97	0.02	32.05	10.93	34.82	12.85	23.67	2.50
12/7/10 12:05	1:00:00	1479458	911.2	919	38.55	17.27								
12/7/10 13:05	1:00:00	1534097	910.7	929	38.52	17.24								
12/7/10 14:05	1:00:00	1588761	911.1	929	38.45	17.17	19.98	0.03	31.85	10.73	34.66	12.69	23.46	2.29
12/7/10 15:05	1:00:00	1643448	911.5	923	38.42	17.14								
12/7/10 16:05	1:00:00	1698165	912.0	938	38.42	17.14	19.98	0.03	31.83	10.71	34.63	12.66	23.43	2.26
12/8/10 7:05	15:00:00	2517828	910.7	914	38.65	17.37	20.02	0.07	32.08	10.96	34.89	12.92	23.73	2.56
12/8/10 8:05	1:00:00	2572430	910.0	933	38.66	17.38								
12/8/10 9:05	1:00:00	2627033	910.1	928	38.7	17.42	20.02	0.07	32.15	11.03	34.96	12.99	23.82	2.65
12/8/10 10:05	1:00:00	2681647	910.2	915	38.7	17.42								
12/8/10 11:05	1:00:00	2736247	910.0	919	38.73	17.45	20.02	0.07	32.16	11.04	34.95	12.98	23.81	2.64
12/8/10 12:05	1:00:00	2790887	910.7	917	38.73	17.45	20.02	0.07	32.11	10.99	34.95	12.98	23.75	2.58
12/8/10 13:05	1:00:00	2845492	910.1	948	38.67	17.39								
12/8/10 14:05	1:00:00	2900142	910.8	928	38.62	17.34	20.03	0.08	32.02	10.90	34.83	12.86	23.65	2.48
12/8/10 15:05	1:00:00	2954790	910.8	929	38.59	17.31								
12/8/10 16:05	1:00:00	3009440	910.8	931	38.55	17.27	20.03	0.08	31.97	10.85	34.80	12.83	23.60	2.43
12/9/10 7:05	15:00:00	3828780	910.4	925	38.66	17.38								
12/9/10 8:05	1:00:00	3883450	911.2	930	38.71	17.43								
12/9/10 9:05	1:00:00	3938039	909.8	937	38.72	17.44								
12/9/10 10:05	1:00:00	3992633	909.9	913	38.8	17.52	20.08	0.13	32.25	11.13	35.04	13.07	23.93	2.76
12/9/10 11:05	1:00:00	4047220	909.8	928	38.8	17.52	20.08	0.13	32.25	11.13	35.06	13.09	23.93	2.76
12/9/10 12:05	1:00:00	4101800	909.7	929	38.81	17.53								
12/9/10 13:05	1:00:00	4156400	910.0	930	38.79	17.51	20.08	0.13	32.20	11.08	35.03	13.06	23.87	2.70
12/9/10 14:05	1:00:00	4211011	910.2	922	38.7	17.42								
12/9/10 15:05	1:00:00	4265620	910.2	914	38.7	17.42	20.10	0.15	32.12	11.00	34.96	12.99	23.77	2.60
12/9/10 16:05	1:00:00	4320180	909.3	920	38.66	17.38								
12/10/10 7:05	15:00:00	5139450	910.3	936	38.73	17.45	20.11	0.16	32.18	11.06	34.99	13.02	23.84	2.67
12/10/10 8:05	1:00:00	5194050	910.0	925	38.78	17.5								
12/10/10 9:05	1:00:00	5248630	909.7	930	38.81	17.53								
12/10/10 10:05	1:00:00	5303180	909.2	923	38.85	17.57								

Table 4-3: TPW-3B Pump Test
Summary of Manual Water Level Measurements and Flow Rates
OW-3 Cluster Wells

		H-TPW-3B					**OW-3A**		**OW-3B1**		**OW-3B2**		**OW-3C**	
Time		Totalizer (gallons)	Calculated Flow Rate (gpm)	Instant. Flow Rate (gpm)	DTW (feet below TOC)	TOC Drawdown (feet)	DTW (feet below PVC)	TOC Drawdown (feet)	DTW (feet below PVC)	TOC Drawdown (feet)	DTW (feet below PVC)	TOC Drawdown (feet)	DTW (feet below PVC)	TOC Drawdown (feet)
12/10/10 11:05	1:00:00	5357820	910.7	937	38.85	17.57								
12/10/10 12:05	1:00:00	5412460	910.7	915	38.86	17.58								
12/10/10 13:05	1:00:00	5467080	910.3	920	38.85	17.57	20.12	0.17	32.29	11.17	35.09	13.12	23.96	2.79
12/10/10 14:05	1:00:00	5521700	910.3	913	38.82	17.54								
12/10/10 15:05	1:00:00	5576300	910.0	915	38.8	17.52	20.13	0.18	32.22	11.10	35.03	13.06	23.88	2.71
12/10/10 16:05	1:00:00	5630960	911.0	941	38.72	17.44								
12/11/10 7:05	15:00:00	6450471	910.6	928	38.68	17.4								
12/11/10 8:05	1:00:00	6505135	911.1	927	38.76	17.48	20.13	0.18	32.18	11.06	34.97	13.00	23.84	2.67
12/11/10 9:00	0:55:00	6555240	911.0	929	38.79	17.51								
12/11/10 9:04	0:04:30				27.8	6.52								
12/11/10 9:05	0:00:30				27.71	6.43								
12/11/10 9:05	0:00:30				26.71	5.43								
12/11/10 9:06	0:00:30				26.42	5.14								
12/11/10 9:06	0:00:30				26.2	4.92								
12/11/10 9:07	0:00:30				26.01	4.73								
12/11/10 9:07	0:00:30				25.85	4.57								
12/11/10 9:08	0:00:30				25.75	4.47								
12/11/10 9:08	0:00:30				25.6	4.32								
12/11/10 9:09	0:00:30				25.51	4.23								
12/11/10 9:09	0:00:30				25.4	4.12								
12/11/10 9:10	0:00:30				25.33	4.05								
12/11/10 9:11	0:01:00				25.17	3.89								
12/11/10 9:12	0:01:00				25.04	3.76								
12/11/10 9:13	0:01:00				24.92	3.64								
12/11/10 9:14	0:01:00				24.82	3.54								
12/11/10 9:15	0:01:00				24.71	3.43								
12/11/10 9:16	0:01:00				24.64	3.36								
12/11/10 9:18	0:02:00				24.48	3.2								
12/11/10 9:19	0:01:00				24.42	3.14	20.13	0.18	24.11	2.99	25.08	3.11	23.33	2.16
12/11/10 9:24	0:05:00				24.11	2.83								
12/11/10 9:29	0:05:00				23.87	2.59								
12/11/10 9:34	0:05:00				23.71	2.43								
12/11/10 9:39	0:05:00				23.44	2.16								
12/11/10 9:44	0:05:00				23.34	2.06								
12/11/10 9:49	0:05:00				23.24	1.96								
12/11/10 9:54	0:05:00				23.15	1.87								
12/11/10 9:59	0:05:00				23.05	1.77								
12/11/10 10:04	0:05:00				23.01	1.73								
12/11/10 10:14	0:10:00				22.9	1.62								
12/11/10 10:24	0:10:00				22.78	1.5								
12/11/10 10:34	0:10:00				22.68	1.4								
12/11/10 11:04	0:30:00				22.48	1.2								
12/11/10 11:34	0:30:00				22.33	1.05	20.15	0.20	22.12	1.00	23	1.03	22.12	0.95
12/11/10 12:04	0:30:00				22.22	0.94								
12/11/10 12:34	0:30:00				22.15	0.87								
12/13/10 11:01	22:27:00				21.23	-0.05	20.08	0.13	21.05	-0.07	21.91	-0.06	21.1	-0.07

Table 4-3: TPW-3B Pump Test
Summary of Manual Water Level Measurements and Flow Rates
OW-1 Cluster Wells

Date	Time	H OW-1A (Feet below PVC)	H OW-1B (Feet below PVC)	H OW-1C (Feet below PVC)	H OW-1D (Feet below PVC)	H TPW-1B (Feet below PVC)
12/6/10 7:55	0750-0757	27.42	28.67	29.52	30.12	28.77
12/6/10 11:20	1120-1123	27.42	35.17	31.3	30.3	35.13
12/6/10 13:15	1312-1316	27.43	35.38	31.45	30.29	35.34
12/6/10 15:00	1458-1502	27.43	35.48	31.53	30.35	35.44
12/7/10 8:00	0758-0802	27.46	36.05	32.15	31.12	36.03
12/7/10 11:20	1120-1124	27.47	36.04	32.11	31.03	36.00
12/7/10 14:48	1448-1453	27.48	35.85	31.9	30.69	35.81
12/8/10 8:26	0826-0831	27.52	36.16	32.25	31.24	36.12
12/8/10 12:10	1210-1217	27.52	36.15	32.23	31.16	36.12
12/8/10 15:15	1515-1519	27.53	36.01	32.08	30.93	35.97
12/9/10 8:25	0825-0830	27.56	36.23	32.33	31.3	36.19
12/9/10 11:09	1109-1112	27.56	36.28	32.38	31.39	36.26
12/9/10 13:40	1340-1345	27.57	36.21	32.3	31.24	36.18
12/9/10 16:13	1613-1618	27.57	36.1	32.19	31.06	36.07
12/10/2010 7:15	0715-0718	27.59	36.2	32.3	31.24	36.17
12/10/2010 10:15	1015-1019	27.6	36.31	32.42	31.43	36.25
12/10/2010 12:47	1247-1251	27.62	36.32	32.43	31.43	36.29
12/10/2010 15:15	1515-1520 *	27.62	36.24	32.34	36.9	36.2
12/11/2010 8:19	0819-0822	27.62	36.2	32.3	31.24	36.15
12/11/2010 9:31	0931-0934	27.62	31.22	31.46	31.34	31.27
12/11/2010 12:05	1205-1208	27.65	29.63	30.43	30.97	29.75
12/13/2010 11:24	1124-1126	27.59	28.65	29.49	30.04	28.76

*Pumping OW-1D for Sample

Table 4-3: TPW-3B Pump Test
Summary of Manual Water Level Measurements and Flow Rates
OW-2 Cluster Wells

Date	Time	H OW-2A (Feet below PVC)	H OW-2B (Feet below PVC)	H OW-2C1 (Feet below PVC)	H OW-2C2 (Feet below PVC)	H OW-2D (Feet below PVC)
12/6/10 7:55	0740-0748	29.62	32.35	31.45	31.02	32.42
12/6/10 11:20	1137-1140	29.63	38.15	33.05	32.63	32.68
12/6/10 13:15	1307-1310	29.63	38.3	33.15	32.75	32.7
12/6/10 15:00	1443-1446	29.63	38.4	33.23	32.8	32.73
12/7/10 8:00	0740-0747	29.65	39	33.86	33.46	33.49
12/7/10 10:50	1050-1055	29.66	38.99	33.85	33.43	33.47
12/7/10 14:40	1440-1446	29.66	38.67	33.62	33.21	33.12
12/8/10 8:55	0855-0859	29.71	39.12	34	33.58	33.65
12/8/10 12:17	1217-1227	29.7	39.09	33.94	33.54	33.57
12/8/10 13:35	1335-1345	29.71	39.01	33.86	33.45	33.44
12/8/10 15:45	1545-1555	29.72	38.93	33.78	33.35	33.36
12/9/10 8:18	0818-0822	29.75	39.16	34.05	33.64	33.69
12/9/10 11:00	1100-1103	29.75	39.22	34.12	33.7	33.78
12/9/10 13:30	1330-1336	29.75	39.16	34.03	33.65	33.66
12/9/10 16:07	1607-1610	29.76	39.05	33.9	33.09	33.48
12/10/10 7:11	0711-0714	29.79	39.15	34.03	33.59	33.65
12/10/10 10:41	1041-1044	29.79	39.26	34.16	33.75	33.84
12/10/10 12:52	1252-1258	29.8	39.26	34.15	33.78	33.83
12/10/10 15:10	1510-1513	29.8	39.19	34.05	33.64	33.72
12/11/10 7:51	0751-0754	29.81	39.14	34.02	33.59	33.62
12/11/10 9:26	0926-0929	29.81	35.05	33.41	33.05	33.74
12/11/10 11:45	1145-1147	29.82	33.39	32.41	31.99	33.35
12/13/10 11:17	1117-1120	29.78	32.33	31.41	31	32.35

Table 4-3: TPW-3B Pump Test
Summary of Manual Water Level Measurements and Flow Rates
OW-4 Cluster Wells

Date	Time	H OW-4A (Feet below PVC)	H OW-4B (Feet below PVC)	H OW-4C (Feet below PVC)
12/6/10 8:00	0759-0803	9.95	10.27	10.62
12/6/10 11:45	1145-1149	9.93	10.38	12.43
12/6/10 13:20	1318-1321	9.94	10.41	12.52
12/6/10 15:20	1518-1520	9.95	10.43	12.62
12/7/10 8:30	0827-0831	9.97	10.55	13.21
12/7/10 11:30	1126-1130	9.97	10.55	13.21
12/7/10 15:45	1545-1547	9.97	10.55	12.93
12/8/10 8:48	0848-0850	10.00	10.61	13.31
12/8/10 12:30	1230-1234	10.00	10.61	13.26
12/8/10 15:46	1546-1550	10.01	10.61	13.1
12/9/10 8:33	0833-0837	10.03	10.65	13.37
12/9/10 11:17	1117-1120	10.03	10.64	13.43
12/9/10 13:49	1349-1350	10.04	10.65	13.34
12/9/10 16:20	1620-1622	10.03	10.65	13.23
12/10/10 7:20	0720-0722	10.04	10.66	13.35
12/10/10 10:09	1009-1011	10.05	10.67	13.45
12/10/10 12:40	1240-1241	10.06	10.68	13.47
12/10/10 15:20	1520-1521	10.05	10.67	13.37
12/11/10 8:30	0830-0831	10.05	10.67	13.35
12/11/10 9:37	0937-0938	10.05	10.55	12.51
12/11/10 12:11	1211-1212	10.05	10.55	11.51
12/13/10 11:32	1132-1133	9.94	10.31	10.6

Table 4-3: TPW-3B Pump Test
Summary of Manual Water Level Measurements and Flow Rates
Vernal Pool Piezometers and Staff Gauges (all measurements feet below TOC)

Date and Time	DTW 12/6/10 8:05	DTW 12/6/10 15:25	DTW 12/7/10 15:45	DTW 12/8/10 15:35	DTW 12/9/10 14:57	DTW 12/10/10 13:47	DTW 12/11/10 7:21	DTW 12/11/10 12:31	DTW 12/13/10 11:40	Max. Drawdown	Notes
H OW 3" well	6.82	6.83	6.84	6.85	6.83	6.92	6.93	6.94	6.91	0.12	
H C-1 FLUSH	8.5	8.49	8.53	8.57	8.6	8.6	8.6	8.6	8.53	0.1	
Date and Time	12/6/10 8:00	12/6/10 15:20	12/7/10 15:50	12/8/10 15:30	12/9/10 14:10	12/10/10 12:19	12/11/10 7:15	12/11/10 12:14	12/13/10 11:37		
VP-E09-A	2.38	2.27	2.39	2.42	2.43	2.44	2.46	2.45	2.33	0.08	
VP-E09-B	2.34	2.35	2.36	2.38	2.4	2.42	2.44	2.43	2.3	0.1	
VP-E09-C	1.99	2.01	2.03	2.05	2.06	2.1	2.08	2.08	1.92	0.11	
Date and Time	12/6/10 8:10	12/6/10 15:40	12/7/10 15:30	12/8/10 15:40	12/9/10 14:20	12/10/10 12:30	12/11/10 7:28	12/11/10 12:21	12/13/10 11:45		
VP-E01-A	2.25	2.23	2.28	2.32	2.34	2.35	2.42	2.4	2.09	0.17	
VP-E01-B	2.2	2.17	2.21	2.25	2.21	2.21	2.21	2.21	2.15	0.01	*ice 12/9 to 12/11
VP-E01-C	2.59	2.59	2.61	2.62	2.69	2.7	2.73	2.71	2.58	0.14	
Date and Time	12/6/10 8:20	12/6/10 15:30	12/7/10 15:20	12/8/10 16:00	12/9/10 14:40	12/10/10 13:15	12/11/10 7:40	12/11/10 11:52	12/13/10 11:57		
VP-E11-A	2.55	2.55	2.56	2.55	2.62	2.58	2.67	2.67	2.49	0.12	
VP-E11-B	2.7	2.71	2.77	2.8	2.81	2.85	2.85	2.85	2.49	0.15	
VP-E11-C	3.52	3.55	3.72	3.8	3.85	3.87	3.85	3.85	3.54	0.33	

Table 4-4: TPW-2CB Pump Test
Summary of Manual Water Level Measurements and Flow Rates
OW-2 Cluster Wells

Time		H-TPW-2C Totalizer (gallons)	Calculated Flow Rate (gpm)	Instant. Flow Rate (gpm)	DTW (feet below TOC)	Drawdown (feet)	Stabilization	Specific Capacity (gpm/ft DD)	OW-2A DTW (feet below PVC)	OW-2A Drawdown (feet)	OW-2B DTW (feet below PVC)	OW-2B Drawdown (feet)	OW-2C1 DTW (feet below PVC)	OW-2C1 Drawdown (feet)	OW-2C2 DTW (feet below PVC)	OW-2C2 Drawdown (feet)	OW-2D DTW (feet below PVC)	OW-2D Drawdown (feet)
12/16/2010									29.7		32.3	0	31.38	0	30.95	0	32.32	0
9:02:00		0			30.54	0				0								
9:03:00	0:01:00	1011		1002	58.05	27.51												
9:05:00	0:02:00	2510	1255	952	57.5	26.96												
9:07:00	0:02:00	4393	878.6	919	57.4	26.86	0.65											
9:10:00	0:03:00	7084	897	902	56.5	25.96	0.9	34.55										
9:21:00	0:11:00	17000	901.5	920	57.78	27.24	-1.28	33.09										
9:30:00	0:09:00	25226	914	925	57.94	27.4	0.16	33.36										
9:40:00	0:10:00	34379	915.3	920	58.12	27.58	0.18	33.19										
9:50:00	0:10:00	43533	915.4	938	58.25	27.71	0.13	33.04										
10:00:00	0:10:00	52720	918.7	924	58.34	27.8	0.09	33.05	29.71	0.01	33.67	1.37	40.09	8.71	44.67	13.72	32.58	0.26
10:30:00	0:30:00	80222	916.7	925	58.5	27.96	0.16	32.79										
11:00:00	0:30:00	107740	917.3	920	58.68	28.14	0.34	32.60										
11:30:00	0:30:00	135246	916.9	926	58.76	28.22	0.26	32.49										
12:00:00	0:30:00	162731	916.2	929	58.86	28.32	0.18	32.35										
13:00:00	1:00:00	217697	916.1	923	58.99	28.45	0.13	32.20										
14:00:00	1:00:00	272686	916.5	918	59.1	28.56	0.11	32.09	29.70	0.00	34.48	2.18	40.82	9.44	45.38	14.43	33.25	0.93
15:00:00	1:00:00	327683	916.6	923	59.23	28.69	0.13	31.95										
16:00:00	1:00:00	382685	916.7	938	59.31	28.77	0.08	31.86	29.70	0.00	34.65	2.35	40.98	9.60	45.56	14.61	33.44	1.12
7:00:00	15:00:00	1207945	915.9	923	59.6	29.06	0.29	31.52										
8:00:00	1:00:00	1262952	932.3	935	59.57	29.03	-0.03	32.12	29.71	0.01	34.86	2.56	41.15	9.77	45.74	14.79	33.59	1.27
9:00:00	1:00:00	1317908	915.9	933	59.55	29.01	-0.02	31.57										
10:00:00	1:00:00	1373060	919.2	927	59.45	28.91	-0.1	31.80										
11:00:00	1:00:00	1428117	917.6	930	59.45	28.91	0	31.74	29.71	0.01	34.79	2.49	41.07	9.69	45.66	14.71	33.45	1.13
12:00:00	1:00:00	1483184	917.8	929	59.45	28.91	0	31.75										
13:00:00	1:00:00	1538261	918.0	930	59.5	28.96	0.05	31.70										
14:00:00	1:00:00	1593289	917.1	927	59.57	29.03	0.07	31.59	29.72	0.02	34.85	2.55	41.16	9.78	45.74	14.79	33.59	1.27
15:00:00	1:00:00	1648333	917.4	929	59.65	29.11	0.08	31.51										
16:00:00	1:00:00	1703373	917.3	925	59.71	29.17	0.06	31.45	29.73	0.03	34.96	2.66	41.29	9.91	45.87	14.92	33.76	1.44
7:00:00	15:00:00	2528435	916.7	935	59.81	29.27	0.1	31.32										
8:00:00	1:00:00	2583468	917.2	926	59.76	29.22	-0.05	31.39										
9:00:00	1:00:00	2638447	916.3	925	59.76	29.22	0	31.36										
10:00:00	1:00:00	2693484	917.3	934	59.7	29.16	-0.06	31.46										
11:00:00	1:00:00	2749931	940.8	923	59.64	29.1	-0.06	32.33	29.76	0.06	34.90	2.60	41.28	9.90	45.76	14.81	33.77	1.45
12:00:00	1:00:00	2803502	892.9	930	59.6	29.06	-0.04	30.72										
13:00:00	1:00:00	2858519	917.0	932	59.62	29.08	0.02	31.53										
14:00:00	1:00:00	2913533	916.9	929	59.69	29.15	0.07	31.45										
15:00:00	1:00:00	2970002	941.2	933	59.71	29.17	0.02	32.26	29.75	0.05	34.99	2.69	41.28	9.90	45.85	14.90	33.76	1.44
16:00:00	1:00:00	3027529	958.8	930	59.8	29.26	0.09	32.77										
7:00:00	15:00:00	3847820	911.4	921	59.94	29.4	0.14	31.00										
8:00:00	1:00:00	3902800	916.3	916	59.91	29.37	-0.03	31.20										
9:00:00	1:00:00	3957800	916.7	920	59.8	29.26	-0.11	31.33										
10:00:00	1:00:00	4012800	916.7	932	59.75	29.21	-0.05	31.38	29.78	0.08	35.01	2.71	41.31	9.93	45.90	14.95	33.76	1.44
11:00:00	1:00:00	4067750	915.8	925	59.72	29.18	-0.03	31.39	29.79	0.09	34.96	2.66	41.25	9.87	45.83	14.88	33.67	1.35
12:00:00	1:00:00	4122800	917.5	915	59.68	29.14	-0.04	31.49										
13:00:00	1:00:00	4177720	915.3	930	59.69	29.15	0.01	31.40	29.77	0.07	34.88	2.58	41.18	9.80	45.75	14.80	33.57	1.25
14:00:00	1:00:00	4232700	916.3	925	59.75	29.21	0.06	31.37	29.79	0.09	34.91	2.61	41.21	9.83	45.78	14.83	33.62	1.30
15:00:00	1:00:00	4287670	916.2	928	59.69	29.15	-0.06	31.43										
16:00:00	1:00:00	4342620	915.8	923	59.79	29.25	0.1	31.31										
7:00:00	15:00:00	5166640	915.6	933	59.82	29.28	0.03	31.27										
8:00:00	1:00:00	5221580	915.7	927	59.85	29.31	0.03	31.24										
9:00:00	1:00:00	5276520	915.7	925	59.85	29.31	0	31.24	29.80	0.10	35.00	2.70	41.31	9.93	45.87	14.92	33.80	1.48
10:00:00	1:00:00	5331480	916.0	918	59.79	29.25	-0.06	31.32	29.79	0.09	34.96	2.66	41.24	9.86	45.81	14.86	33.69	1.37
11:00:00	1:00:00	5386440	916.0	927	59.71	29.17	-0.08	31.40										
12:00:00	1:00:00	5441390	915.8	920	59.63	29.09	-0.08	31.48										
13:00:00	1:00:00	5496430	917.3	931	59.55	29.01	-0.08	31.62	29.79	0.09	34.76	2.46	41.04	9.66	45.61	14.66	33.37	1.05

Table 4-4: TPW-2CB Pump Test
Summary of Manual Water Level Measurements and Flow Rates
OW-2 Cluster Wells

		H-TPW-2C							OW-2A		OW-2B		OW-2C1		OW-2C2		OW-2D	
Time		Totalizer (gallons)	Calculated Flow Rate (gpm)	Instant. Flow Rate (gpm)	DTW (feet below TOC)	Drawdown (feet)	Stabilization	Specific Capacity (gpm/ft DD)	DTW (feet below PVC)	Drawdown (feet)	DTW (feet below PVC)	Drawdown (feet)	DTW (feet below PVC)	Drawdown (feet)	DTW (feet below PVC)	Drawdown (feet)	DTW (feet below PVC)	Drawdown (feet)
14:00:00	1:00:00	5551430	916.7	930	59.54	29	-0.01	31.61										
15:00:00	1:00:00	5606460	917.2	928	59.54	29	-0.15	31.63										
16:00:00	1:00:00	5661450	916.5	928	59.65	29.11	-0.1	31.48										
8:00:00	16:00:00	6541180	916.4	928	59.7	29.16	0.01	31.43	29.79	0.09	34.82	2.52	41.13	9.75	45.70	14.75	33.55	1.23
9:00:00	1:00:00	6596140	916.0	928	59.68	29.14	-0.11	31.43										
9:04:00	0:04:00	6599891	317102.8	928	59.68	29.14												
9:04:30	0:00:30				35.4	4.86												
9:05:00	0:00:30				35.29	4.75												
9:05:30	0:00:30				33.95	3.41												
9:06:00	0:00:30				33.68	3.14												
9:06:30	0:00:30				33.55	3.01												
9:07:00	0:00:30				33.4	2.86												
9:07:30	0:00:30				33.25	2.71												
9:08:00	0:00:30				33.15	2.61												
9:08:30	0:00:30				33.08	2.54												
9:09:00	0:00:30				32.98	2.44												
9:10:00	0:01:00				32.95	2.41												
9:11:00	0:01:00				32.85	2.31												
9:12:00	0:01:00				32.75	2.21												
9:13:00	0:01:00				32.68	2.14												
9:14:00	0:01:00				32.62	2.08												
9:19:00	0:05:00				32.37	1.83												
9:24:00	0:05:00				32.2	1.66												
9:29:00	0:05:00				32.04	1.5												
9:34:00	0:05:00				31.94	1.4			29.79	0.09	33.80	1.50	32.77	1.39	32.32	1.37	33.34	1.02
9:44:00	0:10:00				31.8	1.26												
9:54:00	0:10:00				31.68	1.14												
10:04:00	0:10:00				31.57	1.03												
10:34:00	0:30:00				31.33	0.79												
11:04:00	0:30:00				31.15	0.61												
11:34:00	0:30:00				31.03	0.49			29.77	0.07	32.82	0.52	31.82	0.44	31.39	0.44	32.62	0.30
12:35:00	1:01:00				30.35	-0.19			29.74	0.04	32.11	-0.19	31.17	-0.21	30.75	-0.20	32.03	-0.29

Table 4-4: TPW-2CB Pump Test
Summary of Manual Water Level Measurements and Flow Rates
OW-1 Cluster Wells

Date and Time	H OW-1A (Feet below PVC)	H OW-1B (Feet below PVC)	H OW-1C (Feet below PVC)	H OW-1D (Feet below PVC)	H TPW-1B (Feet below PVC)
12/16/10 7:25	27.51	28.65	29.49	30.04	28.77
12/16/10 10:20	27.51	29.83	32.01	30.22	30.01
12/16/10 14:20	27.5	30.58	32.69	30.84	30.7
12/16/10 16:05	27.51	30.77	32.88	31.05	30.85
12/17/10 8:45	27.51	30.92	33	31.17	31.02
12/17/10 11:15	27.52	30.85	32.93	30.97	30.96
12/17/10 15:40	27.53	31.02	33.12	31.28	31.13
12/18/10 8:05	27.56	31.1	33.2	31.34	31.21
12/18/10 11:30	27.55	30.97	33.04	31.14	31.07
12/18/10 13:30	27.61	31.06	33.17	31.31	31.17
12/19/10 8:28	27.57	31.15	33.25	31.4	31.25
12/19/10 11:09	27.59	31.02	33.1	31.17	31.13
12/19/10 13:35	27.6	30.97	33.06	31.09	31.12
12/19/10 16:10	27.59	31.06	33.17	31.32	31.17
12/20/10 7:38	27.6	31.12	33.22	31.38	31.22
12/20/10 10:11	27.59	31	33.09	31.15	31.12
12/20/10 13:23	27.59	30.82	32.89	30.85	30.93
12/20/10 15:47	27.59	30.83	32.92	30.94	30.94
12/21/10 7:47	27.6	30.91	32.99	31.1	31.02
12/21/10 10:12	27.6	30.39	29.66	30.67	29.75
12/22/10 12:14	27.54	28.46	29.28	29.72	28.59

Table 4-4: TPW-2C Pump Test
Summary of Manual Water Level Measurements and Flow Rates
OW-3 Cluster Wells

Date and Time	H OW-3A (Feet below PVC)	H OW-3B1 (Feet below PVC)	H OW-3B2 (Feet below PVC)	H OW-3C (Feet below PVC)	TPW-3B (Feet below PVC)
12/16/10 8:00	20	21.05	21.22	21.09	21.22
12/16/10 10:15	20.00	22.27	22.47	24.95	22.46
12/16/10 13:54	19.99	23.05	23.25	25.66	23.15
12/16/10 15:40	20	23.22	23.4	25.83	23.4
12/17/10 8:30	20.01	23.42	23.6	26.00	23.59
12/17/10 11:10	20.01	23.34	23.53	25.91	23.52
12/17/10 13:50	20.02	23.41	23.59	26	23.59
12/17/10 15:53	20.04	23.53	23.73	26.13	23.69
12/18/10 7:52	20.06	23.61	23.77	26.2	23.77
12/18/10 11:25	20.05	23.62	23.61	26.03	23.44
12/18/10 13:20	20.06	23.71	23.74	26.15	23.54
12/19/10 8:24	20.08	23.65	23.84	26.24	23.8
12/19/10 11:06	20.09	23.57	23.71	26.09	23.67
12/19/10 13:39	20.1	23.46	23.65	26.04	23.63
12/19/10 16:01	20.09	23.56	23.75	26.15	23.71
12/20/10 7:33	20.1	23.6	23.81	26.21	23.75
12/20/10 10:07	20.09	23.51	23.7	26.09	23.66
12/20/10 13:18	20.1	23.31	23.49	25.87	23.46
12/20/10 15:53	20.1	23.33	23.51	25.9	23.49
12/21/10 7:53	20.1	23.39	23.58	25.97	23.55
12/21/10 10:07	20.1	22.1	22.33	22.04	22.29
12/22/10 12:27	20.03	20.87	21.07	20.88	21.03

Table 4-4: TPW-2C Pump Test
Summary of Manual Water Level Measurements and Flow Rates
OW-4 Cluster Wells
Manual Water Level Readings at District H

Date and Time	H OW-4A (Feet below PVC)	H OW-4B (Feet below PVC)	H OW-4C (Feet below PVC)	C-1 Flush (Feet below PVC)	Square 3" (Feet below PVC)
12/16/10 7:45	9.83	10.24	10.59	8.41	6.93
12/16/10 10:45	9.83	10.26	12.02	8.42	6.94
12/16/10 13:20	9.83	10.3	12.47	8.41	6.91
12/16/10 16:15	9.95	10.43	12.62	8.41	6.92
12/17/10 9:10	9.82	10.39	12.84	8.41	6.94
12/17/10 11:25	9.81	10.38	12.78	8.41	6.94
12/17/10 14:55	9.82	10.4	12.93	8.41	6.94
12/17/10 16:10	9.83	10.41	13	8.41	6.94
12/18/10 8:15	9.82	10.44	13.04	8.43	6.95
12/18/10 11:42	9.8	10.41	12.89	8.4	6.92
12/18/10 13:55	9.81	10.42	12.98	8.4	6.93
12/19/10 8:35	9.82	10.45	13.1	8.4	6.93
12/19/10 10:14	9.82	10.43	12.95	8.4	6.92
12/19/10 13:17	9.82	10.43	12.9	8.4	6.94
12/19/10 16:18	9.81	10.43	13.03	8.4	6.93
12/20/10 7:45	9.81	10.43	13.06	8.4	6.93
12/20/10 10:17	9.81	10.42	12.93	8.39	6.92
12/20/10 13:36	9.8	10.4	12.72	8.4	6.92
12/20/10 16:05	9.8	10.4	12.77	8.4	6.92
12/21/10 7:28	9.79	10.4	12.84	8.4	6.91
12/21/10 10:18	9.77	10.36	11.42	8.37	6.89
12/22/10 12:57	9.71	10.18	10.33	8.34	6.87

Table 4-4: TPW-3B Pump Test
Summary of Manual Water Level Measurements and Flow Rates
Vernal Pool Piezometers and Staff Gauges (all measurements feet below TOC)

Date and Time	DTW 12/15/10 11:40	DTW 12/16/10 7:35	DTW 12/16/10 13:25	DTW 12/17/10 14:35	DTW 12/18/10 14:30	DTW 12/19/10 13:13	DTW 12/20/10 13:35	DTW 12/21/10 7:23	DTW 12/21/10 11:20	DTW 12/22/10 13:03	Max. Drawdown
VP-E09-A	2.28	2.3	2.3	2.33	2.31	2.32	2.27	2.21	2.2	2.16	0.03
VP-E09-B	2.25		2.27	2.28	2.28	2.3	2.25	2.19	2.18	2.13	0.05
VP-E09-C	1.9	1.9	1.86	1.9	1.89	1.88	1.83	1.84	1.83	1.71	0

Date and Time	12/15/10 11:58	12/16/10 7:50	12/16/10 13:30	12/17/10 14:45	12/18/10 14:45	12/19/10 13:25	12/20/10 13:40	12/21/10 7:37	12/21/10 11:15	12/22/10 13:10	
VP-E01-A	2.01	2.08	2.08	2.14	2.1	2.18	2.14	2.13	2.13	2.02	0.1
VP-E01-B	2.06	2.08	2.07	2.07	2.1	2.15	2.14	2.13	2.13	2.06	0.07
VP-E01-C	2.57	2.6	2.58	2.58	2.58	2.59	2.56	2.58	2.55	2.52	-0.01

Date and Time	12/15/10 12:21	12/16/10 8:08	12/16/10 13:45	12/17/10 14:20	12/18/10 14:15	12/19/10 13:48	12/20/10 13:13	12/21/10 7:05	12/21/10 10:40	12/22/10 12:47	
VP-E11-A	2.45	2.46	2.41	2.53	2.53	2.53	2.6	2.62	2.62	2.35	0.16
VP-E11-B	2.62	2.61	2.55	2.64	2.65	2.7	2.47	2.47	2.47	2.39	0.09
VP-E11-C	3.35	3.33	3.35	3.56	3.57	3.61	3.58	3.55	3.52	3.32	0.28

Table 4-5: Combined Pump Test (TPW-3B and TPW-2C)
Summary of Manual Water Level Measurements and Flow Rates
OW-3 Cluster Wells

H-TPW-3B									OW-3A		OW-3B1		OW-3B2		OW-3C	
Time		Totalizer (gallons)	Calculated Flow Rate (gpm)	Instant. Flow Rate (gpm)	DTW (feet below TOC)	Drawdown (feet)	Stabilization	Specific Capacity (gpm/ft DD)	DTW (feet below PVC)	Drawdown (feet)	DTW (feet below PVC)	Drawdown (feet)	DTW (feet below PVC)	Drawdown (feet)	DTW (feet below PVC)	Drawdown (feet)
3/22/11 0:00									18.44		20.07		20.27		20.16	
3/22/11 9:55		0			20.33	0										
3/22/11 10:00		0			20.33	0										
3/22/11 10:02		0	START			0										
3/22/11 10:03	0:01:00		0		29.95	9.62										
3/22/11 10:04	0:02:00		0		30.63	10.3	10.3	0.00								
3/22/11 10:05	0:03:00	3046	761.5		30.51	10.18	-0.12	74.80								
3/22/11 10:09	0:07:00	4499	726.5	738	31.15	10.82	0.64	67.14								
3/22/11 10:10	0:08:00	5949	725		31.29	10.96	0.14	66.15								
3/22/11 10:14	0:12:00	8775	706.5		31.7	11.37	0.41	62.14								
3/22/11 10:23	0:21:00	15300	725		32.35	12.02	0.65	60.32								
3/22/11 10:28	0:25:00	18894	718.8	723	32.59	12.26	0.24	58.63								
3/22/11 10:32	0:04:00	21764	717.5		32.76	12.43	0.17	57.72								
3/22/11 10:53	0:21:00	36759	714.0		33.39	13.06	0.63	54.67								
3/22/11 11:00	0:07:00	41747	712.6		33.55	13.22	0.16	53.90								
3/22/11 12:00	1:00:00	84380	710.6		34.32	13.99	0.77	50.79								
3/22/11 13:00	1:00:00	126996	710.3	740	34.6	14.27	0.28	49.77	18.44	0.00	29.49	9.42	31.16	10.89	25.10	4.94
3/22/11 14:00	1:00:00	169550	709.2	731	34.8	14.47	0.2	49.01								
3/22/11 15:00	1:00:00	211671	713.9	736	34.86	14.53	0.06	49.13								
3/22/11 16:00	1:00:00	255441	729.5	733	34.93	14.6	0.07	49.97	18.45	0.01	29.86	9.79	31.54	11.27	25.37	5.21
3/22/11 17:00	1:00:00	296332	681.5	758	34.93	14.6	0	46.68								
3/23/11 8:00	15:00:00	929176	703.2	725	35.25	14.92	0.32	47.13								
3/23/11 9:00	1:00:00	971365	703.2	746	35.32	14.99	0.07	46.91								
3/23/11 10:00	1:00:00	1013890	708.8	728	35.49	15.16	0.17	46.75								
3/23/11 11:00	1:00:00	1057020	718.8	745	35.53	15.2	0.04	47.29	18.51	0.07	30.50	10.43	32.19	11.92	25.97	5.81
3/23/11 12:00	1:00:00	1100032	716.9	736	35.56	15.23	0.03	47.07								
3/23/11 13:00	1:00:00	1143090	717.6	740	35.58	15.25	0.02	47.06								
3/23/11 14:00	1:00:00	1185983	714.9	714	35.57	15.24	-0.01	46.91								
3/23/11 15:00	1:00:00	1229007	717.1	747	35.54	15.21	-0.03	47.14								
3/23/11 16:00	1:00:00	1271979	716.2	756	35.49	15.16	-0.05	47.24	18.53	0.09	30.43	10.36	32.1	11.83	25.87	5.71
3/23/11 17:00	1:00:00	1314979	716.7	760	35.45	15.12	-0.04	47.40								
3/24/11 8:00	15:00:00	1960089	716.8	716	35.4	15.07	-0.05	47.56								
3/24/11 9:00	1:00:00	2003165	717.9	721	35.45	15.12	0.05	47.48	18.57	0.13	30.32	10.25	32.03	11.76	25.76	5.60
3/24/11 10:00	1:00:00	2046104	715.7	735	35.46	15.13	0.01	47.30								
3/24/11 11:00	1:00:00	2089041	715.6	743	35.51	15.18	0.05	47.14								
3/24/11 12:00	1:00:00	2132024	716.4	749	35.56	15.23	0.05	47.04								
3/24/11 13:00	1:00:00	2175079	717.6	747	35.61	15.28	0.05	46.96								
3/24/11 14:00	1:00:00	2218042	716.1	724	35.62	15.29	0.01	46.83	18.59	0.15	30.58	10.51	32.3	12.03	26.05	5.89
3/24/11 15:00	1:00:00	2260993	715.9	745	35.62	15.29	0	46.82								
3/25/11 8:00	17:00:00	2993600	718.2	741	35.43	15.1	-0.19	47.57								
3/25/11 9:00	1:00:00	3036300	711.7	735	35.46	15.13	0.03	47.04								
3/25/11 10:00	1:00:00	3080000	728.3	750	35.48	15.15	0.02	48.07	18.64	0.20	30.45	10.38	32.13	11.86	25.89	5.73
3/25/11 11:00	1:00:00	3123150	719.2	742	35.55	15.22	0.07	47.25								
3/25/11 13:00	2:00:00	3209540	719.9	740	35.65	15.32	0.1	46.99								
3/25/11 15:00	2:00:00	3295780	718.7	743	35.54	15.21	-0.11	47.25	18.65	0.21	30.44	10.37	32.13	11.86	25.88	5.72
3/25/11 17:00	2:00:00	3381975	718.3	737	35.41	15.08	-0.13	47.63								
3/25/11 18:00	1:00:00	3425120	719.1	765	35.47	15.14	0.06	47.50								
3/26/11 12:00	18:00:00	4201622	719.0	737	35.58	15.25	0.11	47.15	18.69	0.25	30.54	10.47	32.24	11.97	25.95	5.79
3/26/11 13:00	1:00:00	4244650	717.1	722	35.64	15.31	0.06	46.84								
3/26/11 14:00	1:00:00	4287715	717.8	703	35.67	15.34	0.03	46.79								
3/26/11 15:08	1:08:00	4330915	720.0	765	35.69	15.36	0.02	46.88								
3/26/11 16:00	0:52:00	4374050	718.9	743	35.72	15.39	0.03	46.71	18.69	0.25	30.68	10.61	32.39	12.12	26.12	5.96
3/27/11 12:00	20:00:00	5234600	717.1	732	35.58	15.25	-0.14	47.02	18.72	0.28	30.55	10.48	32.24	11.97	26.00	5.84
3/27/11 13:00	1:00:00	5277440	714.0	769	35.6	15.27	0.02	46.76								
3/27/11 14:00	1:00:00	5320330	714.8	718	35.66	15.33	0.06	46.63								
3/28/11 9:00		5858444		PUMP OFF UPON ARRIVAL -												

Table 4-5: Combined Pump Test (TPW-3B and TPW-2C)
Summary of Manual Water Level Measurements and Flow Rates
OW-2 Cluster Wells

H-TPW-2C									OW-2A		OW-2B		OW-2C1		OW-2C2		OW-2D	
Time		Totalizer (gallons)	Calculated Flow Rate (gpm)	Instant. Flow Rate (gpm)	DTW (feet below TOC)	Drawdown (feet)	Stabilization	Specific Capacity (gpm/ft DD)	DTW (feet below PVC)	Drawdown (feet)	DTW (feet below PVC)	Drawdown (feet)	DTW (feet below PVC)	Drawdown (feet)	DTW (feet below PVC)	Drawdown (feet)	DTW (feet below PVC)	Drawdown (feet)
3/22/11 0:00									28.12		31.34	0	30.45	0	30.05	0	31.54	0
3/22/11 9:56		0			29.82	0				0								
3/22/11 10:00		0			29.82	0												
3/22/11 10:02		0	START			0												
3/22/11 10:03	0:01:30		0		54.45	24.63												
3/22/11 10:04	0:02:00		0		53.18	23.36	23.36	0.00										
3/22/11 10:05	0:03:00		0		53.36	23.54	0.18	0.00										
3/22/11 10:09	0:07:00		0	738	54.62	24.8	1.26	0.00										
3/22/11 10:10	0:08:00		0		54.76	24.94	0.14	0.00										
3/22/11 10:15	0:13:00	10858	835.2		55.11	25.29	0.35	33.03										
3/22/11 10:22	0:20:00	16310	778.9		51.58	21.76	-3.53	35.79										
3/22/11 10:45	0:41:30	33000	725.7	723	52.12	22.3	0.54	32.54										
3/22/11 10:50	0:05:00	36616	723.2	741	52.25	22.43	0.13	32.24										
3/22/11 11:00	0:10:00	43866	725.0		52.36	22.54	0.11	32.17										
3/22/11 12:00	1:00:00	87350	724.7		52.92	23.1	0.56	31.37										
3/22/11 13:00	1:00:00	130856	725.1	738	53.16	23.34	0.24	31.07	28.12	0.00	37.55	6.21	39.04	8.59	42.42	12.37	32.70	1.16
3/22/11 14:00	1:00:00	174695	730.7	737	53.36	23.54	0.2	31.04										
3/22/11 15:00	1:00:00	217763	730.0	741	53.42	23.6	0.06	30.93										
3/22/11 16:00	1:00:00	262707	724.9	733	53.37	23.55	-0.05	30.78	28.12	0.00	37.92	6.58	39.30	8.85	42.70	12.65	32.79	1.25
3/22/11 17:00	1:00:00	304749	700.7	758	53.39	23.57	0.02	29.73										
3/23/11 8:00	15:00:00	956290	723.9	725	53.79	23.97	0.4	30.20										
3/23/11 9:00	1:00:00	999703	723.6	746	53.82	24	0.03	30.15										
3/23/11 10:00	1:00:00	1043151	724.1	733	53.89	24.07	0.07	30.08										
3/23/11 11:00	1:00:00	1086518	722.8	742	53.94	24.12	0.05	29.97	28.18	0.06	38.53	7.19	39.89	9.44	43.29	13.24	33.46	1.92
3/23/11 12:00	1:00:00	1129936	723.6	744	54.01	24.19	0.07	29.91										
3/23/11 13:00	1:00:00	1173281	722.4	750	54.11	24.29	0.1	29.74										
3/23/11 14:00	1:00:00	1216718	724.0	731	54.1	24.28	-0.01	29.82										
3/23/11 15:00	1:00:00	1260216	725.0	742	54.03	24.21	-0.07	29.94										
3/23/11 16:00	1:00:00	1303637	723.7	728	53.97	24.15	-0.06	29.97	28.2	0.08	38.47	7.13	39.82	9.37	43.20	13.15	33.29	1.75
3/23/11 17:00	1:00:00	1347119	724.7	741	53.92	24.1	-0.05	30.07										
3/24/11 8:00	15:00:00	2000046	725.5	742	53.86	24.04	-0.06	30.18										
3/24/11 9:00	1:00:00	2043662	726.9	744	53.91	24.09	0.05	30.18	28.24	0.12	38.34	7.00	39.68	9.23	43.07	13.02	33.13	1.59
3/24/11 10:00	1:00:00	2087270	726.8	739	53.97	24.15	0.06	30.10										
3/24/11 11:00	1:00:00	2130866	726.6	752	54.02	24.2	0.05	30.02										
3/24/11 12:00	1:00:00	2174416	725.8	737	54.06	24.24	0.04	29.94										
3/24/11 13:00	1:00:00	2217966	725.8	736	54.13	24.31	0.07	29.86	28.25	0.13	38.61	7.27	39.98	9.53	43.39	13.34	33.53	1.99
3/24/11 14:00	1:00:00	2261550	726.4	741	54.12	24.3	-0.01	29.89										
3/24/11 15:00	1:00:00	2305126	726.3	738	54.14	24.32	0.02	29.86										
3/25/11 8:00	17:00:00	3047640	728.0	755	53.95	24.13	-0.19	30.17										
3/25/11 9:00	1:00:00	3091374	728.9	734	53.96	24.14	0.01	30.19										
3/25/11 10:00	1:00:00	3135180	730.1	748	53.96	24.14	0	30.24	28.3	0.18	38.47	7.13	39.83	9.38	43.23	13.18	33.31	1.77
3/25/11 11:00	1:00:00	3178940	729.3	745	54.02	24.2	0.06	30.14										
3/25/11 13:00	2:00:00	3266385	728.7	751	54.2	24.38	0.18	29.89										
3/25/11 15:00 *	2:00:00	3337426	592.0	742	53.54	23.72	-0.66	24.96	28.32	0.20	38.47	7.13	39.71	9.26	43.01	12.96	33.52	1.98
3/25/11 17:00 *	2:00:00	3387291	415.5	727	53.39	23.57	-0.15	17.63										
3/25/11 18:00	1:00:00	3430030	712.3	719	53.57	23.75	0.18	29.99										
3/26/11 12:00	18:00:00	4201325	714.2	730	53.79	23.97	0.22	29.79	28.36	0.24	38.55	7.21	39.82	9.37	43.15	13.10	33.46	1.92
3/26/11 13:00	1:00:00	4244250	715.4	738	53.85	24.03	0.06	29.77										
3/26/11 14:00	1:00:00	4287200	715.8	708	53.83	24.01	-0.02	29.81										
3/26/11 15:00	1:00:00	4330150	715.8	722	53.86	24.04	0.03	29.78										
3/26/11 16:00	1:00:00	4373095	715.8	725	53.86	24.04	0	29.77	28.36	0.24	38.71	7.37	39.98	9.53	43.32	13.27	33.67	2.13
3/27/11 12:00	20:00:00	5232730	716.4	733	53.79	23.97	-0.07	29.89										
3/27/11 13:00	1:00:00	5275700	716.2	738	53.9	24.08	0.11	29.74										
3/27/11 14:00	1:00:00	5318690	716.5	727	53.88	24.06	-0.02	29.78										
3/28/11 9:00	19:00:00	6137920	718.6	736	52.4	22.58	-1.48	31.83										

Table 4-5: Combined Pump Test (TPW-3B and TPW-2C)
Summary of Manual Water Level Measurements and Flow Rates
OW-1 Cluster Wells

Date	Times	H OW-1A (feet below PVC)	H OW-1B (feet below PVC)	H OW-1C (feet below PVC)	H OW-1D (feet below PVC)	H TPW-1B (feet below PVC)
3/22/11 7:40	0740-0745	25.92	27.63	28.51	29.19	27.75
3/22/11 12:34	1234-1236	25.92	34.23	32.46	30.26	34.21
3/22/11 16:20	1620-1623	25.92	34.63	32.76	30.3	34.63
3/23/11 11:21	1121-1126	25.98	35.23	33.36	31.02	35.23
3/23/11 16:30	1630-1635	25.99	35.16	33.25	30.77	35.15
3/24/11 8:42	0842-0846	26.02	35.06	33.41	30.64	35.05
3/24/11 16:41	1441-1445	26.06	35.3	33.4	31.02	35.28
3/25/11 10:10	1009-1012	26.10	35.17	33.26	30.8	35.16
3/25/11 14:46	1446-1449	26.11	35.2	33.31	31.05	35.21
3/26/11 11:53	1153-1156	26.15	35.23	33.33	30.95	35.25
3/26/11 16:21	1621-1624	26.14	35.4	33.5	31.19	35.4
3/27/11 12:22	1222-1225	26.19	35.3	33.38	31	35.29

Table 4-5: Combined Pump Test (TPW-3B and TPW-2C)
Summary of Manual Water Level Measurements and Flow Rates
OW-2 Cluster Wells

Date	Times	H OW-2A (feet below PVC)	H OW-2B (feet below PVC)	H OW-2C1 (feet below PVC)	H OW-2C2 (feet below PVC)	H OW-2D (feet below PVC)	H OW-2D (feet below PVC)
3/22/11 7:50	0750-0753	28.12	31.34	30.45	30.05	31.54	0
3/22/11 12:41	1241-1243	28.12	37.55	39.04	42.42	32.7	1.16
3/22/11 16:13	1613-1615	28.12	37.92	39.3	42.7	32.79	1.25
3/23/11 11:02	1102-1109	28.18	38.53	39.89	43.29	33.46	1.92
3/23/11 16:11	1611-1618	28.2	38.47	39.82	43.20	33.29	1.75
3/24/11 8:30	0830-0834	28.24	38.34	39.68	43.07	33.13	1.59
3/24/11 13:25	1325-1327	28.25	38.61	39.98	43.39	33.53	1.99
3/25/11 10:17	1017-1020	28.3	38.47	39.83	43.23	33.31	1.77
3/25/11 14:36	1436-1440	28.32	38.47	39.71	43.01	33.52	1.98
3/26/11 12:04	1204-1206	28.36	38.55	39.82	43.15	33.46	1.92
3/26/11 16:15	1615-1618	28.36	38.71	39.98	43.32	33.67	2.13
3/27/11 12:05	1205-1207	28.36	38.71	39.98	43.32	33.67	2.13

Table 4-5: Combined Pump Test (TPW-3B and TPW-2C)
Summary of Manual Water Level Measurements and Flow Rates
OW-3 Cluster Wells

Date Date	Times	H OW-3A (feet below PVC)	H OW-3B1 (feet below PVC)	H OW-3B2 (feet below PVC)	H OW-3C (feet below PVC)
3/22/11 7:46	0746-0749	18.44	20.07	20.27	20.16
3/22/11 12:38	1238-1240	18.44	29.49	31.16	25.1
3/22/11 16:16	1616-1618	18.45	29.86	31.54	25.37
3/23/11 11:11	1111-1115	18.51	30.5	32.19	25.97
3/23/11 16:20	1620-1628	18.53	30.43	32.1	25.87
3/24/11 8:35	0835-0840	18.57	30.32	32.03	25.76
3/24/11 13:30	1330-1335	18.59	30.58	32.3	26.05
3/25/11 10:13	1013-1015	18.64	30.45	32.13	25.89
3/25/11 14:32	1432-1435	18.65	30.44	32.13	25.88
3/26/11 11:58	1158-1159	18.69	30.54	32.24	25.95
3/26/11 16:20	1619-1620	18.69	30.68	32.39	26.12

Table 4-5: Combined Pump Test (TPW-3B and TPW-2C)
Summary of Manual Water Level Measurements and Flow Rates
OW-4 Cluster Wells

Date	Times	H OW-4A (feet below PVC)	H OW-4B (feet below PVC)	H OW-4C (feet below PVC)	C-1 Flush (feet below PVC)	Square 3" (feet below PVC)
3/22/11 8:06	0806-0808	8.21	8.8	9.62	6.75	6.85
3/22/11 12:08	1208-1212	8.23	8.96	12.54	6.76	6.85
3/22/11 16:24	1624-1626	8.21	9.04	12.94	6.77	6.85
3/23/11 11:35	1135-1141	8.23	9.16	13.25	6.79	6.85
3/23/11 17:35	1735-1740	8.24	9.17	13.34	6.79	6.86
3/24/11 9:30	0930-0935	8.24	9.18	13.33	6.81	6.86
3/24/11 14:49	1449-1452	8.23	9.21	13.35	6.82	6.85
3/25/11 10:36	1036-1038	8.29	9.24	13.43	6.85	6.85
3/25/11 14:40	1440-1442	8.27	9.24	13.46	6.85	6.85
3/26/11 11:44	1144-1146	8.30	9.26	13.49	6.87	6.85
3/26/11 16:07	1607-1611	8.30	9.27	13.66	6.87	6.85

Table 4-5: Combined Pump Test (TPW-3B and TPW-2C)
Summary of Manual Water Level Measurements and Flow Rates
Vernal Pool Piezometers and Staff Gauges (all measurements feet below TOC)

	DTW-Pre	DTW	DD	DTW	DD	DTW	DD	DTW	DD	DTW	DD
	3/22/11 8:07	3/22/11 12:15	3/22/11 12:15	3/23/11 10:22	3/23/11 10:22	3/24/11 9:26	3/24/11 10:22	3/25/11 10:39	3/25/11 10:39	3/26/11 12:21	3/26/11 12:21
VP-E09-A	0.91	0.92	0.01	0.83	-0.08	0.93	0.02	0.94	0.03	0.95	0.04
VP-E09-B	0.9	0.89	-0.01	0.86	-0.04	0.85	-0.05	0.9	0.00	0.92	0.02
VP-E09-C	0.36	0.34	-0.02	0.36	0.00	0.35	-0.01	0.38	0.02	0.42	0.06
Date and Time	3/22/11 8:18	3/22/11 12:26	3/22/11 12:26	3/23/11 10:32	3/23/11 10:32	3/24/11 9:37	3/24/11 9:37	3/25/11 10:47	3/25/11 10:47	3/26/11 12:27	3/26/11 12:27
VP-E01-A	0.84	0.84	0.00	0.83	-0.01	0.82	-0.02	0.86	0.02	0.88	0.04
VP-E01-B	0.8	0.81	0.01	0.78	-0.02	0.84	0.04	0.82	0.02	0.85	0.05
VP-E01-C	0.82	0.82	0.00	0.79	-0.03	0.77	-0.05	0.85	0.03	0.88	0.06
Date and Time	3/22/11 8:33	3/22/11 12:48	3/22/11 12:48	3/23/11 10:10	3/23/11 10:10	3/24/11 9:10	3/24/11 9:10	3/25/11 10:23	3/25/11 10:23	3/26/11 12:10	3/26/11 12:10
VP-E11-A	2.08	2.08	0.00	2.09	0.01	2.1	0.02	2.11	0.03	2.12	0.04
VP-E11-B	2.12	2.08	-0.04	2.19	0.07	2.24	0.12	2.28	0.16	2.29	0.17
VP-E11-C	2.31	2.32	0.01	2.54	0.23	2.65	0.34	2.74	0.43	2.79	0.48

Table 4-6 Observation Well Water Quality Results
Field and Laboratory Analyses
District H OW-1D and OW-2D
Pump Test Results

Date/Time	12/1/10 12:10	12/1/10 14:30	12/8/10 16:45	12/10/10 15:40	12/1/10 10:00	12/1/10 11:55	12/8/10 14:50	12/10/10 13:10
Pump Test Sample	Pre-Test	Pre-Test	2 Days	4 Days	Pre-Test	Pre-Test	2 Days	4 Days
Sample ID	H-OW-1D	H-OW-1D	H-OW-1D-2	H-OW-1D-3	H-OW-2D	H-OW-2D	H-OW-2D-2	H-OW-2D-3
Laboratory Analytical Results								
Iron, Total (mg/l)		6.1	5.7	6		3.1	3.2	3.4
Sodium Total (mg/l)		38	42	43		13	15	16
Total Dissolved Solids (mg/l)		240	280	300		140	150	180
Chloride (mg/l)		99	110	110		26	29	32
Sulfate (mg/l)		23	10	12		9	12	10
Field Analytical Results								
pH	6.6	6.43	6.33		6.70	6.78	6.47	
Specific Conductance (µmhos/cm°C)	419.3	461.2	451.8		172.7	169.2	121.0	
Temperature	10.9	11.2	10.7		11.1	11.4	11.0	
DO(%)	36.3	11.2	11.8		5.1	21.6	19.6	
DO (mg/l)	3.93	1.22	1.31		0.56	2.29	2.12	
ORP	-76	-14.6	-3.9		-6.3	-61.7	-7.7	

Date/Time	12/1/10 12:10	12/1/10 2:30	12/18/10 12:30	12/20/10 9:40	12/1/10 10:00	12/1/10 11:55	12/18/10 11:30	12/20/10 8:40
Pump Test Sample	Pre-Test	Pre-Test	2 Days	4 Days	Pre-Test	Pre-Test	2 Days	4 Days
Sample ID	H-OW-1D	H-OW-1D	H-OW-1D-2D	H-OW-1D-4D	H-OW-2D	H-OW-2D	H-OW-2D-2D	H-OW-2D-4D
Laboratory Analytical Results								
Iron, Total (mg/l)		6.1	6.1	5.6		3.1	3.8	3.5
Sodium Total (mg/l)		38	42	41		13	17	15
Total Dissolved Solids (mg/l)		240	260	280		140	130	150
Chloride (mg/l)		99	100	110		26	30	29
Sulfate (mg/l)		23	9	12		9	11	10
Field Analytical Results								
pH	6.6	6.43	6.13	6.21	6.70	6.78	6.28	6.21
Specific Conductance (µmhos/cm°C)	419.3	461.2	452.0	461.3	172.7	169.2	173.4	181.7
Temperature	10.9	11.2	11.8	11.1	11.1	11.4	11.5	10.2
DO (%)	36.3	11.2	-	-	5.1	21.6	-	-
DO (mg/l)	3.93	1.22	0.69	2.01	0.56	2.29	8.3	1.57
ORP	-76	-14.6	9.5	23.0	-6.3	-61.7	7.2	13.8

Date/Time	3/16/11 12:00	3/24/11 12:50	3/28/11 15:35	3/16/11 9:00	3/24/11 11:40	3/28/11 14:17
Pump Test Sample	Pre-Test	2 Days	6 Days 5 hours	Pre-Test	2 Days	6 Days 4 hours
Sample ID	H-OW-1D	H-OW-1D-2D	H-OW-1D-4D	H-OW-2D	H-OW-2D-2D	H-OW-2D-4D
Laboratory Analytical Results						
Iron, Total (mg/l)	6.2		6.4	3.5		3.6
Sodium Total (mg/l)	39		49	14		17
Total Dissolved Solids (mg/l)	240		180	78		80
Chloride (mg/l)	120		140	26		45
Sulfate (mg/l)	14		11	8		10
Field Analytical Results						
pH	6.01	6.36	6.34	6.24	6.62	6.48
Specific Conductance (µmhos/cm°C)	408.2	404.8	406.5	146.7	146.5	150.2
Conductivity (µmhos/cm)	300.1	299.6	302.9	105.8	107.9	111.6
Temperature	11.1	11.4	11.6	10.4	11.2	11.5
DO (%)	19.0			20.5		
DO (mg/l)		1.36	2.24		0.17	1.06
ORP	358.3	136.6	316.3	300.2	249.1	320.6

Table 7-1 Comparison of Calibrated Values of Hydraulic Conductivity and Storage for MLU and SEAWAT

MLU					SEAWAT								
						Nearfield				Farfiled			
Zone	Kh (ft/d)	Kv (ft/d)	Kh/Kv	Ss (ft^{-1})	Layer	Kh (ft/d)	Kv (ft/d)	Kh/ Kv	Ss (ft^{-1})	Kh (ft/d)	Kv (ft/d)	Kh/ Kv	Ss (ft^{-1})
A	150	75	2	6.7x10^{-3}-3.3x10^{-3}	1	200	100	2	1.0x10^{-3}	200	100	2	1.0x10^{-5}
					2				1.0x10^{-4}				5.0x10^{-5}
A/B	1-2	0.07-0.25	8-15	2.0x10^{-4}-3.0x10^{-4}	3	0.20	0.02	10	5.0x10^{-5}	120	40	3	5.0x10^{-5}
						10	1.0	10					
B	100-230	3.3-11.5	9-70	3.0x10^{-5}-2.0x10^{-7}	4	72	7.2	10	1.0x10^{-4}	70	20	3.5	5.0x10^{-5}
					5								
					6								
B/C	50	2.5-3.9	13-20	3.0x10^{-6}-6.0x10^{-5}	7	32	3.2	10	2.0x10^{-5}	70	20	3.5	5.0x10^{-5}
C	75-160	6.4-11.4	7-25	6.0x10^{-7}-3.0x10^{-6}	8	98	10	9.8	2.0x10^{-5}	90	15	6	5.0x10^{-5}
					9								
					10								
C/D	10	0.4	25	5.0x10^{-6}-9.0x10^{-6}	11	15	1.5	10	2.0x10^{-5}	50	5	10	5.0x10^{-5}
D	20-40	0.4-0.6	35-100	8x10^{-7}-1.6x10^{-5}	12	50	3	10	2.0x10^{-5}	50	3	16.7	5.0x10^{-5}
					13								
					14								
					15								
					16								
Below MLU	--	--	--	--	17	10	0.01	1000	5.0x10^{-5}	10	0.1	100	5.0x10^{-5}

Figures

Figure 1 - Site Locus Map
District H
Eastham, MA

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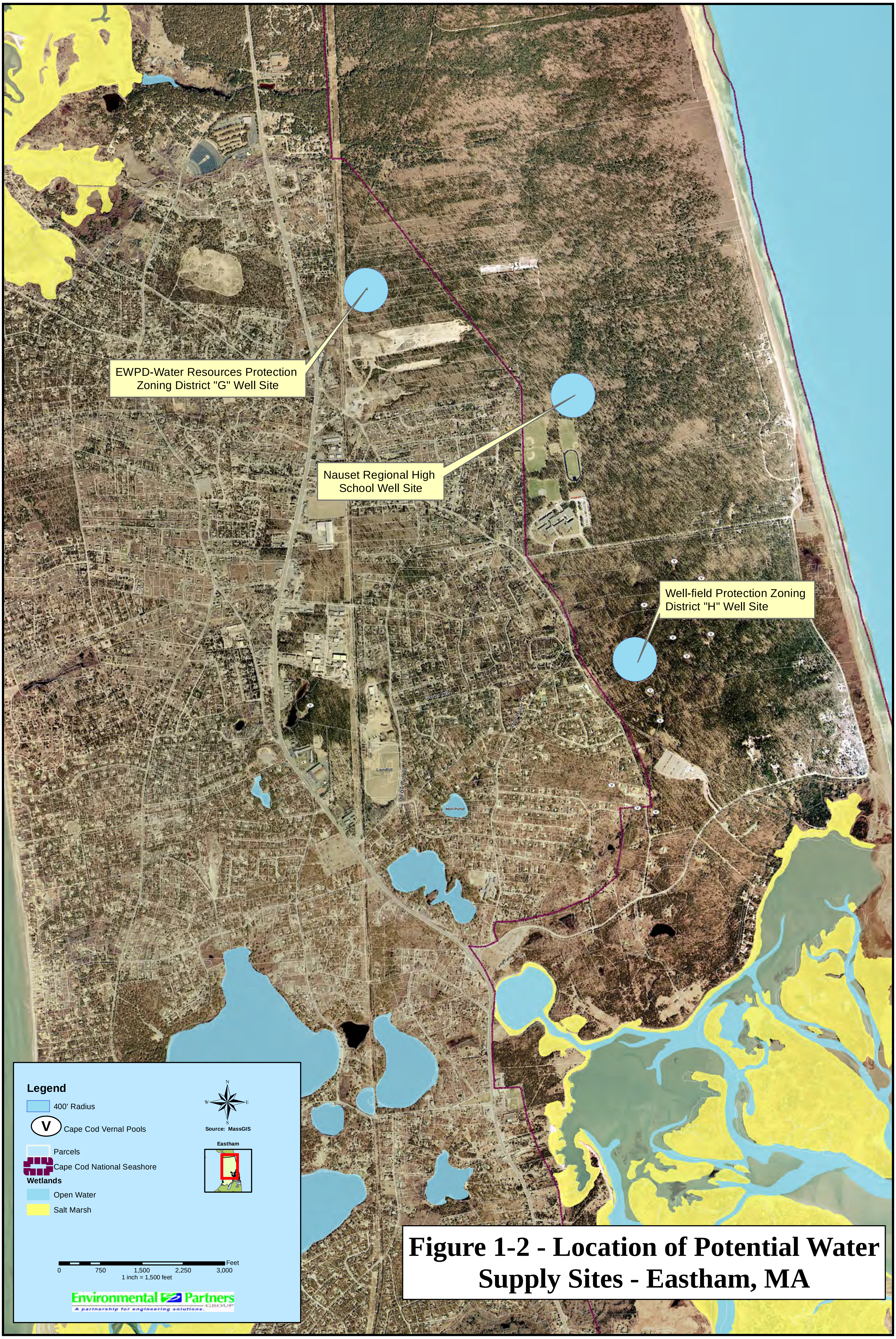


Figure 1-2 - Location of Potential Water Supply Sites - Eastham, MA

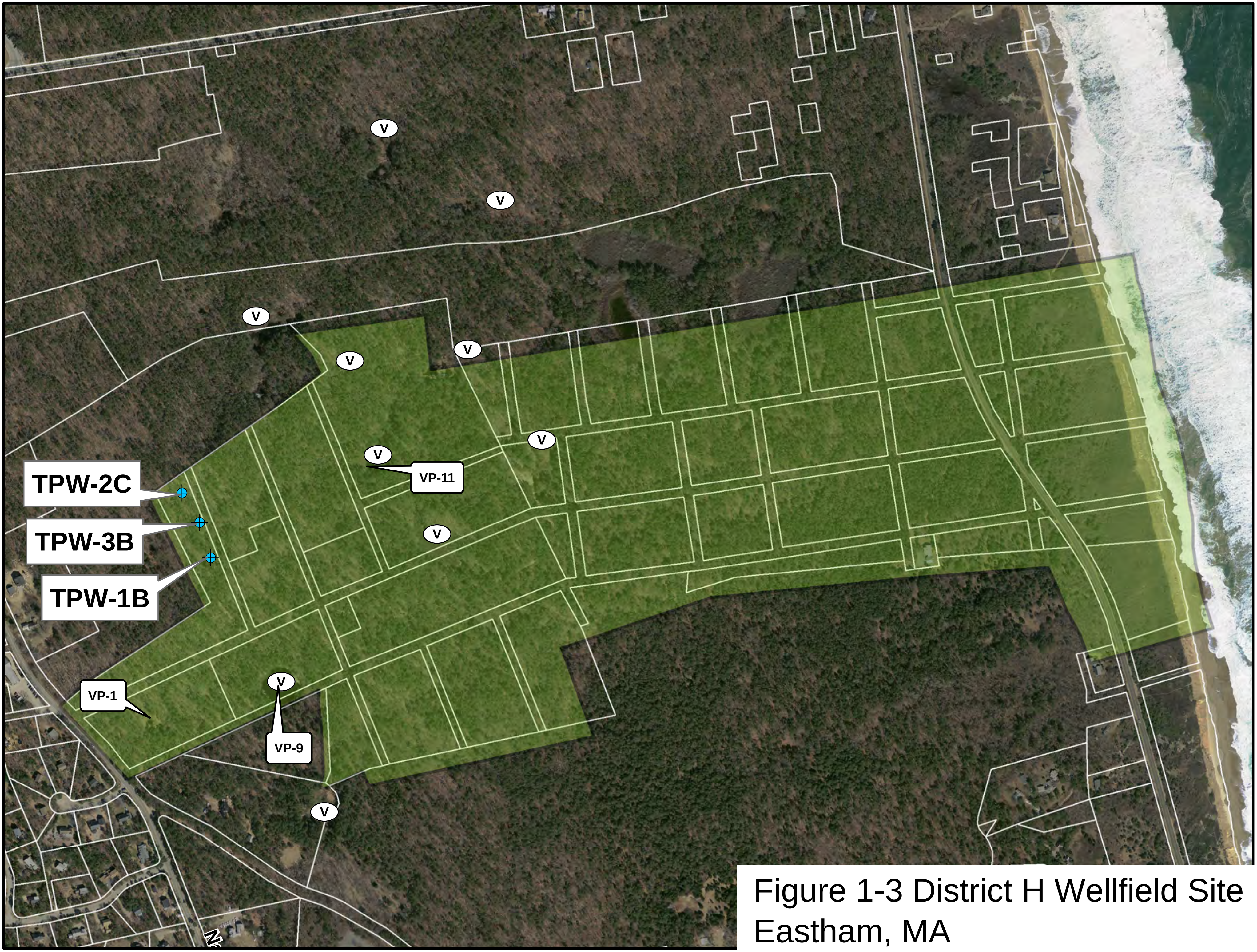


Figure 1-3 District H Wellfield Site
Eastham, MA

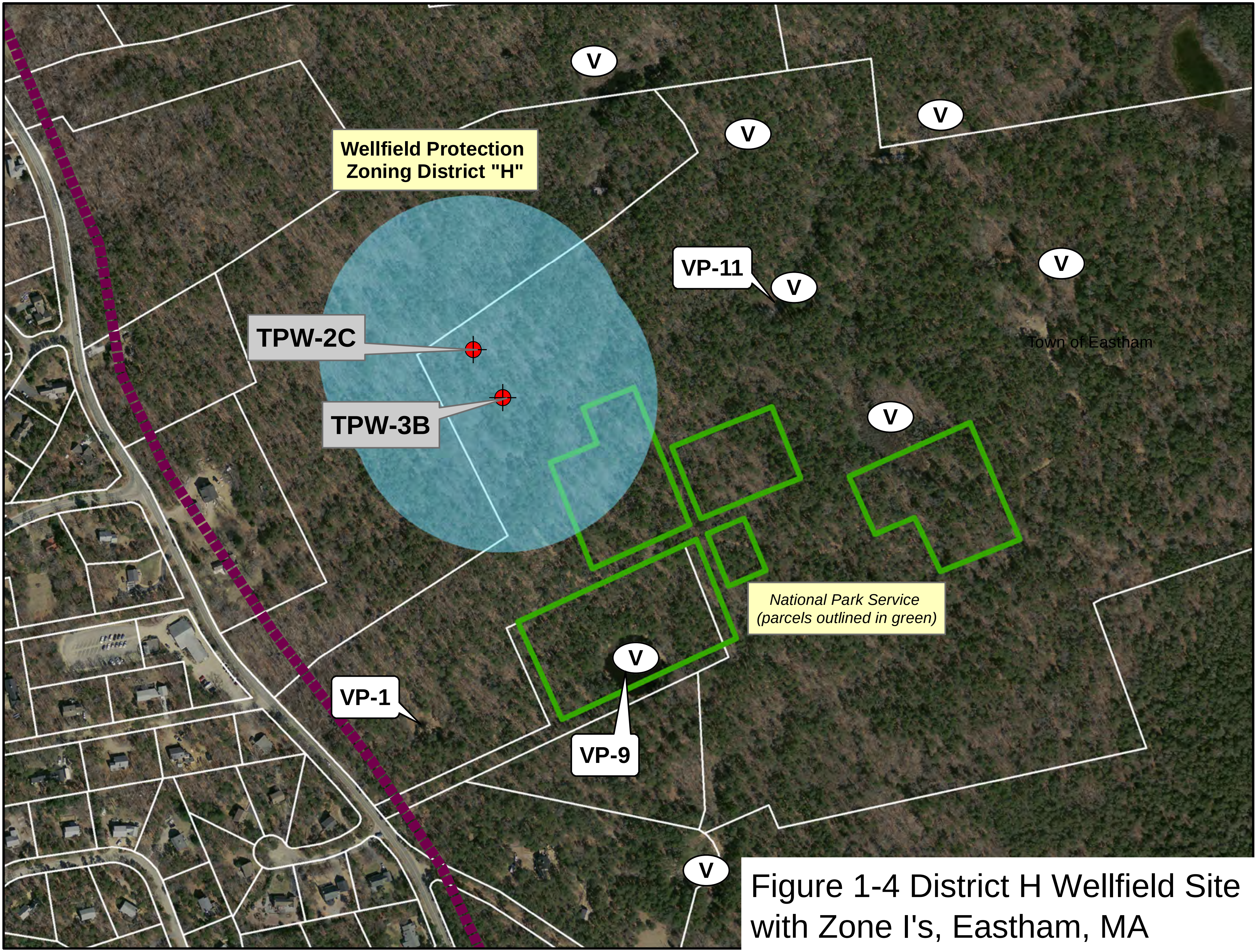
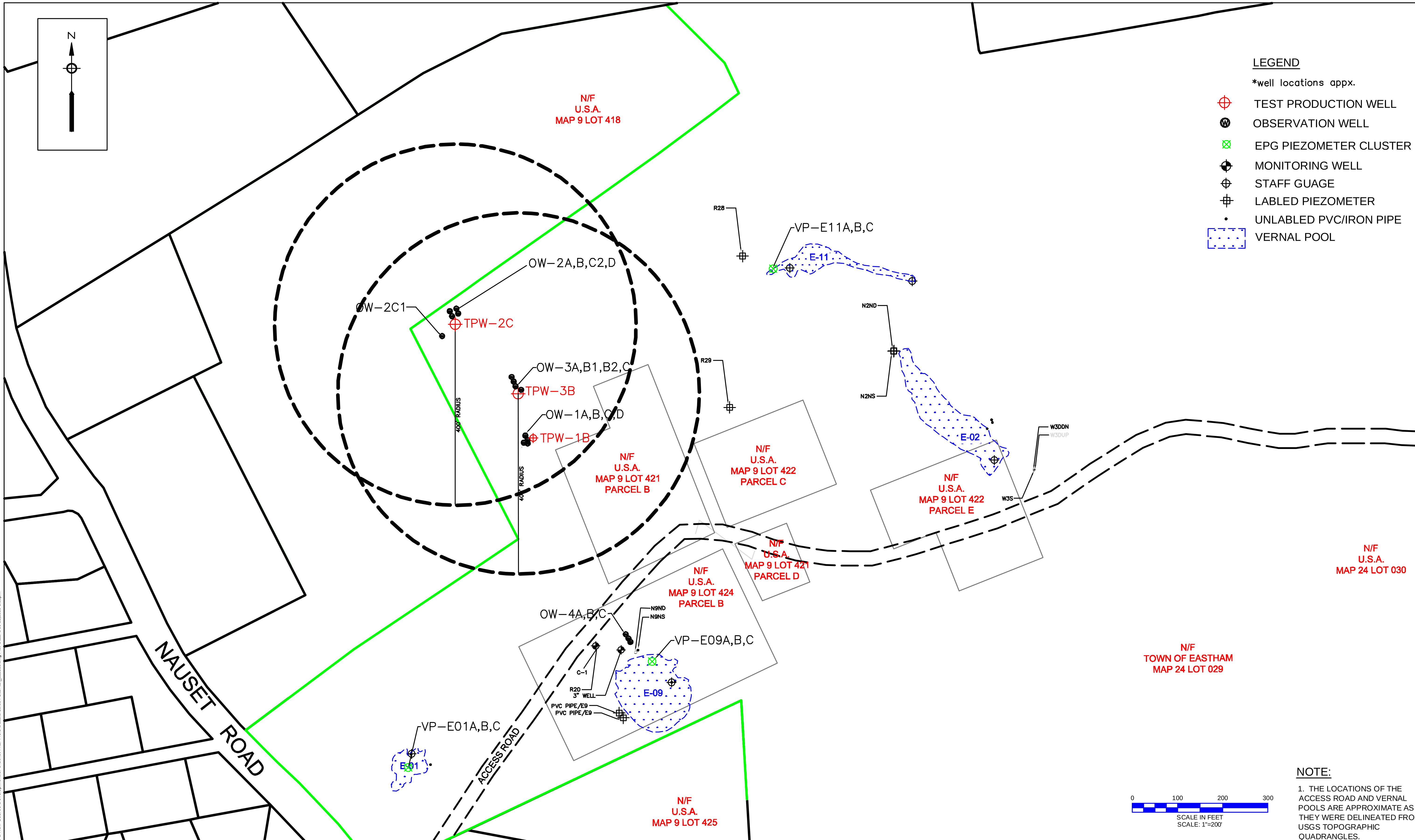


Figure 1-4 District H Wellfield Site with Zone I's, Eastham, MA



NOTE:

1. THE LOCATIONS OF THE ACCESS ROAD AND VERNAL POOLS ARE APPROXIMATE AS THEY WERE DELINEATED FROM USGS TOPOGRAPHIC QUADRANGLES.

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			Scale	1"=200' (11X17)
			Date	
			Job No.	
			Designed by	NMA
			Drawn by	NMA
			Checked by	AMP
			Approved by	MNW

SITE PLAN OF DISTRICT H

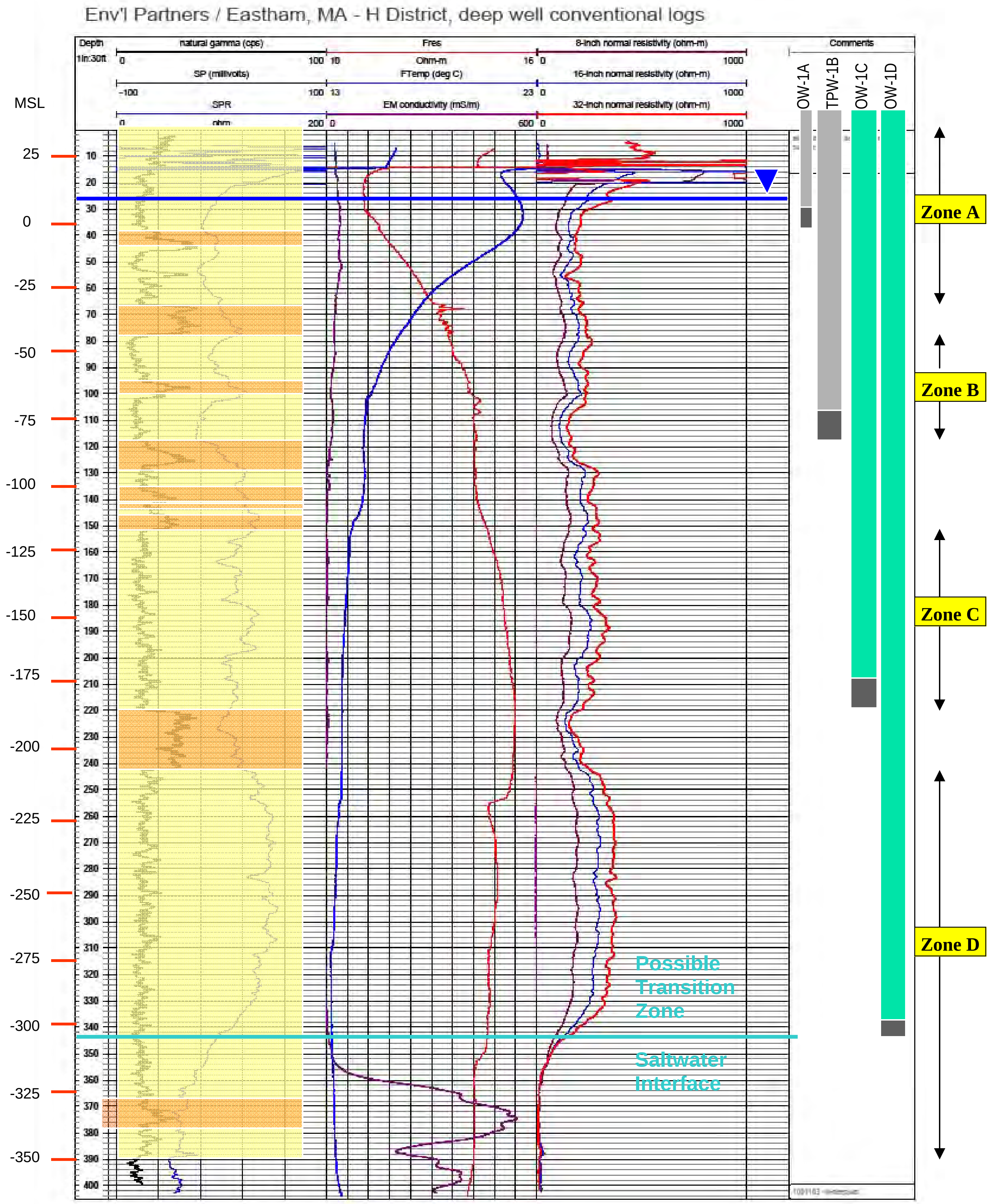
DISTRICT H
NAUSET ROAD
EASTHAM, MA

NOT FOR CONSTRUCTION

Sheet No.

Figure 1-5

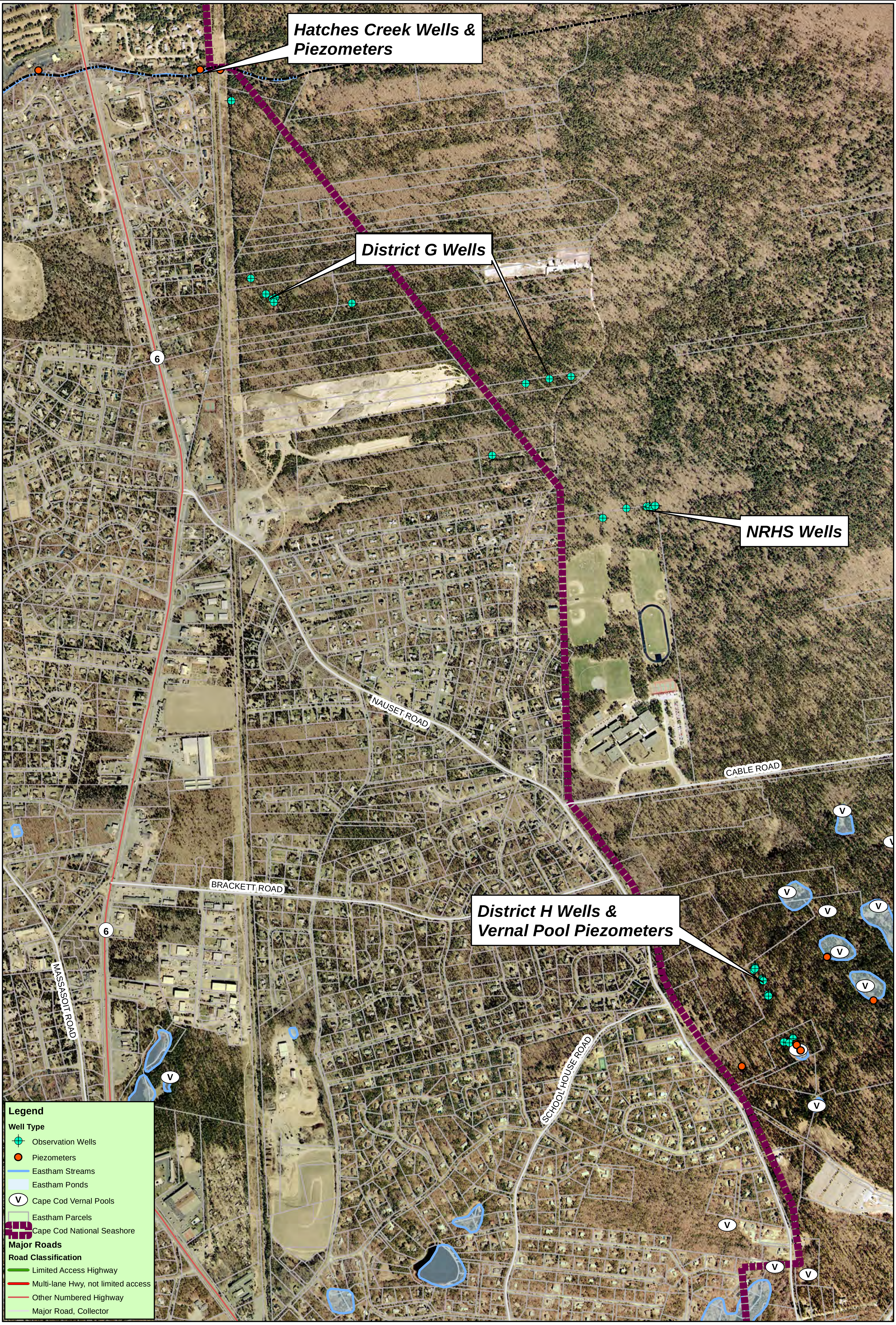
Figure 2-1. Geophysical Log - District H Site - OW-1 Cluster



Sand

Silt and Clay

August 2009



0 420 840 1,680 Feet

1 inch = 850 feet

N S E W

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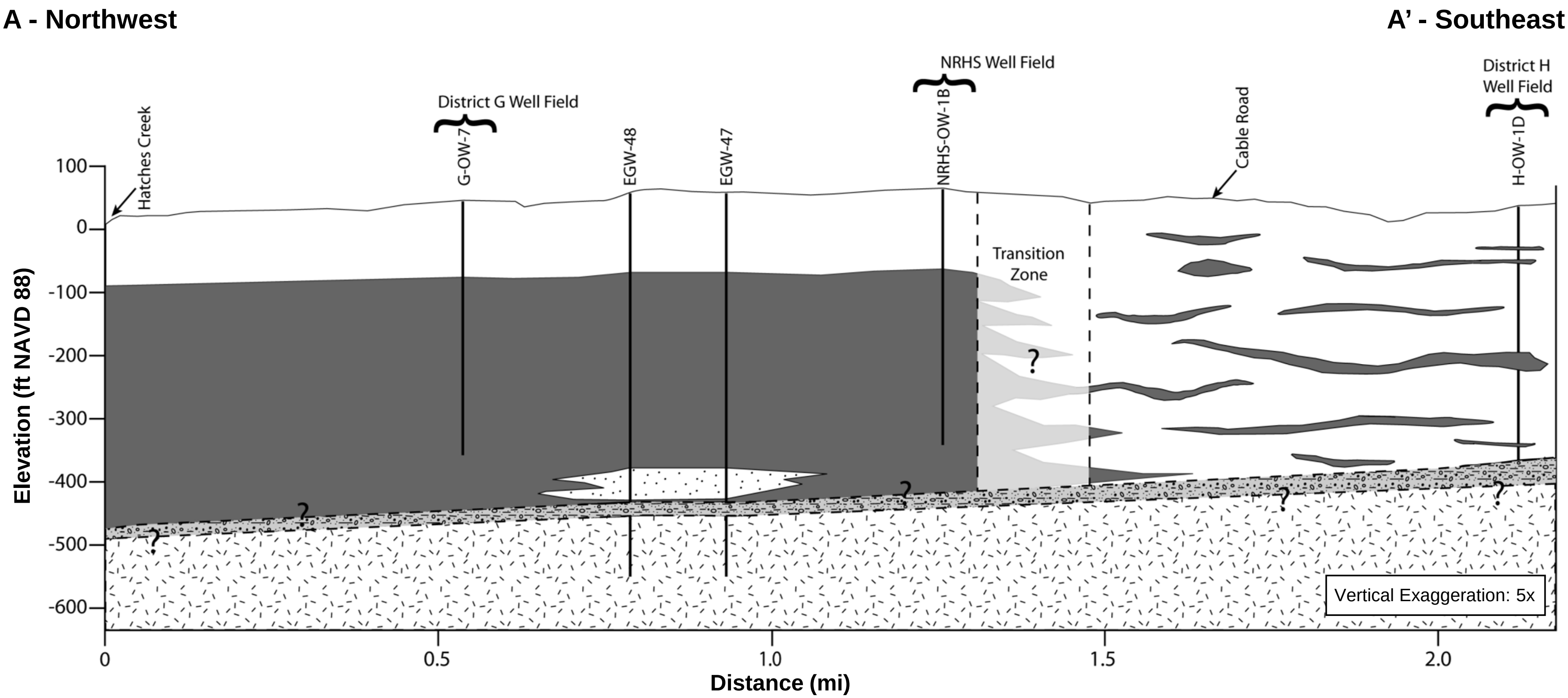
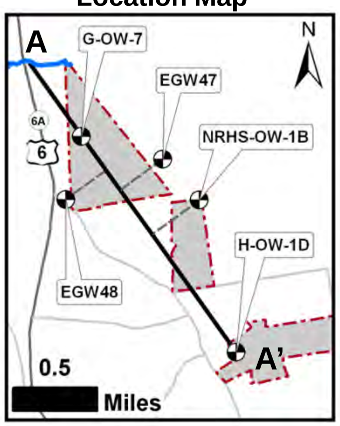
Figure 3-1: Eastham New Source Field Activities
Groundwater Wells & Piezometers
District G, NRHS & District H
Eastham, MA



Location Map



Eastham Plain
(Sands with minor silts, clays and gravels)

Cape Cod Bay Deposits
(Clays and silts with occasional sand lens)

Collapsed Ice – Contact Deposits
(Sands with minor silts and clays)

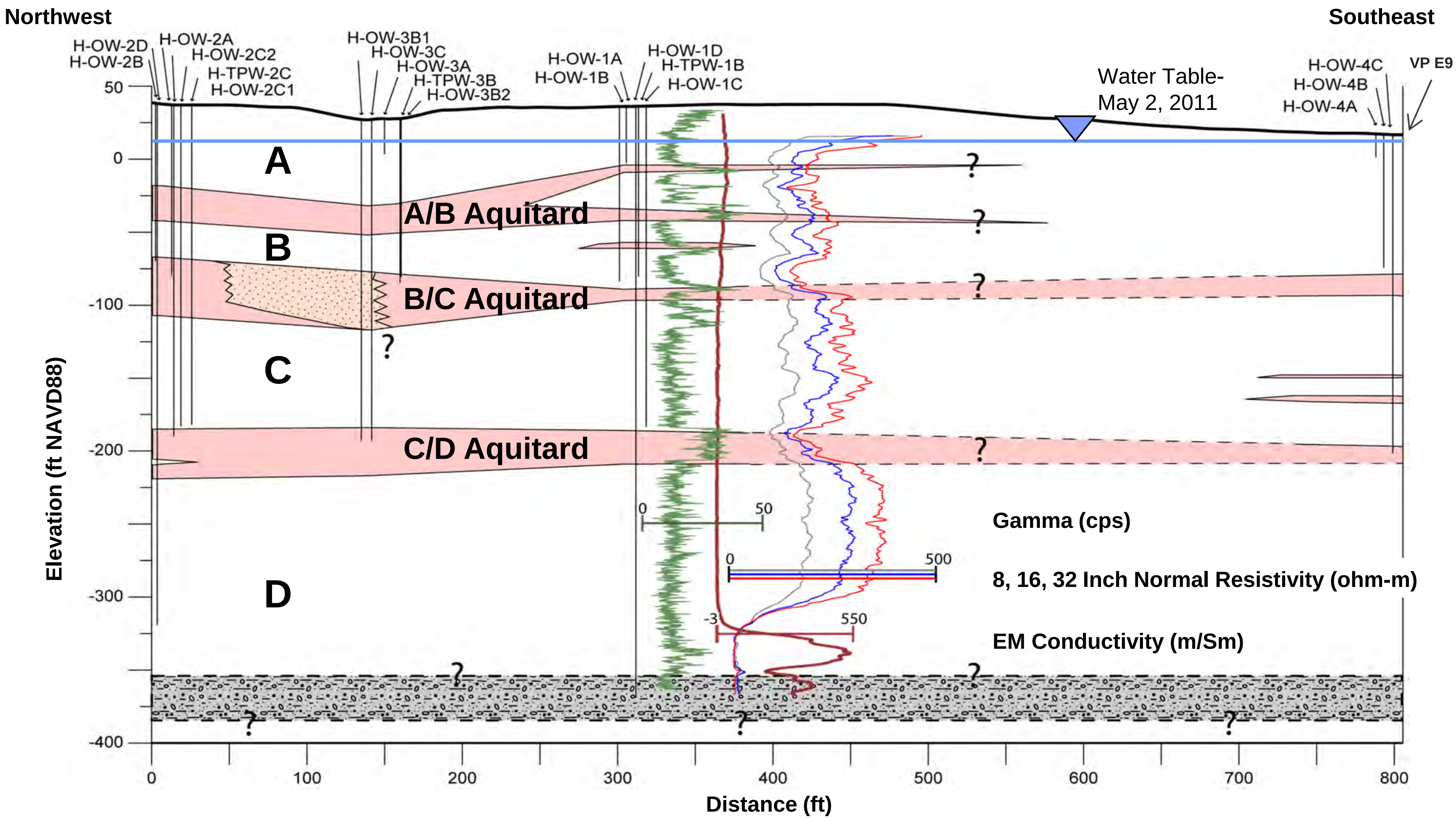
Glacial Till
(Sand, Silt, Clay, Gravel)

Bedrock

General Hydrologic Cross Section
A – A'

McLane Environmental, LLC
McLane Environmental, LLC, 707 Alexander Rd, Suite 206
Princeton, NJ 08540 | www.mclaneenv.com

Figure 3-2



Aquifer (Fine to medium sand with traces of coarser sand and gravel)

Aquitard (Silty clay and silt / Silty sand)

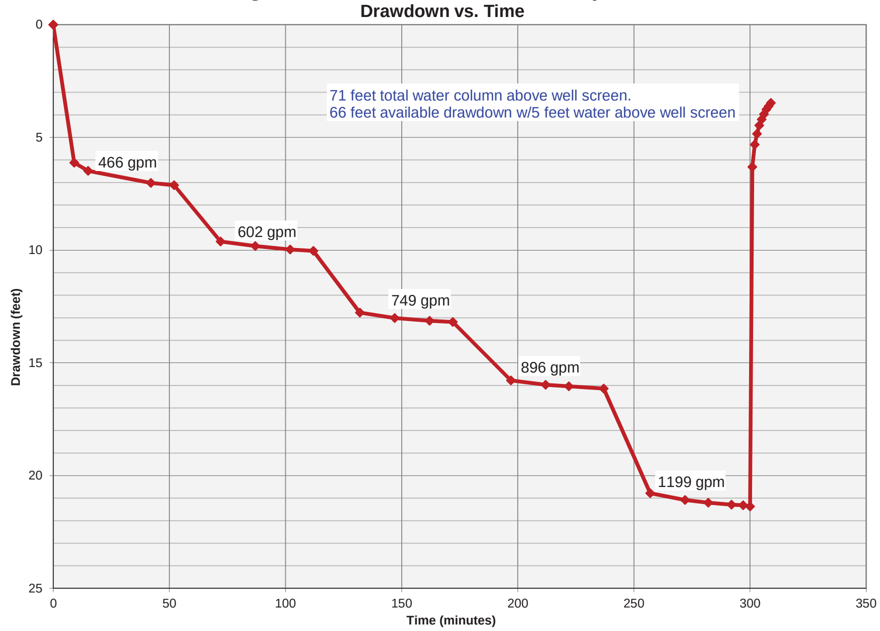
Till or weathered bedrock

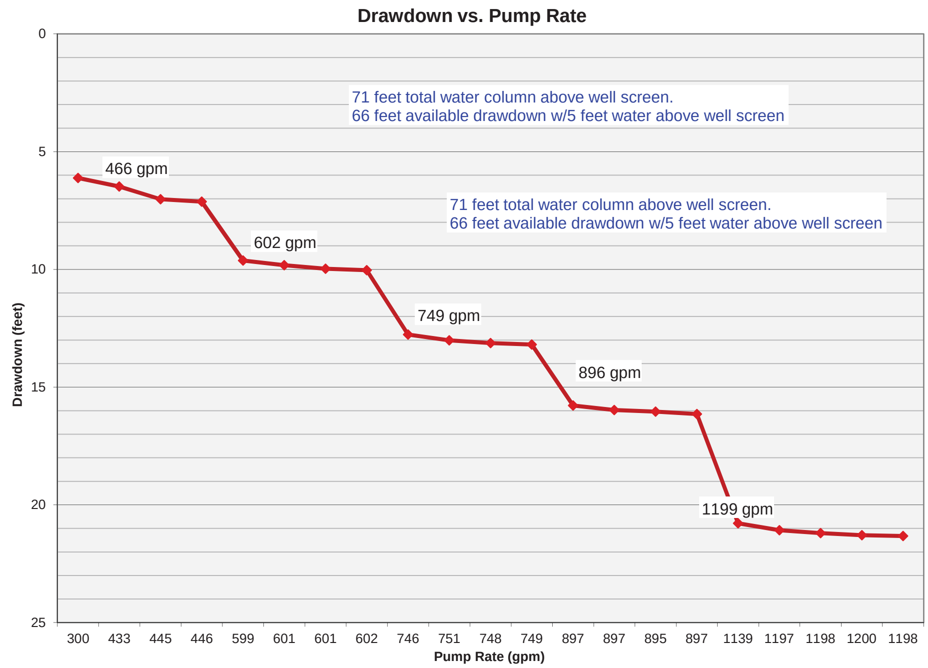
District H Well Field Hydrologic
Cross Section B–B'

MCLANE ENVIRONMENTAL, LLC
McLane Environmental, LLC, 707 Alexander Rd, Suite 206
Princeton, NJ 08540 | www.mclaneenv.com

Figure 3-3

Figure 3-4: District H TPW-3B Step Test





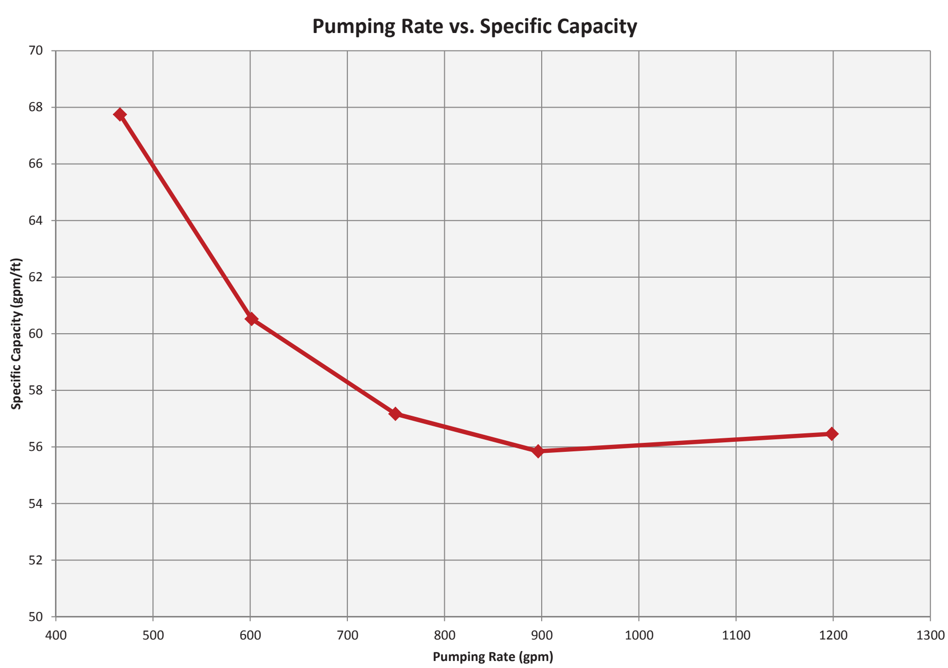


Figure 3-5: District H TPW-2C Step test

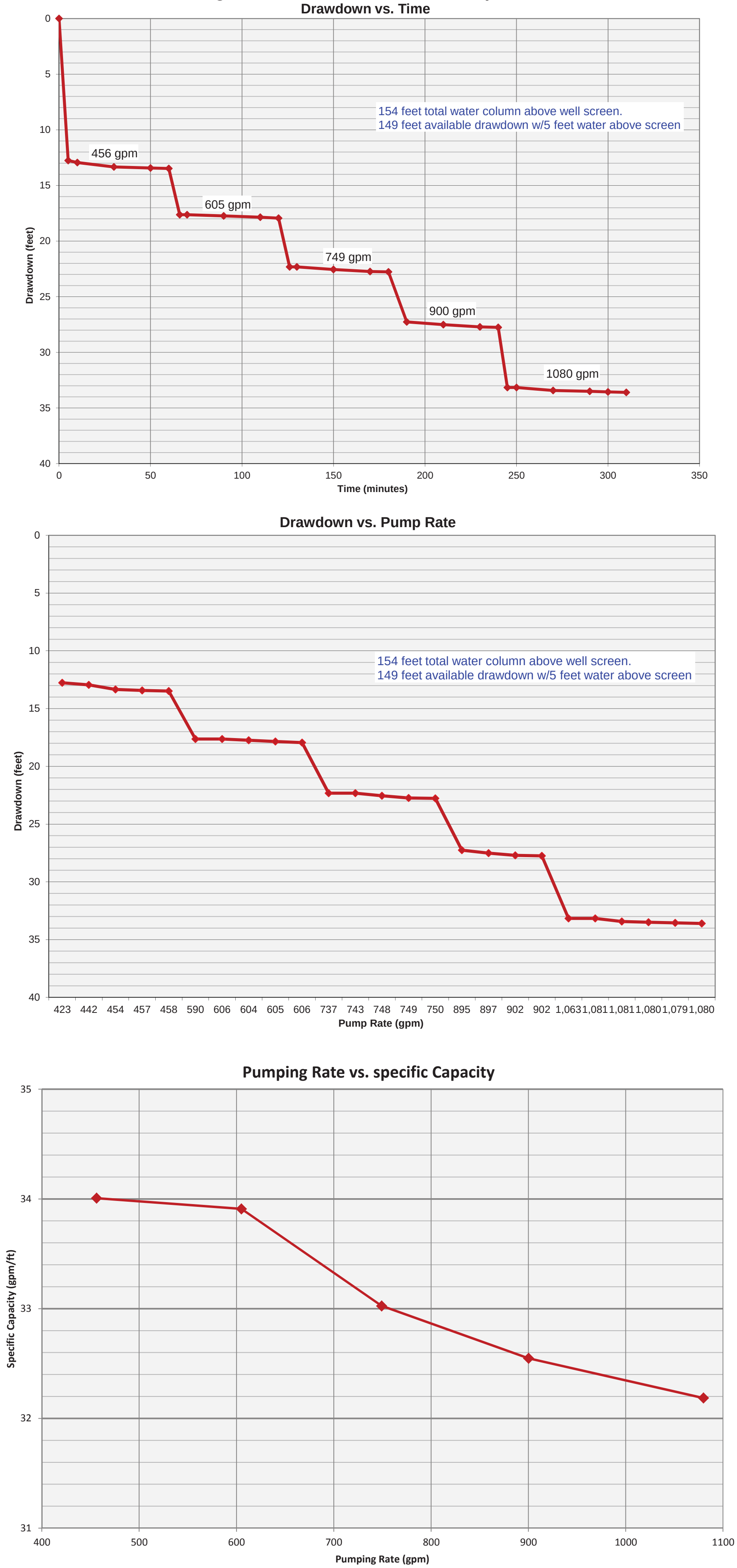


FIGURE 3-7: NRHS Water Level Elevations for Production Zone Well OW-1A August 2009 through May 2011

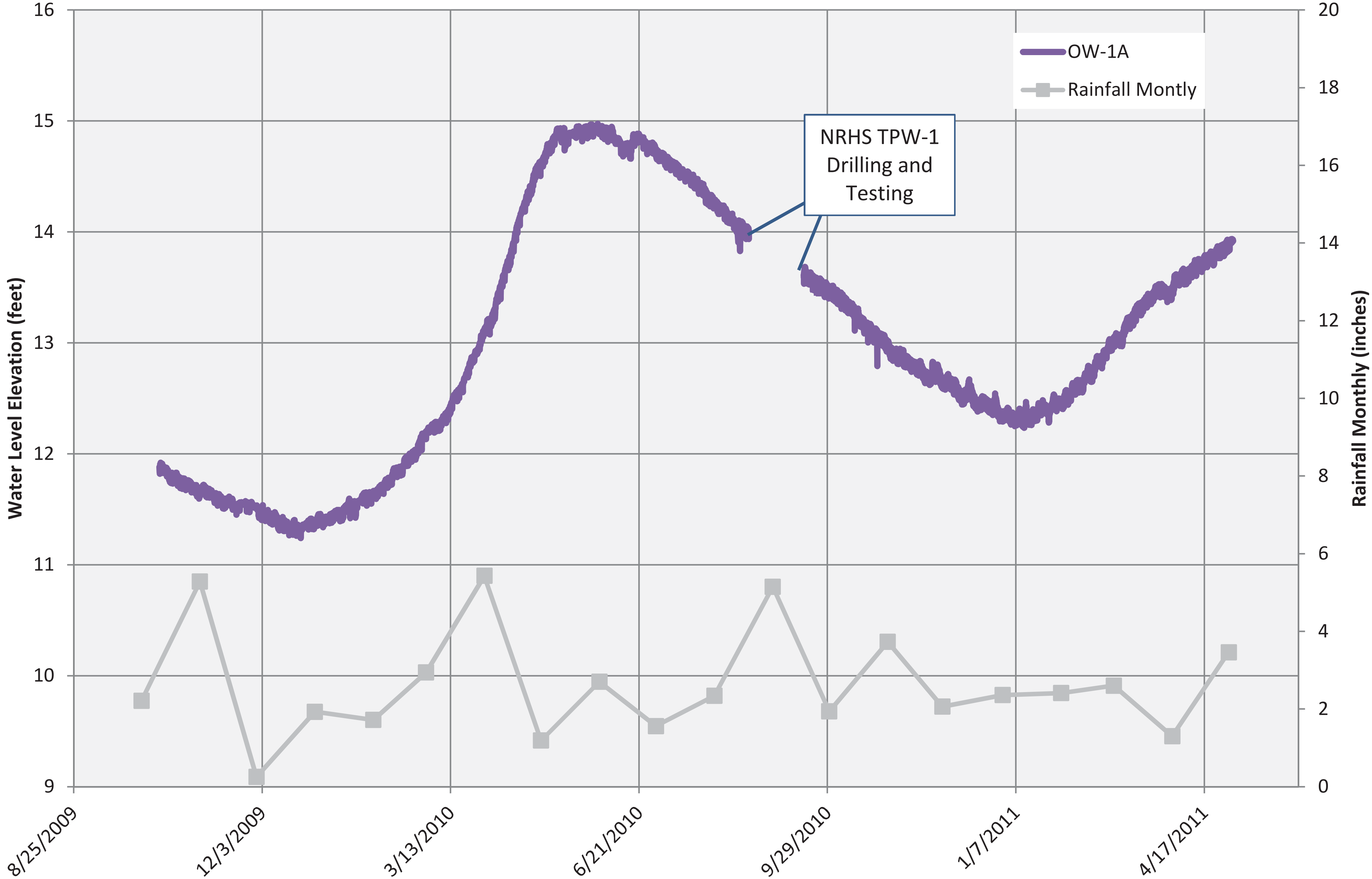
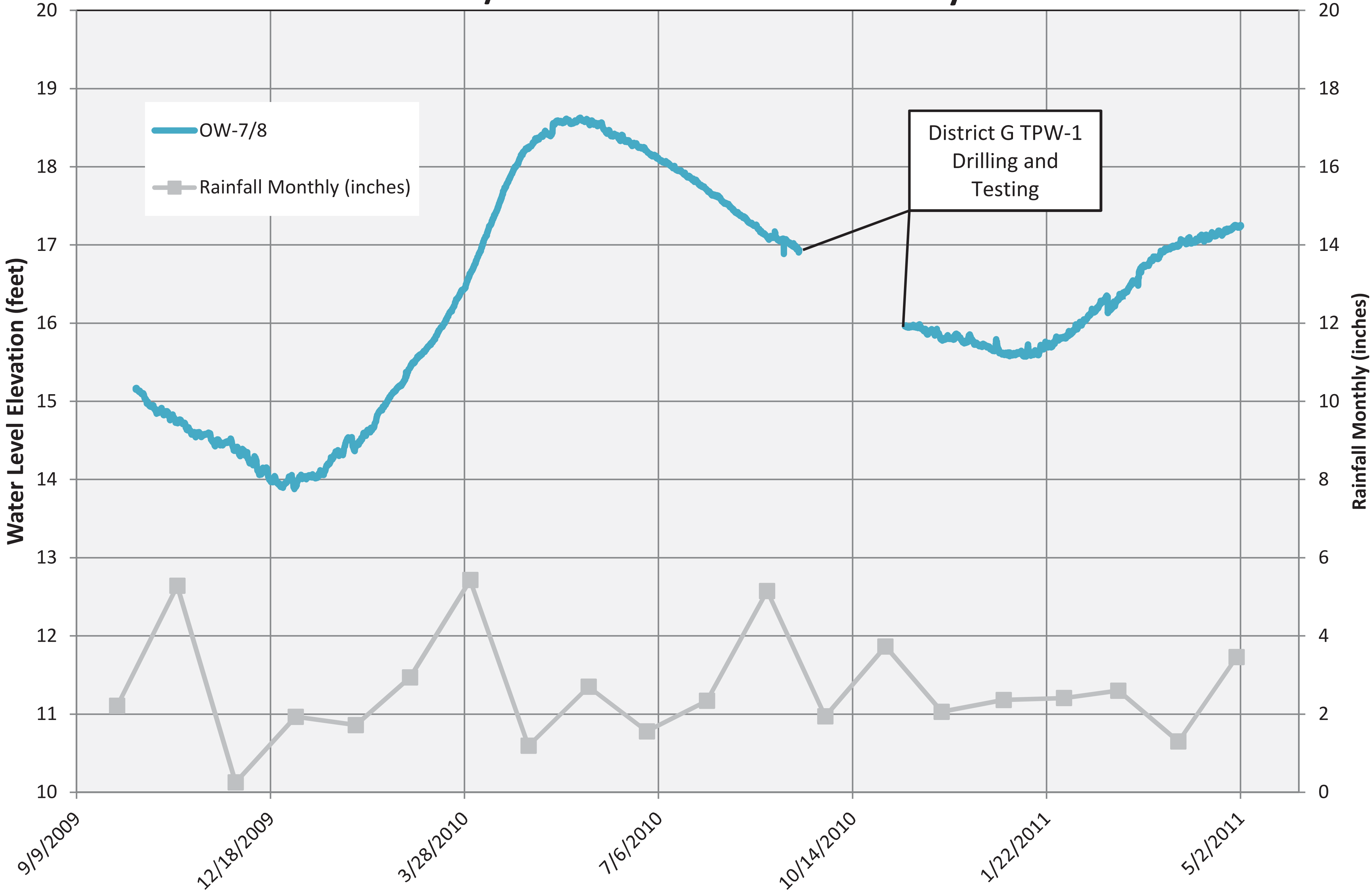


FIGURE 3-8: District G Water Level Elevations for Production Zone Wells OW-7/OW-8 October 2009 thru May 2010



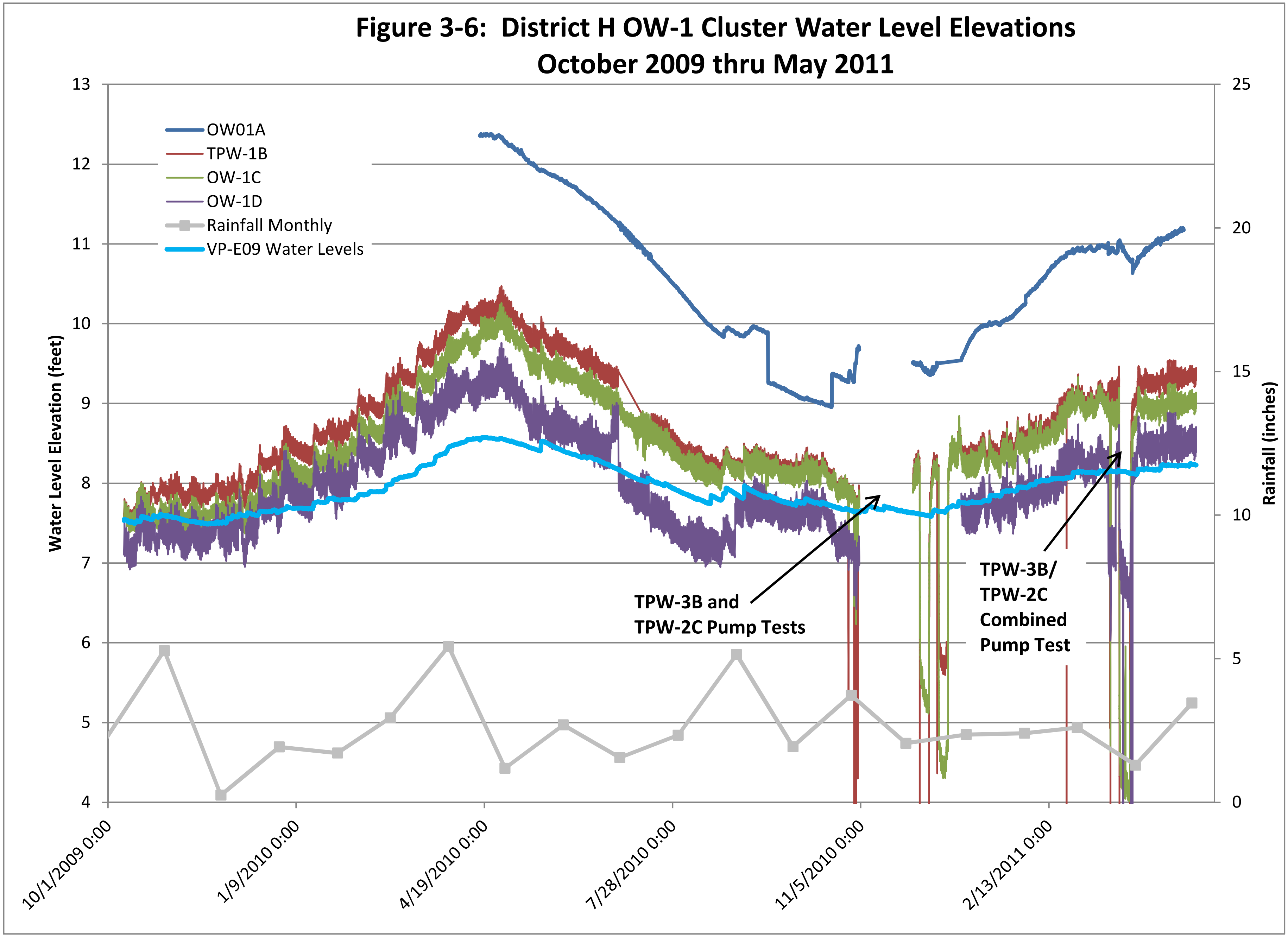
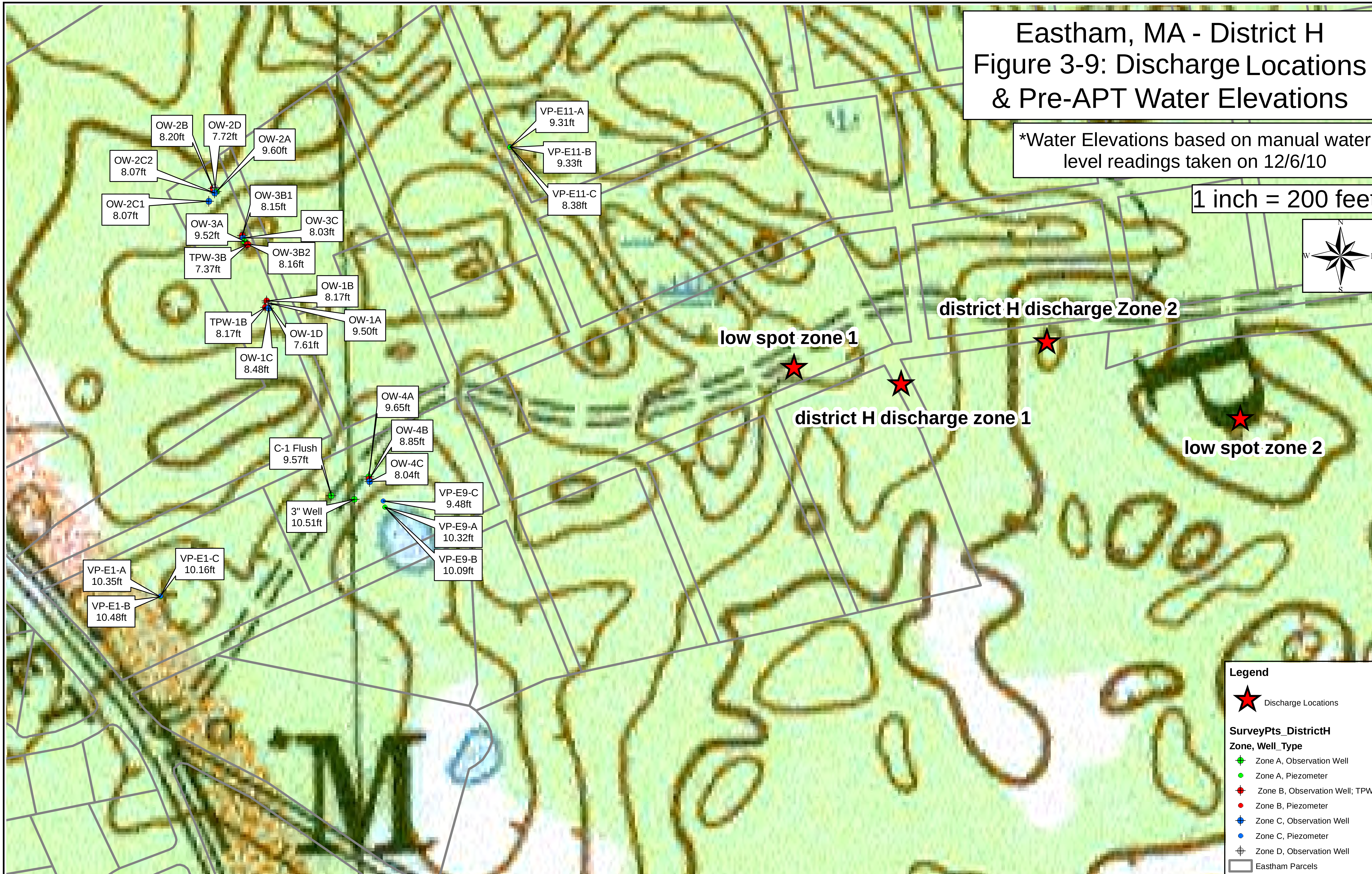
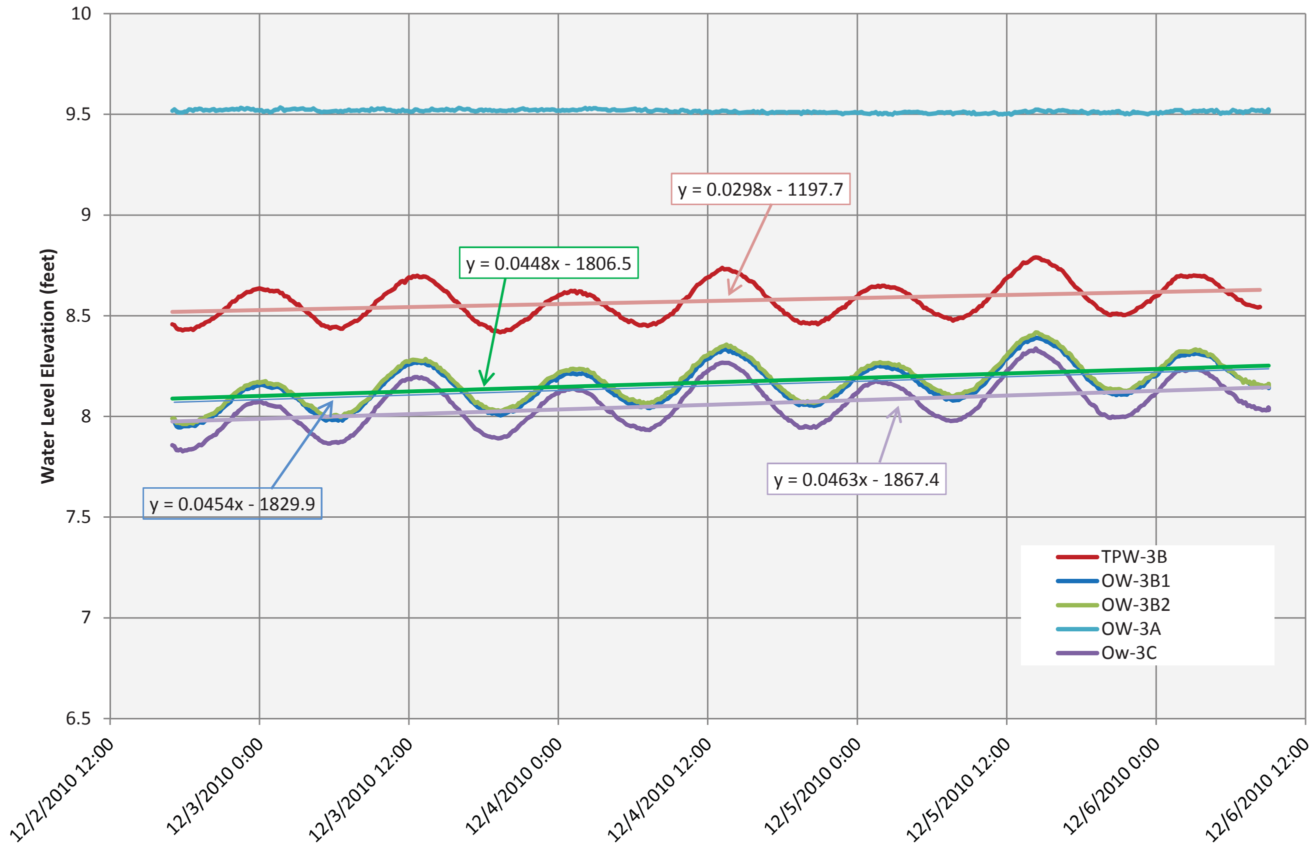


Figure 3-6: District H OW-1 Cluster Water Level Elevations
October 2009 thru May 2011
OW01A
TPW-1B
OW-1C
OW-1D
Rainfall Monthly
VP-E09 Water Levels
Water Level Elevation (feet)
Rainfall (inches)
13
12
11
10
9
8
7
6
5
4
25
20
15
10
5
0
TPW-3B and
TPW-2C Pump Tests
TPW-3B/
TPW-2C
Combined
Pump Test
10/1/2009 0:00
1/9/2010 0:00
4/19/2010 0:00
7/28/2010 0:00
11/5/2010 0:00
2/13/2011 0:00



Eastham, MA - District H
Figure 3-9: Discharge Locations & Pre-APT Water Elevations
*Water Elevations based on manual water level readings taken on 12/6/10
1 inch = 200 feet
N
E
S
W
OW-2B 8.20ft
OW-2D 7.72ft
OW-2A 9.60ft
OW-2C2 8.07ft
OW-2C1 8.07ft
OW-3B1 8.15ft
OW-3A 9.52ft
OW-3C 8.03ft
TPW-3B 7.37ft
OW-3B2 8.16ft
OW-1B 8.17ft
TPW-1B 8.17ft
OW-1A 9.50ft
OW-1D 7.61ft
OW-1C 8.48ft
VP-E11-A 9.31ft
VP-E11-B 9.33ft
VP-E11-C 8.38ft
OW-4A 9.65ft
OW-4B 8.85ft
OW-4C 8.04ft
C-1 Flush 9.57ft
3" Well 10.51ft
VP-E9-C 9.48ft
VP-E9-A 10.32ft
VP-E9-B 10.09ft
VP-E1-C 10.16ft
VP-E1-A 10.35ft
VP-E1-B 10.48ft
low spot zone 1
district H discharge Zone 2
district H discharge zone 1
low spot zone 2
Legend
Discharge Locations
SurveyPts_DistrictH
Zone, Well_Type
Zone A, Observation Well
Zone A, Piezometer
Zone B, Observation Well; TPW
Zone B, Piezometer
Zone C, Observation Well
Zone C, Piezometer
Zone D, Observation Well
Eastham Parcels

Figure 4-1: TPW-3B Pre-Test Water Levels
December 2 - 6, 2010



TPW-3B Pre-Test Water Levels
December 2 - 6, 2010

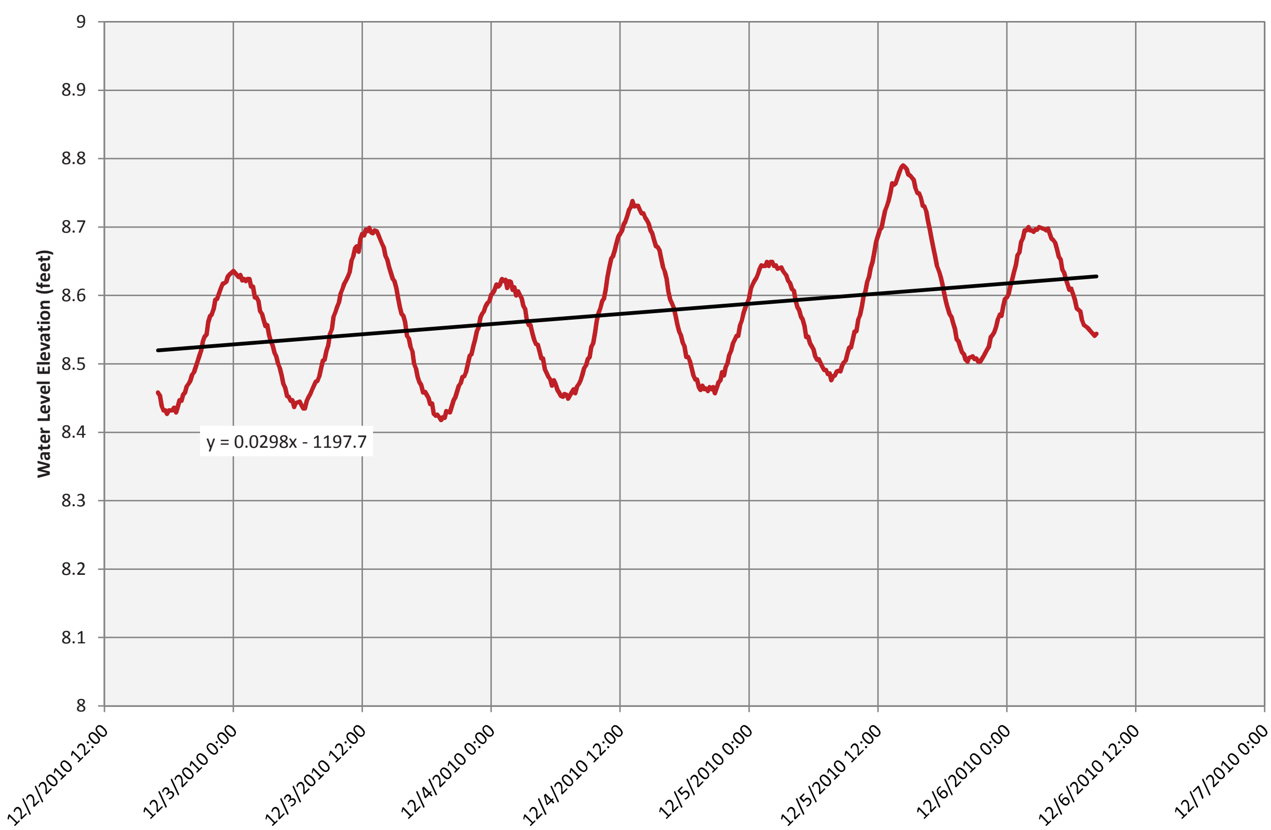


Figure 4-2: TPW-3B Pumping Test OW-3 Cluster Drawdown vs. Time

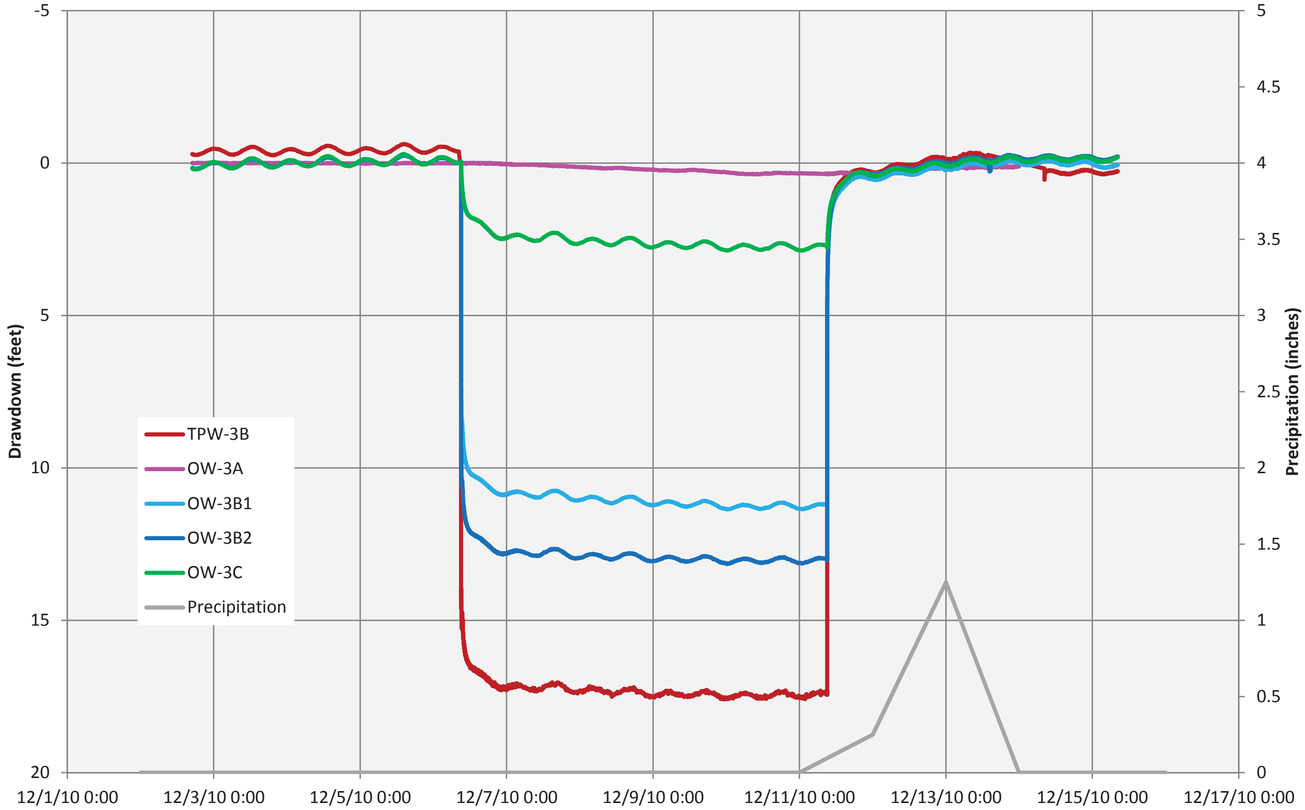


Figure 4-3: TPW-3B Pumping Test Zone B Wells Drawdown vs. Time

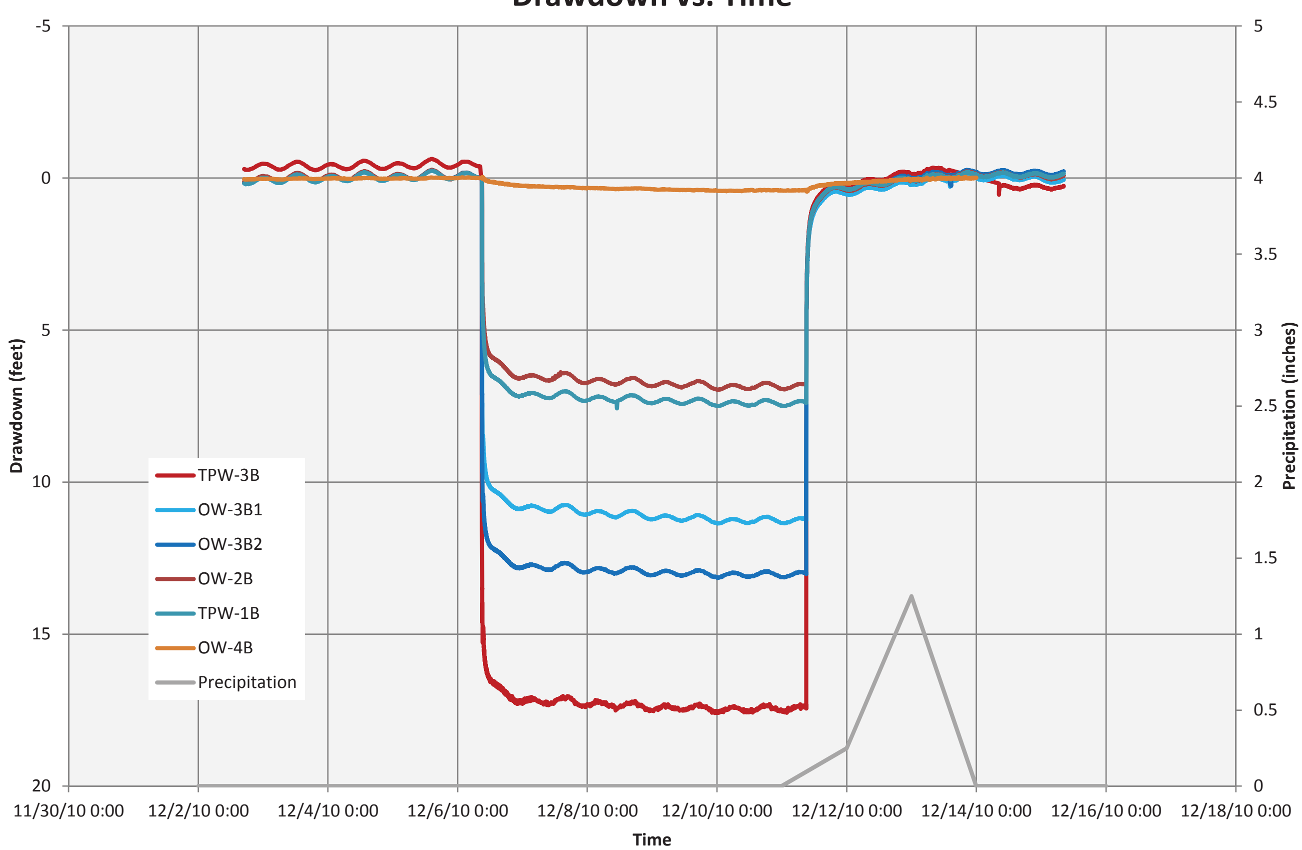


Figure 4-4: TPW-3B Pumping Test OW-3 Cluster Drawdown vs. Time

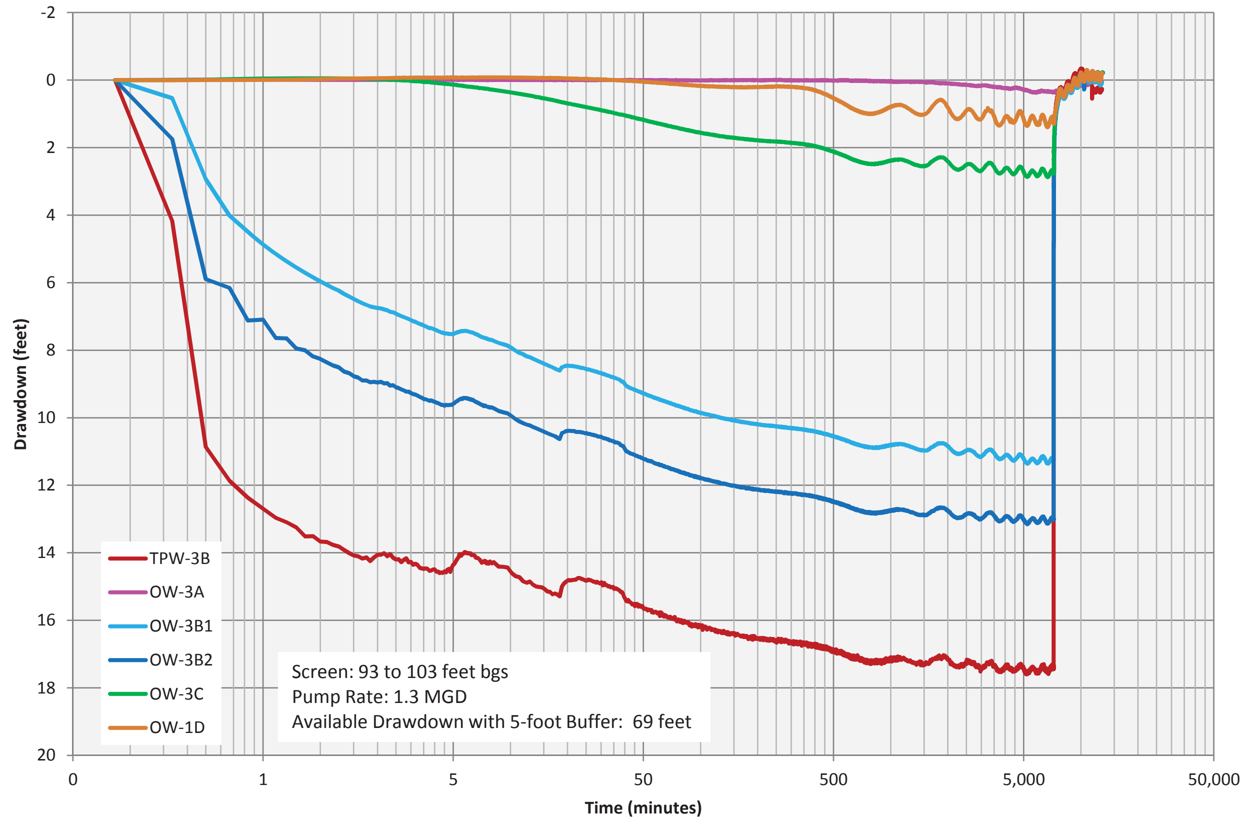


Figure 4-5: TPW-3B Pumping Test Zone B Wells Drawdown vs. Time

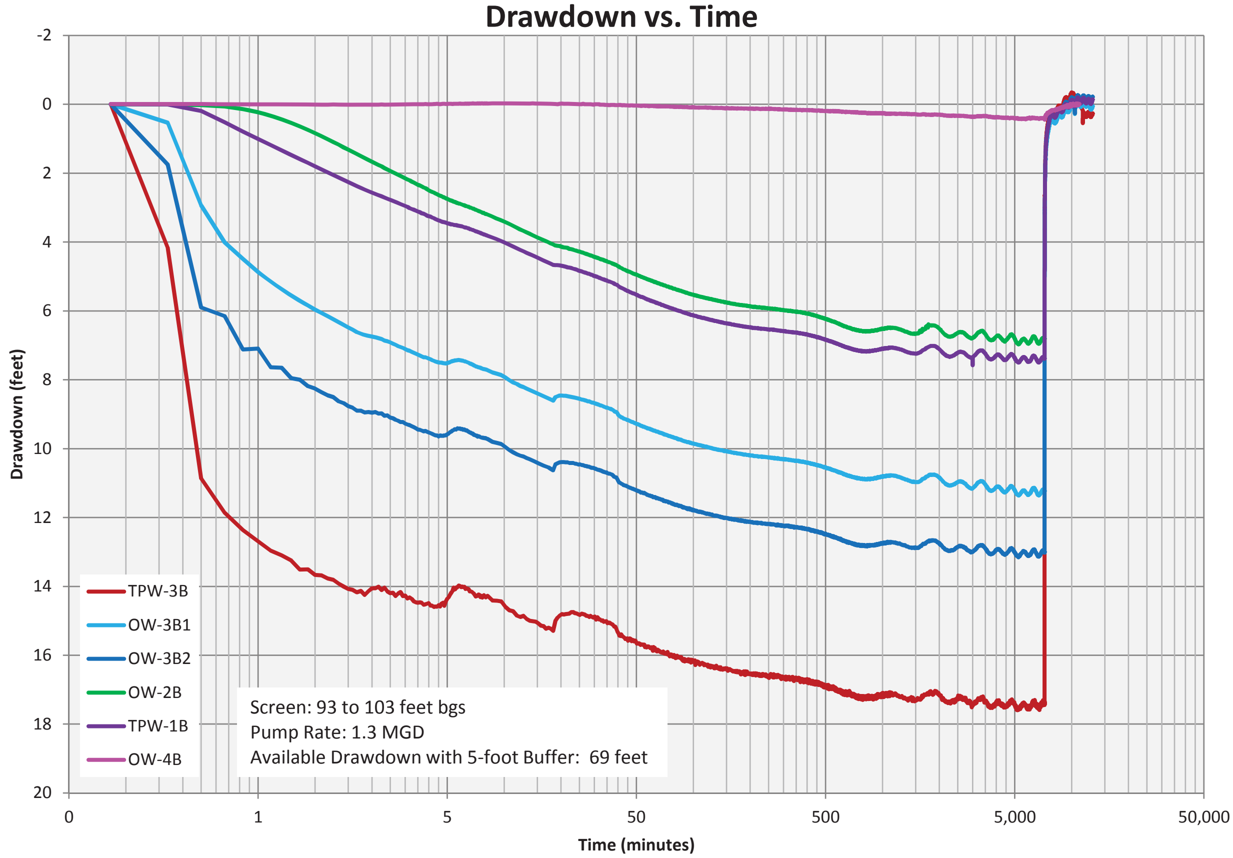


Figure 4-6: TPW-3B Pumping Test Last 48-Hours Drawdown vs. Time

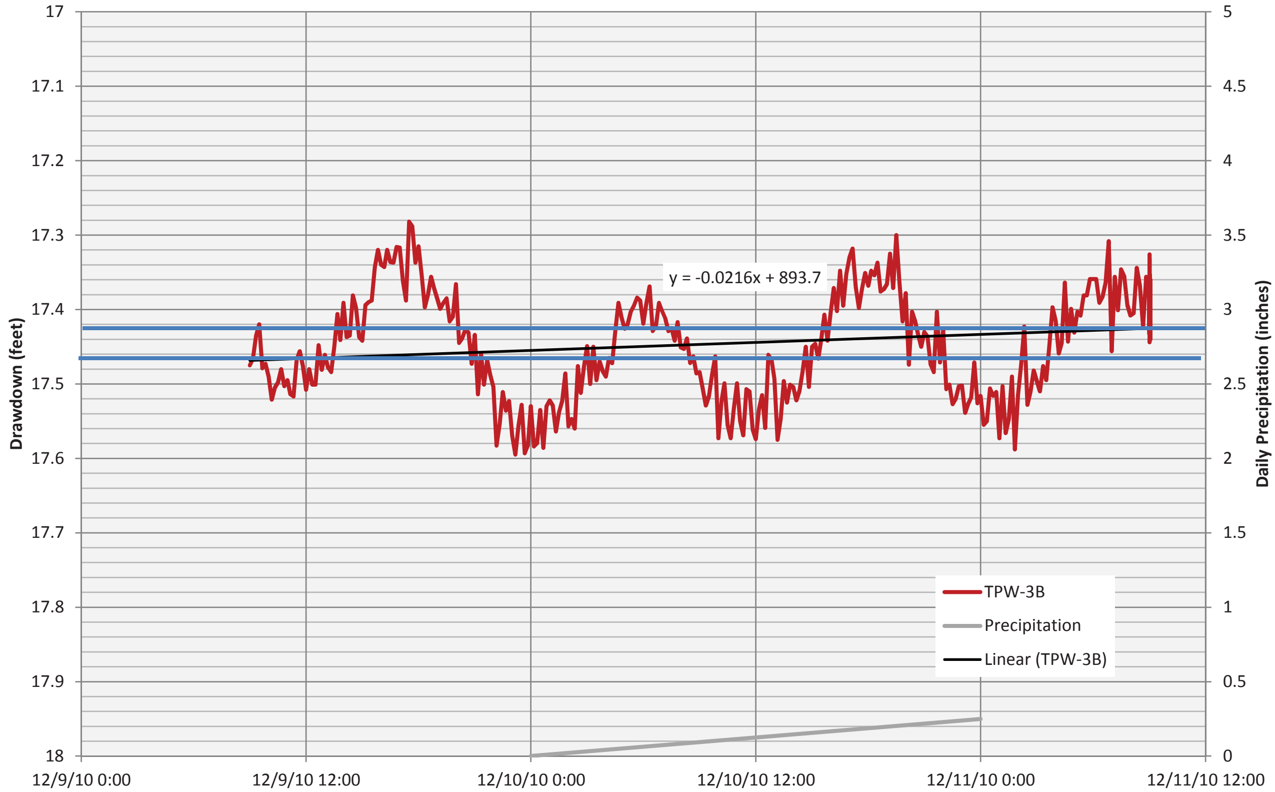
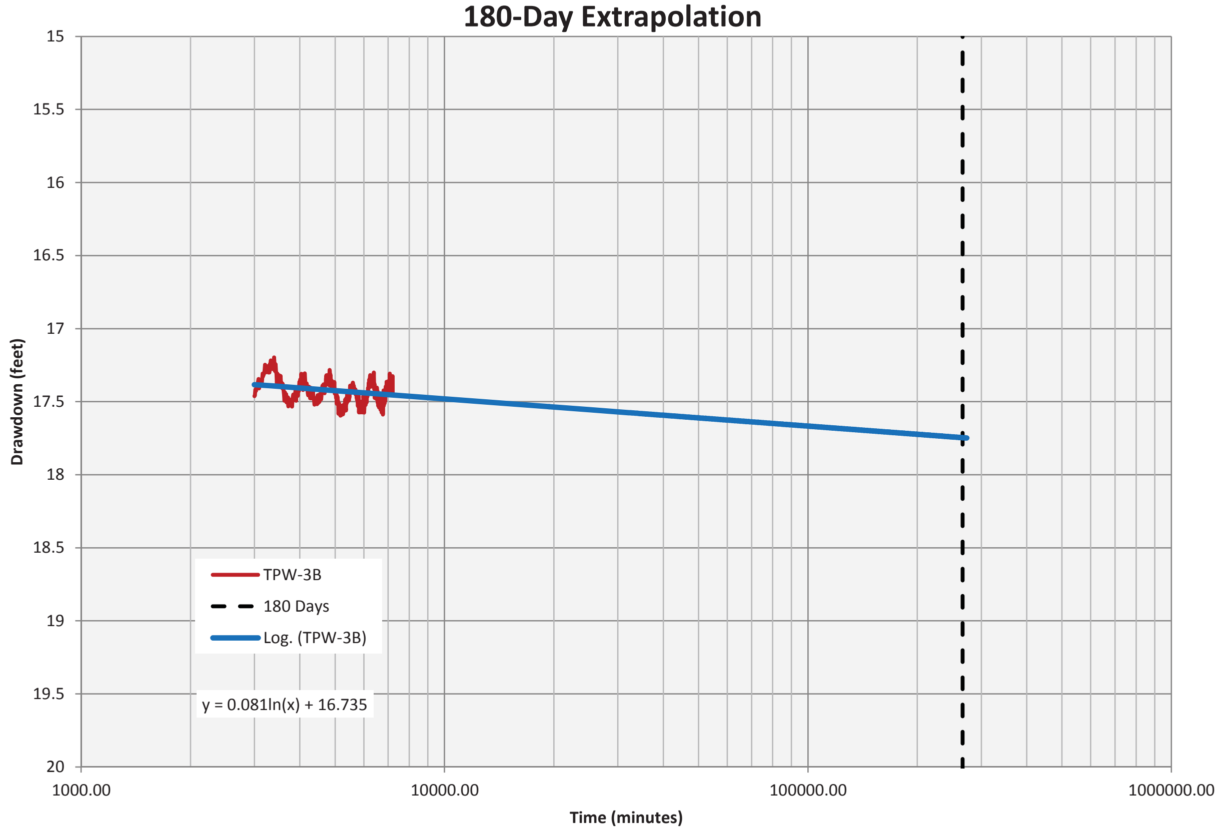


Figure 4-7: TPW-3B Pumping Test Last 70 hours 180-Day Extrapolation



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			Scale	1"=200' (11X17)
			Date	
			Job No.	
			Designed by	NMA
			Drawn by	NMA
			Checked by	AMP
			Approved by	MNW

TPW-3B Pump test: Zone B
Pre-Test Water Level Elevation Map
(December 5-6, 2010)

DISTRICT H
NAUSET ROAD
EASTHAM, MA

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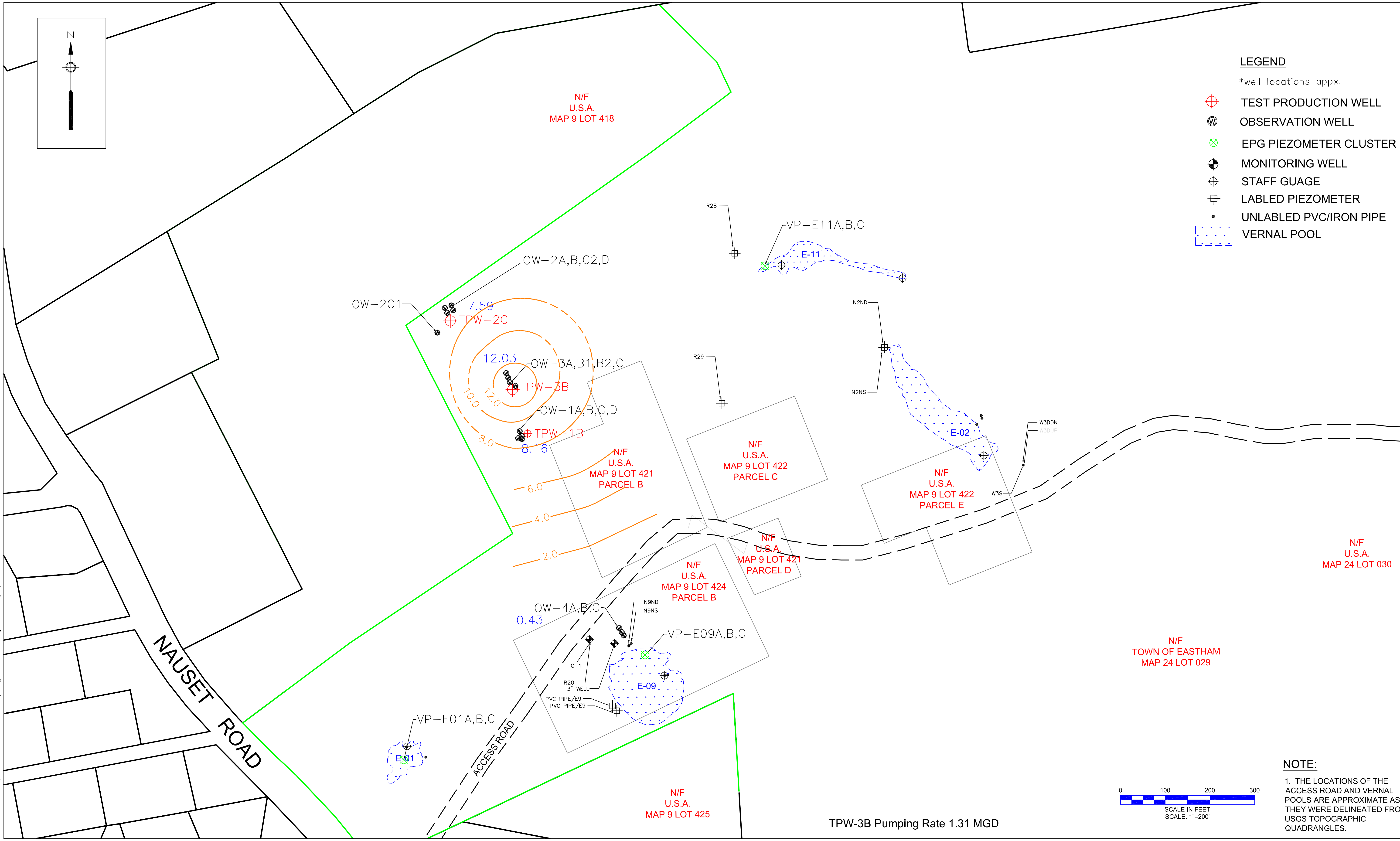
Sheet No.

Figure 4-8



Drawing file: k\Eastham_217\217-1001 Phase 2 New Source Development\6. District H\7. Source Final Report\Figures\FIGURE 4-9.dwg Plot Date: May 03,2013-11:50am

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			Scale	1"=200' (11X17)
			Date	
			Job No.	
			Designed by	NMA
			Drawn by	NMA
			Checked by	AMP
			Approved by	MNW

TPW-3B Pump test: Zone B
End of test Drawdown Map
(December 11, 2010)

DISTRICT H
NAUSET ROAD
EASTHAM, MA

NOT FOR CONSTRUCTION

Sheet No.

Figure 4-9

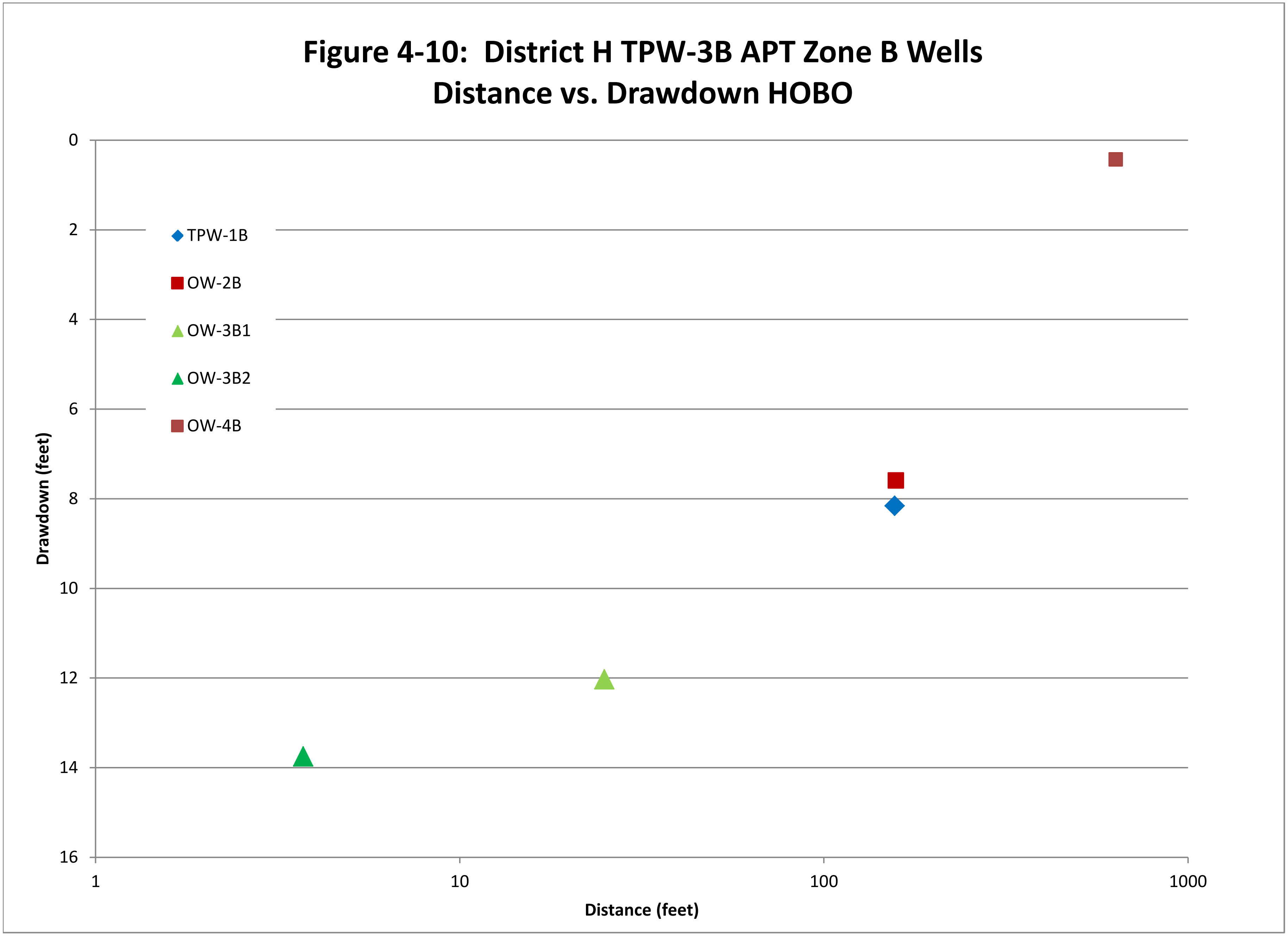
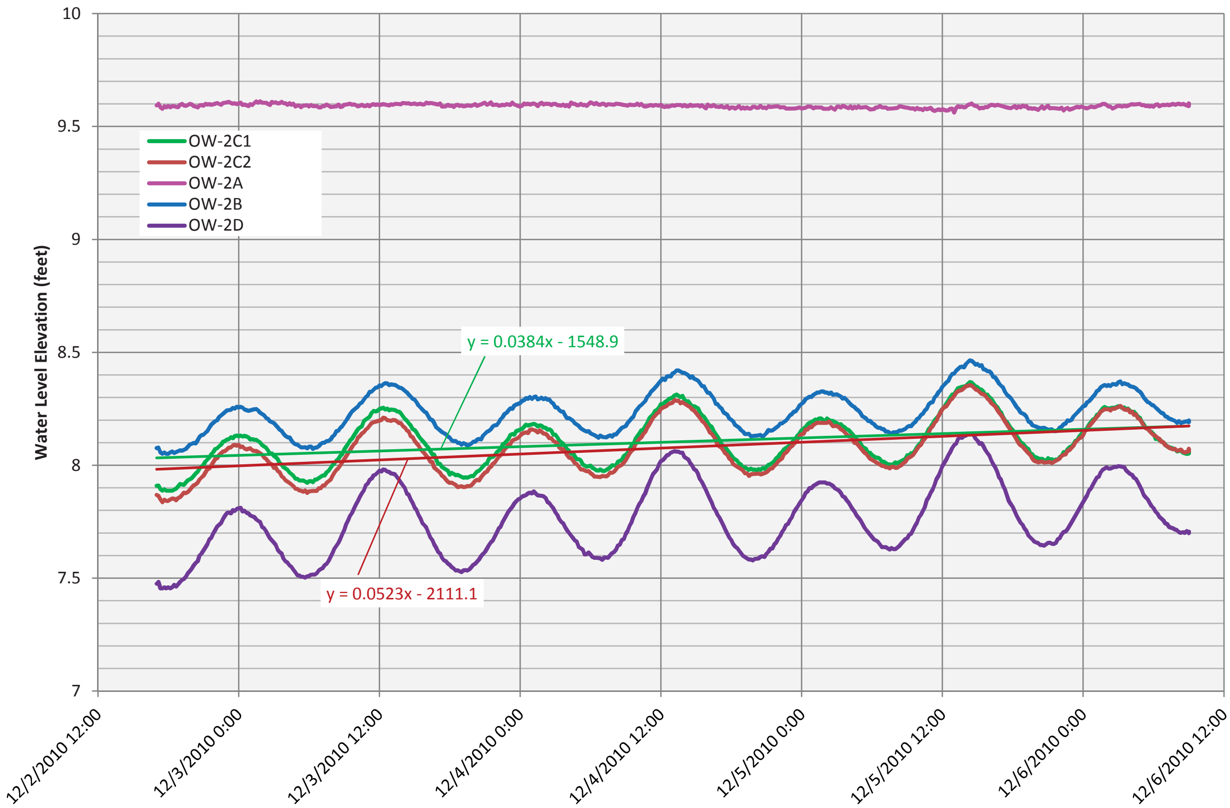


Figure 4-10: District H TPW-3B APT Zone B Wells
Distance vs. Drawdown HOBO
Drawdown (feet)
0
2
4
6
8
10
12
14
16
TPW-1B
OW-2B
OW-3B1
OW-3B2
OW-4B
1
10
100
1000
Distance (feet)

Figure 4-11: OW-2 Cluster Wells Pre-Pump Tests Water Levels
December 2-6, 2010



OW-2C1 Pre-Pump Tests WAter Levels
December 2-6, 2010

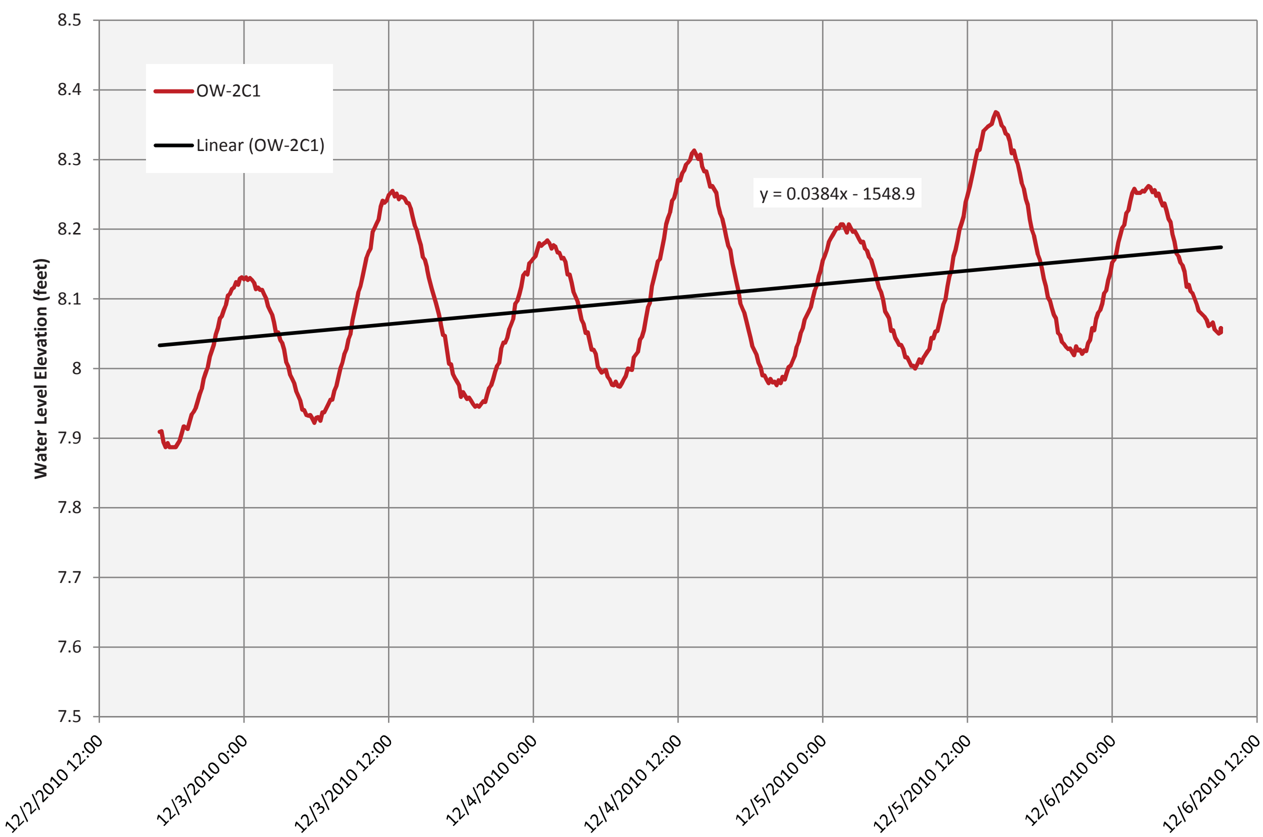


Figure 4-12: TPW-2C Pumping Test OW-2 Cluster Drawdown vs. Time

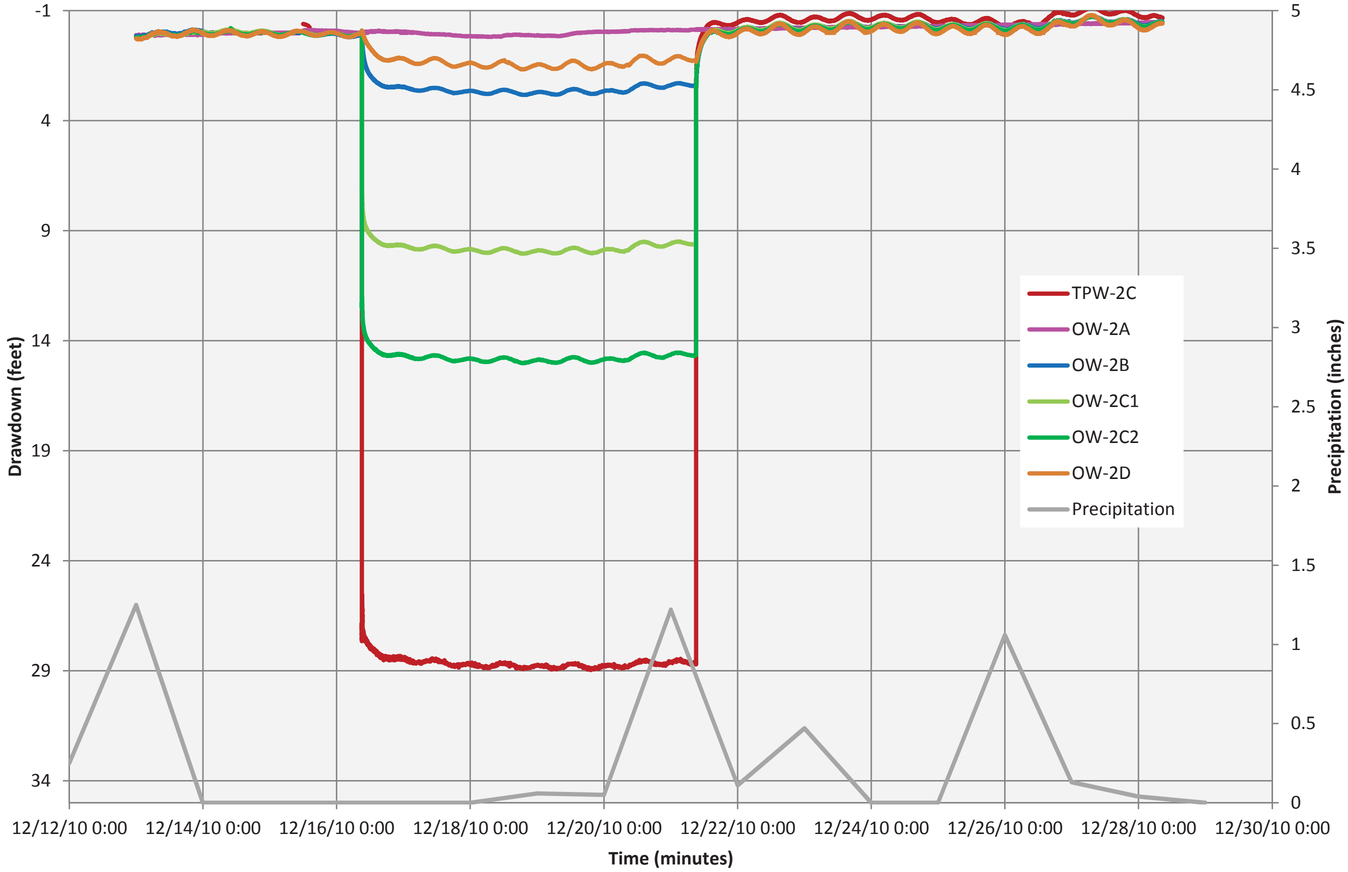


Figure 4-13: TPW-2C Pumping Test Zone C Wells Drawdown vs. Time

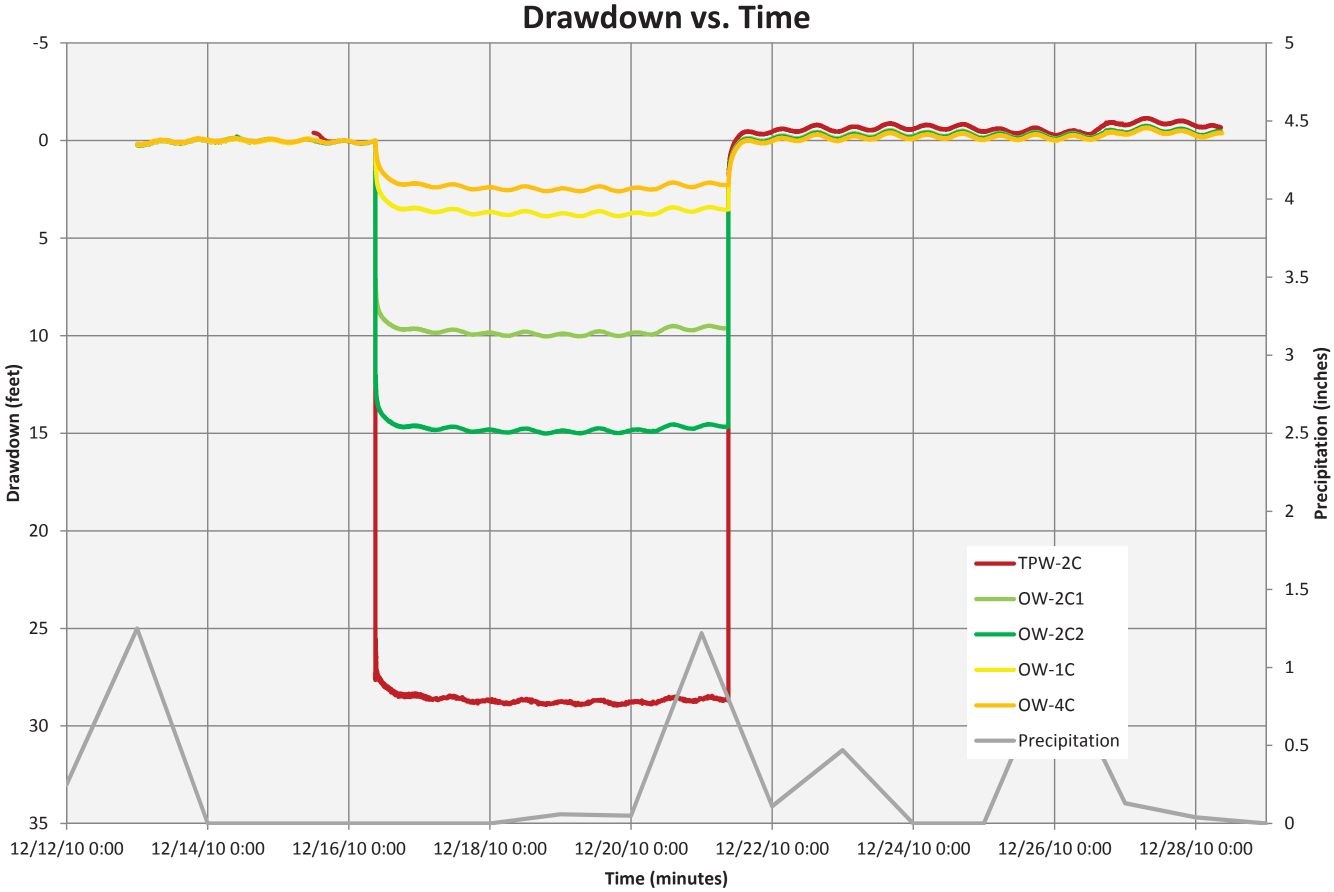


Figure 4-14: TPW-2C Pumping Test OW-2 Cluster
Drawdown vs. Time

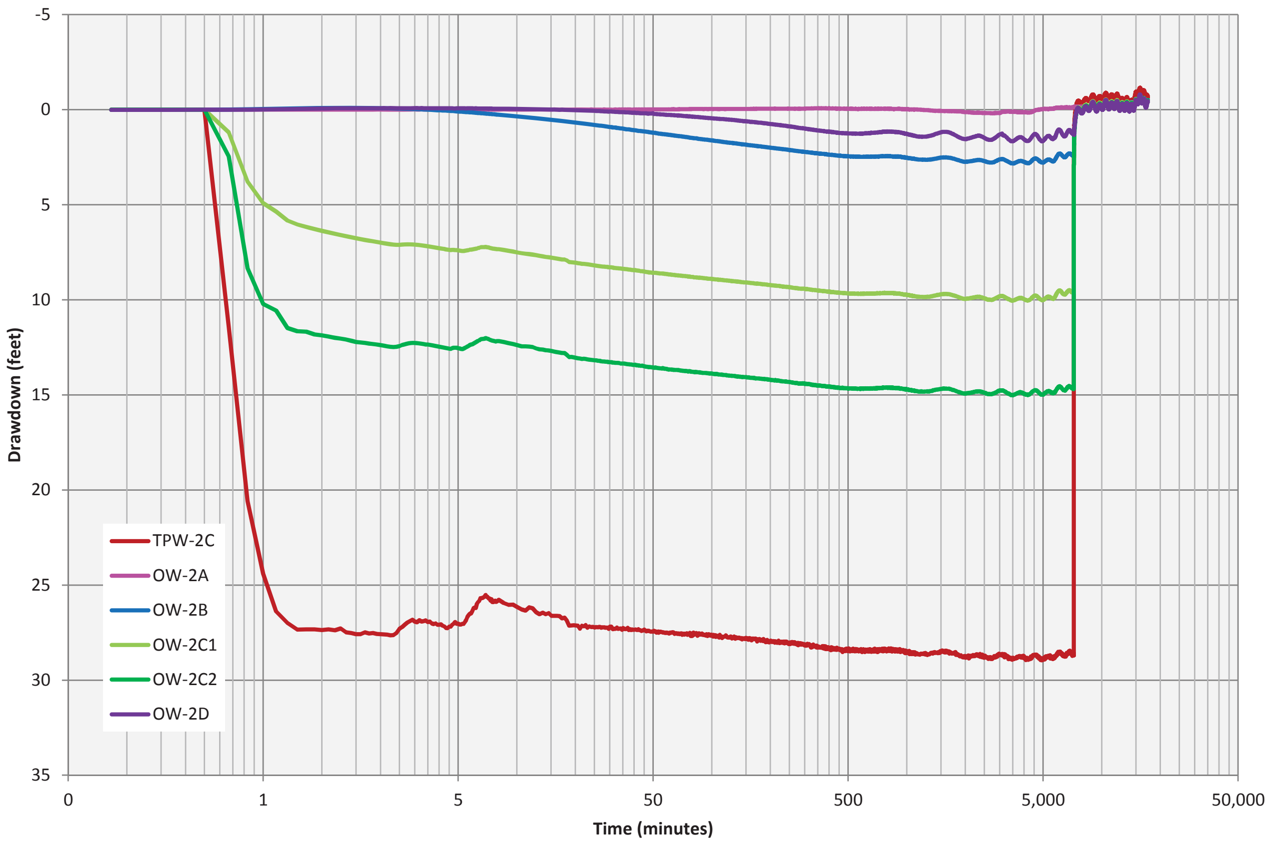


Figure 4-15: TPW-2C Pumping Test Zone C Wells
Drawdown vs. Time

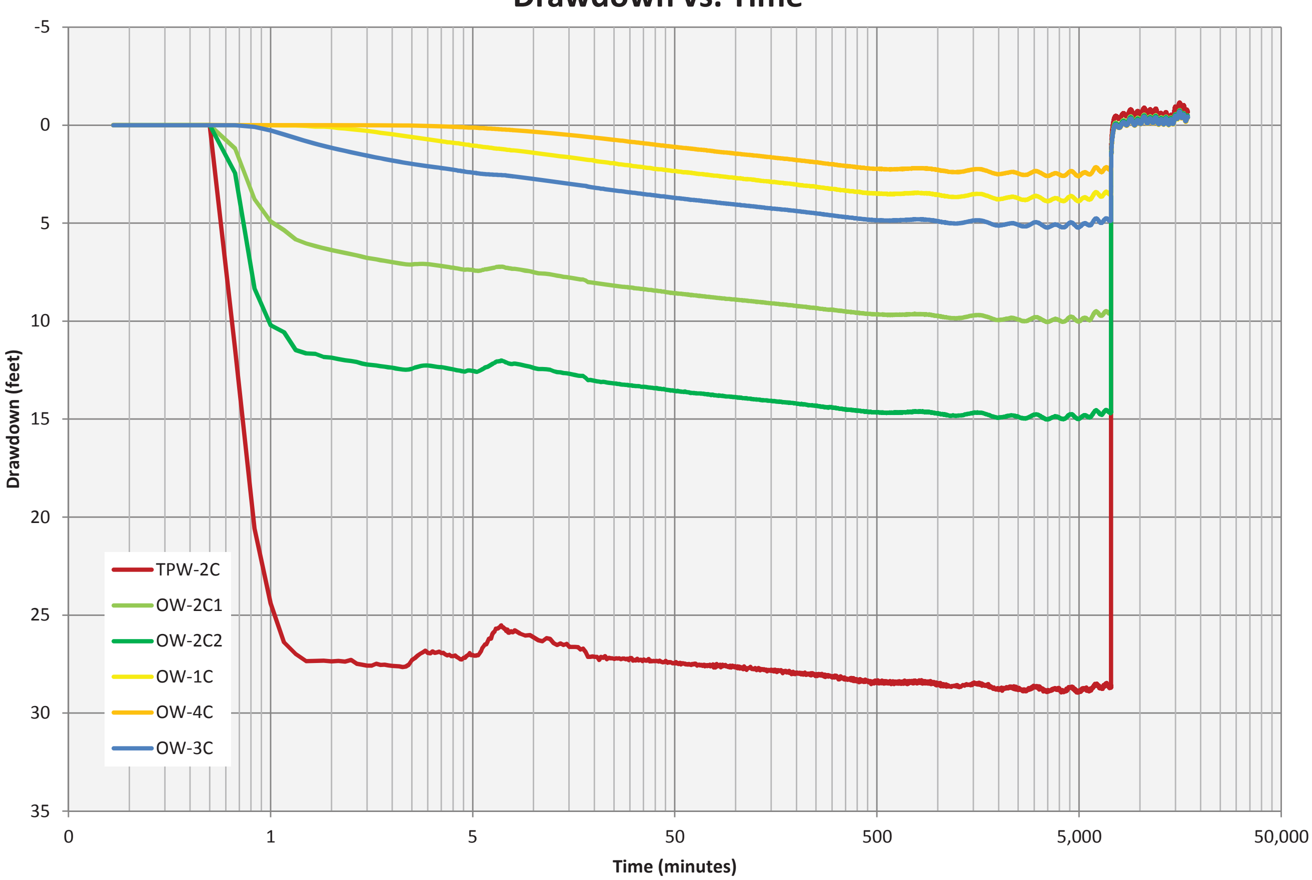


Figure 4-16: TPW-2C Pumping Test - Last 48-hours

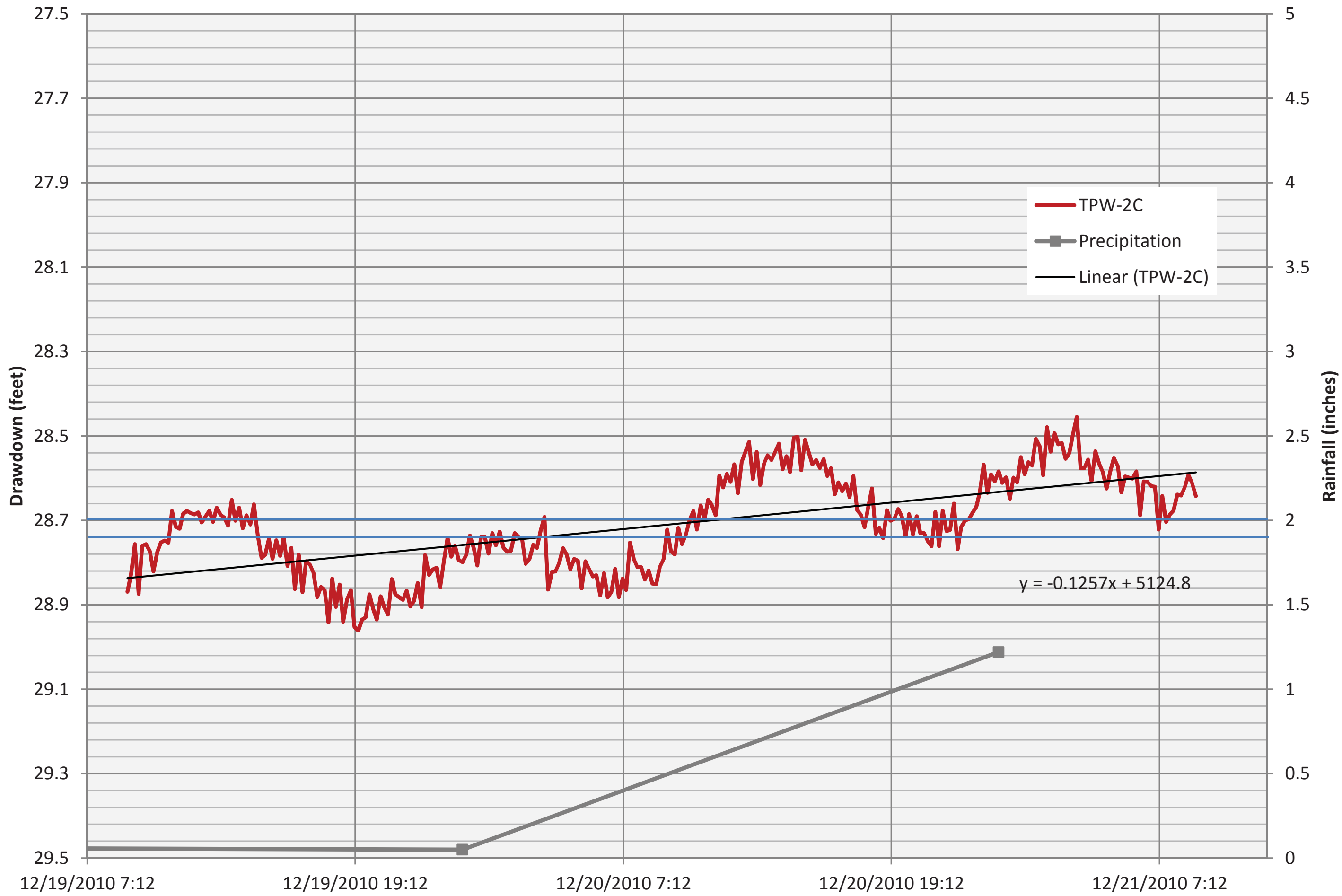
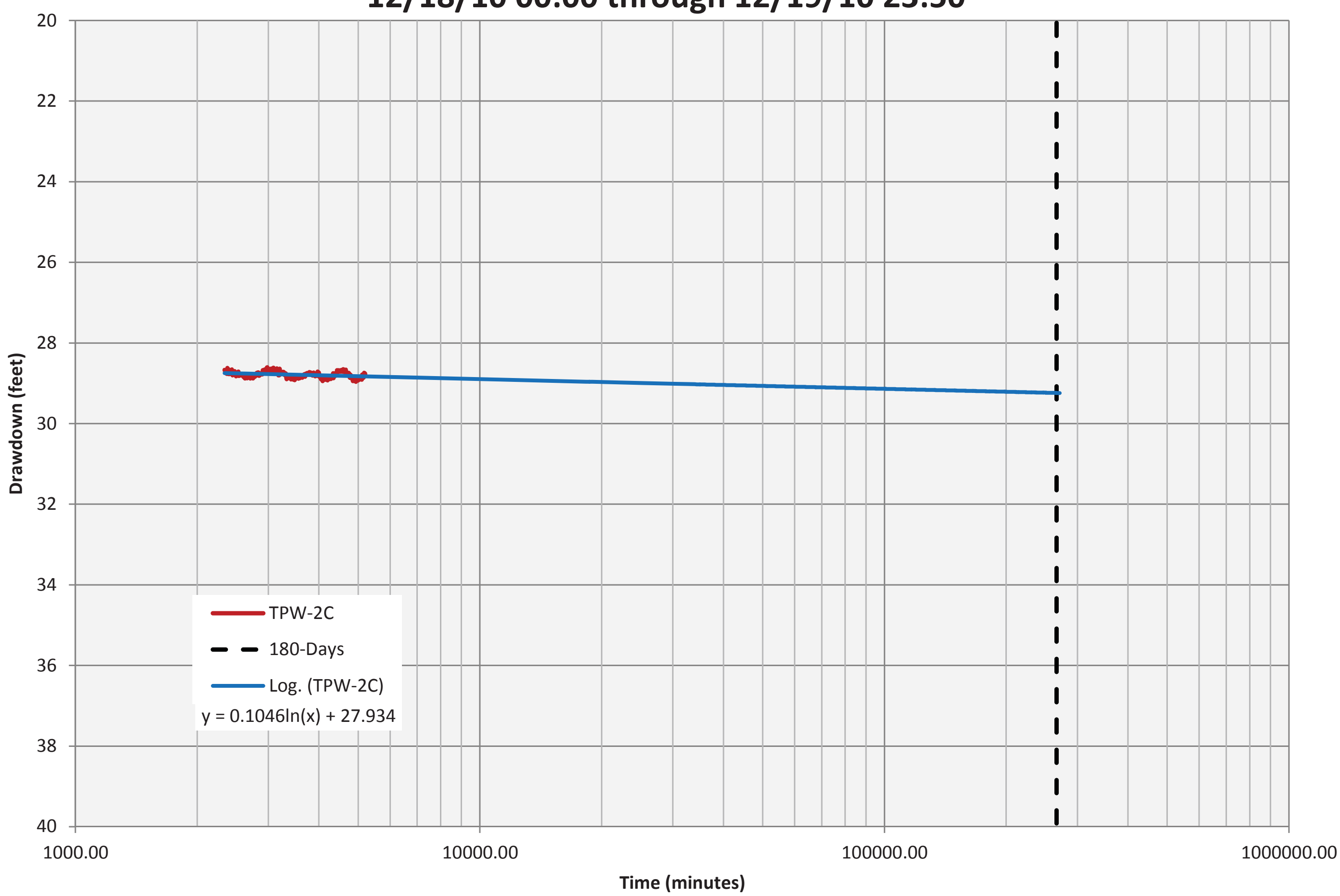


Figure 4-17: TPW-2C Pumping Test 180-Day Extrapolation 12/18/10 00:00 through 12/19/10 23:50



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			Drawn by	NMA
			Checked by	AMP
			Approved by	MNW

TPW-2C Pump test: Zone C
Pre-Test Water Level Elevation Map
(December 15-16, 2010)

DISTRICT H
NAUSET ROAD
EASTHAM, MA

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Figure 4-18

NOTE:

1. THE LOCATIONS OF THE ACCESS ROAD AND VERNAL POOLS ARE APPROXIMATE AS THEY WERE DELINEATED FROM USGS TOPOGRAPHIC QUADRANGLES.

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TPW-2C Pump Test: Zone C
End of test Drawdown Map
(December 22, 2010)

DISTRICT H
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EASTHAM, MA

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Figure 4-19

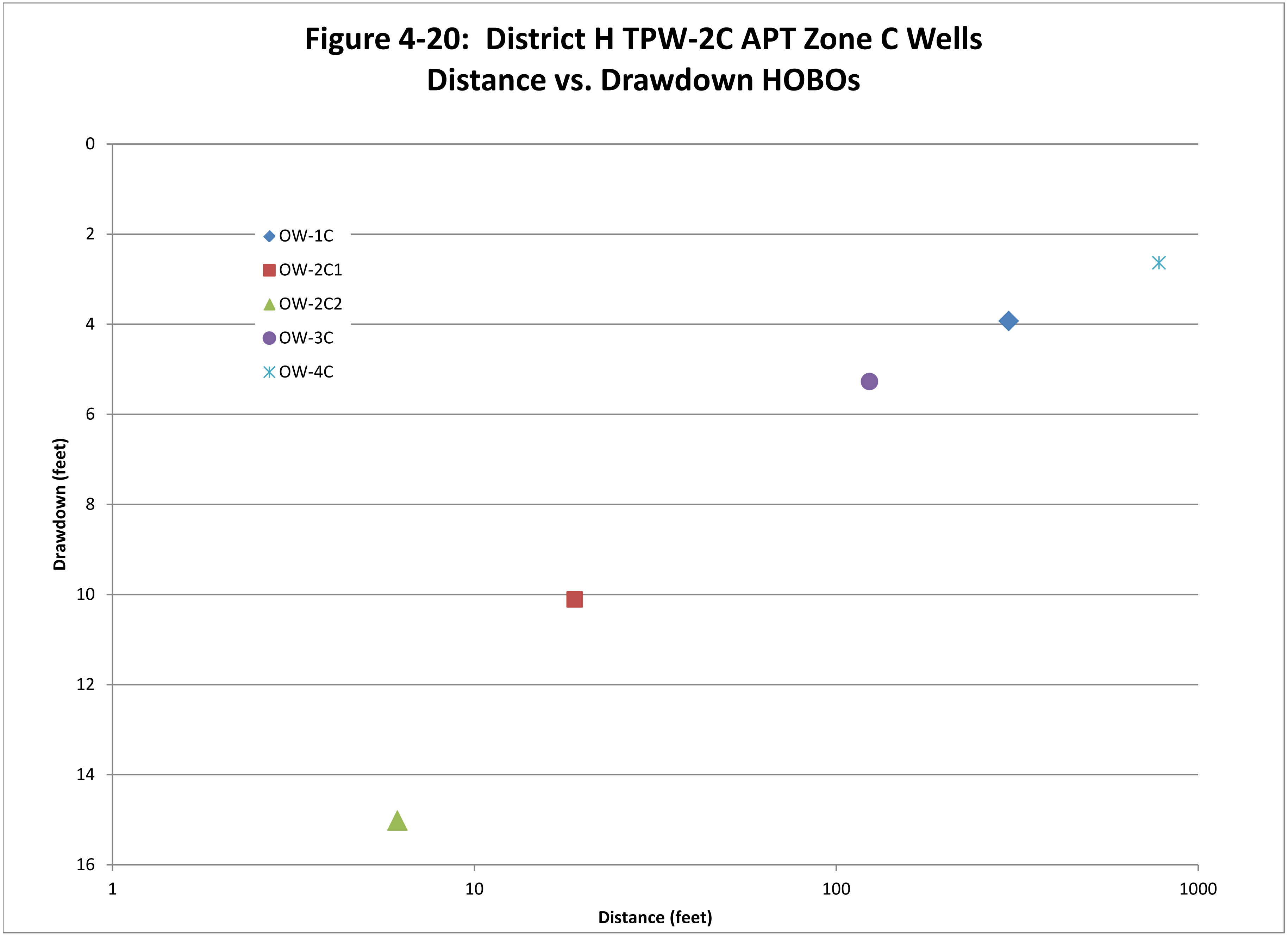


Figure 4-20: District H TPW-2C APT Zone C Wells
Distance vs. Drawdown HOBOs
0
2
4
6
8
10
12
14
16
Drawdown (feet)
OW-1C
OW-2C1
OW-2C2
OW-3C
OW-4C
1
10
100
1000
Distance (feet)

Figure 4-21: Combined Pump Test - Zone B Wells
Background Water Levels

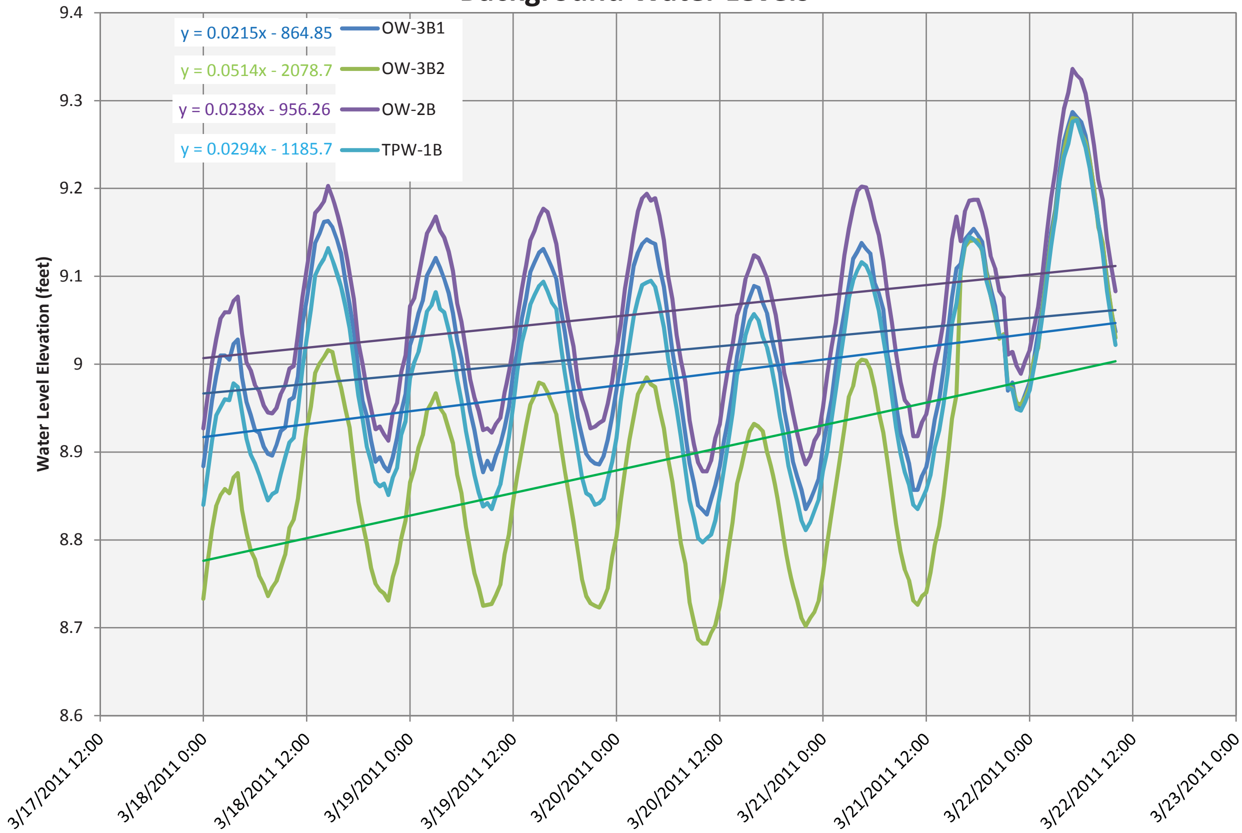


Figure 4-22: Combined Pump Test - Zone C Wells
Background Water Levels

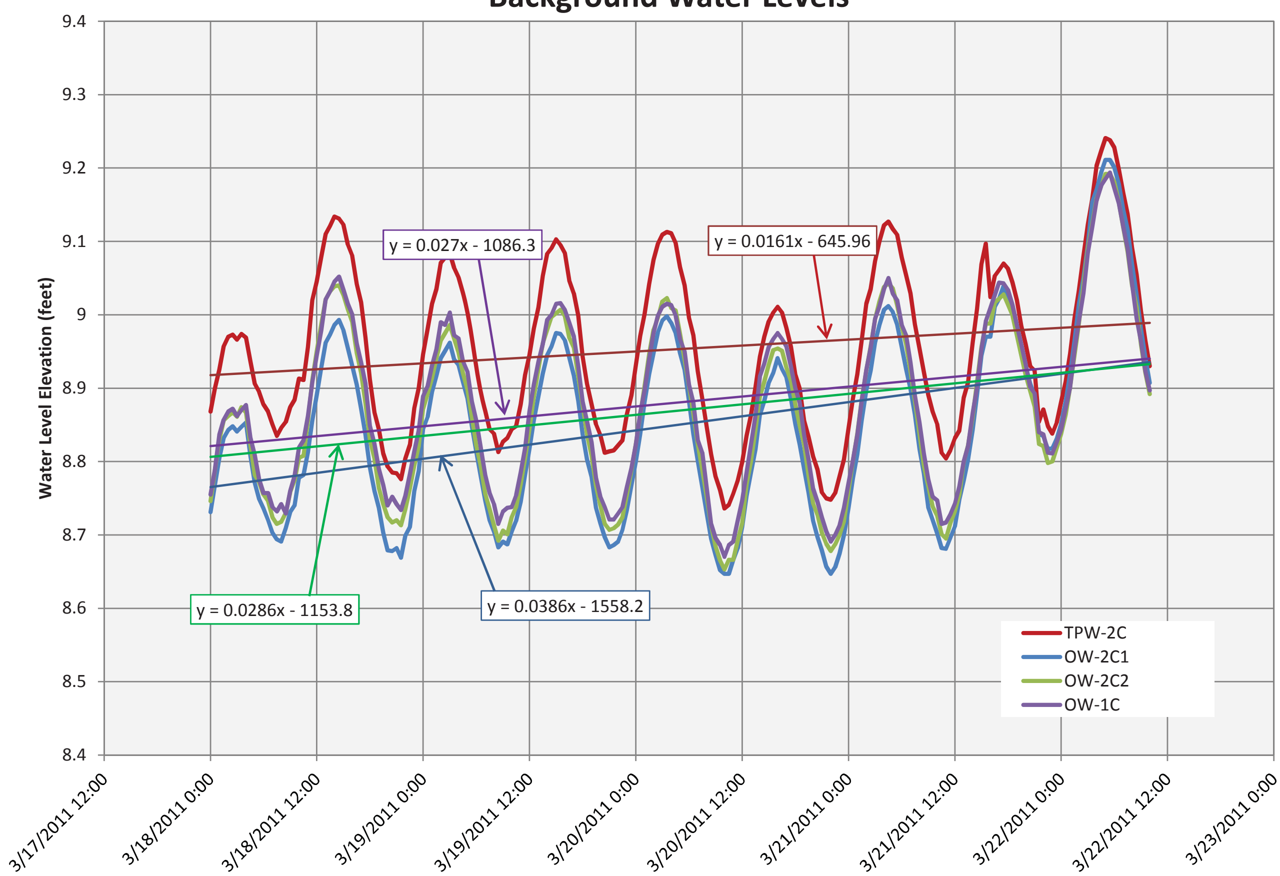


Figure 4-23: Combined APT - OW-3 Cluster Wells
Drawdown vs. Time

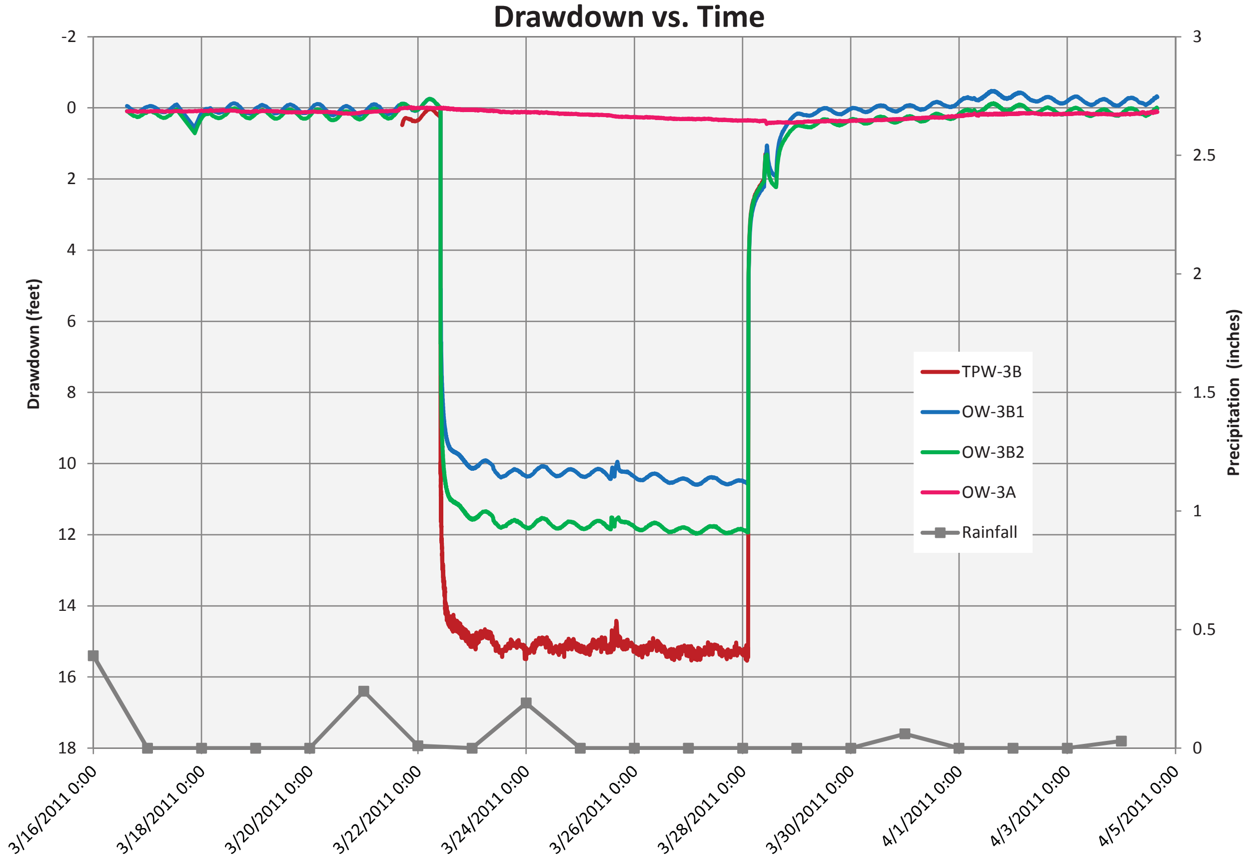


Figure 4-24: Combined APT Zone B Wells
Drawdown vs. Time

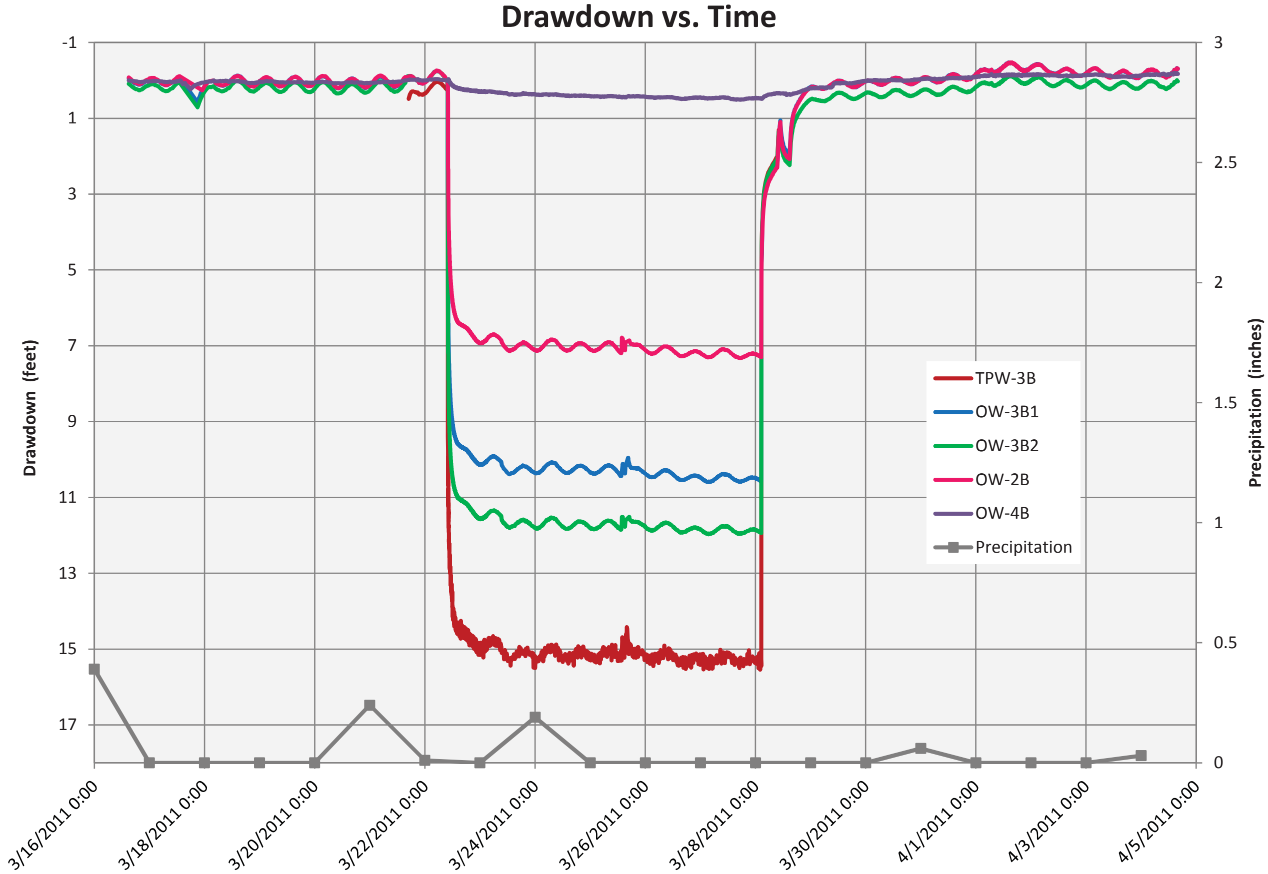


Figure 4-25: Combined APT TPW-3B and OW-3 Cluster Wells Drawdown vs. Time

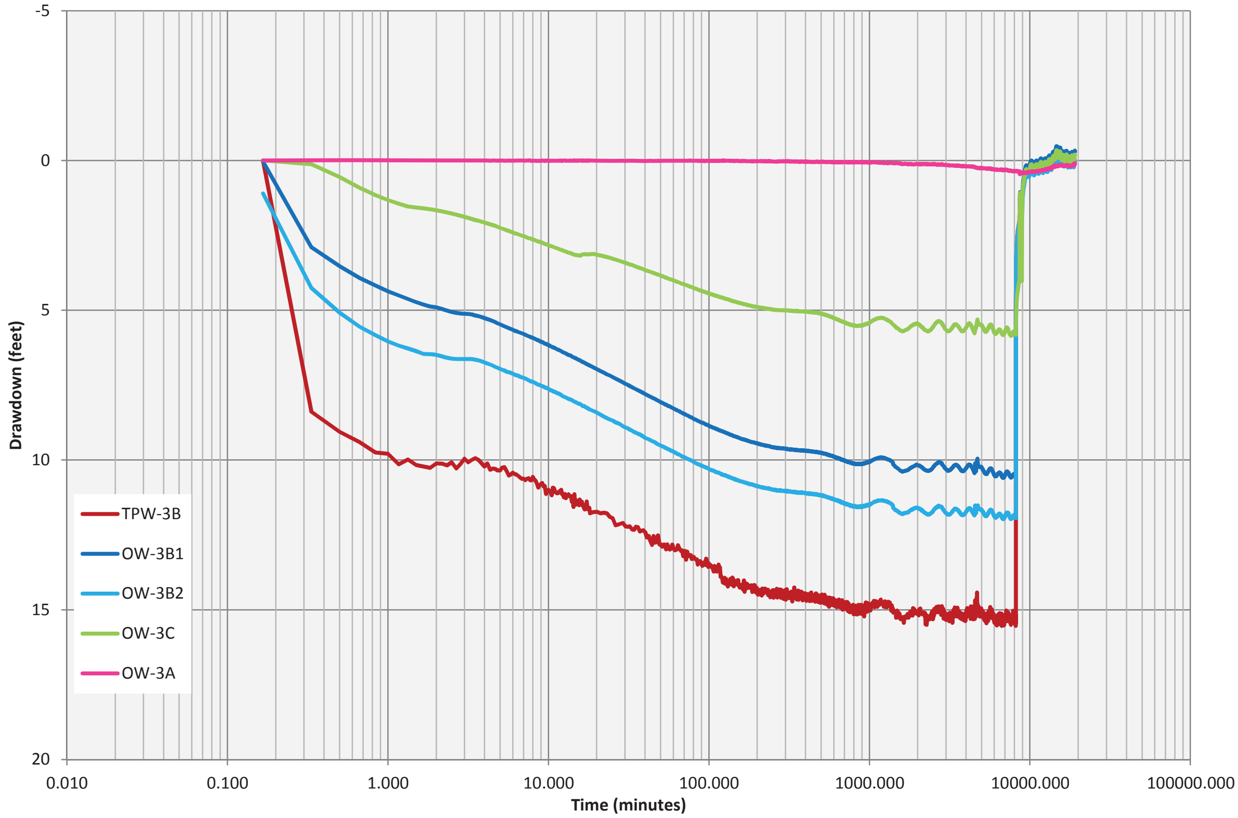


Figure 4-26: Combined APT TPW-3B and OW-3 Cluster Wells Drawdown vs. Time

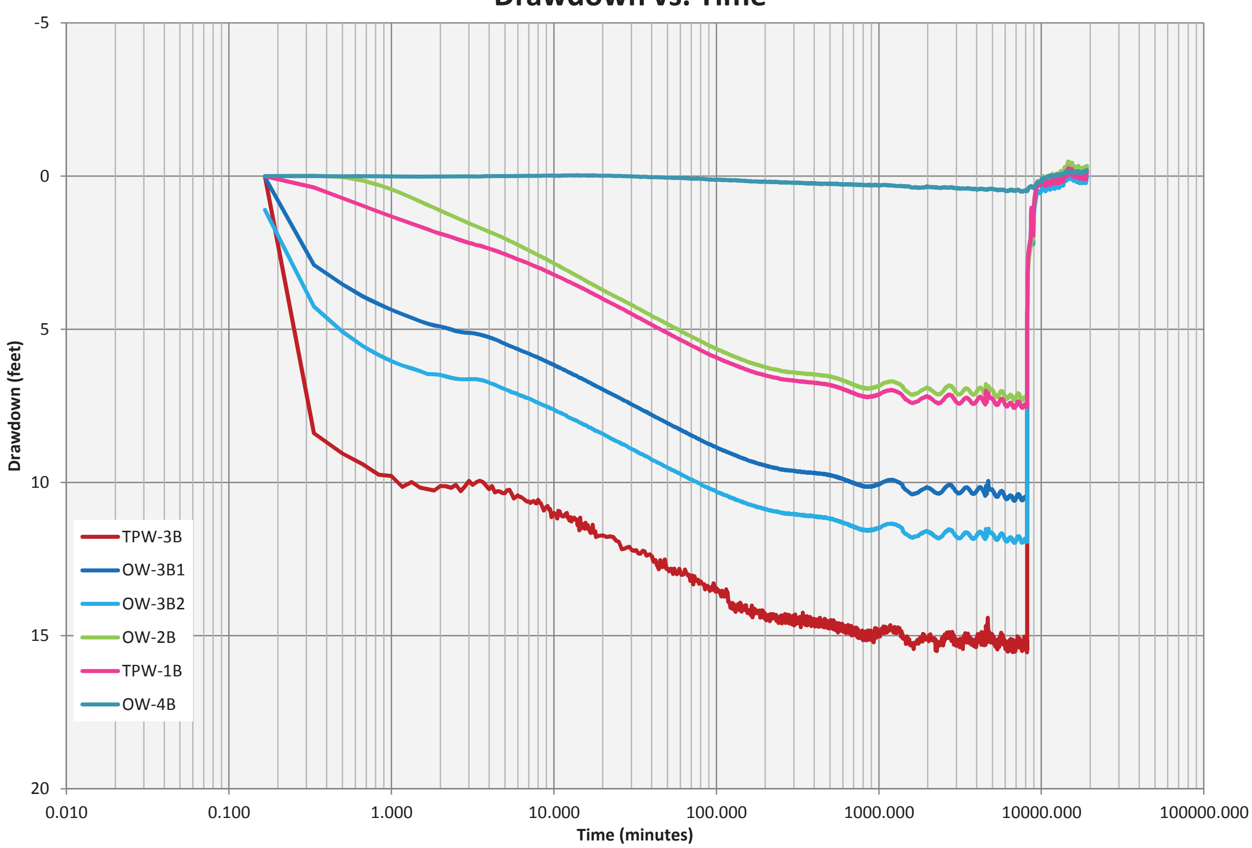


Figure 4-27: Combined APT - OW-2 Cluster Wells Drawdown vs. Time

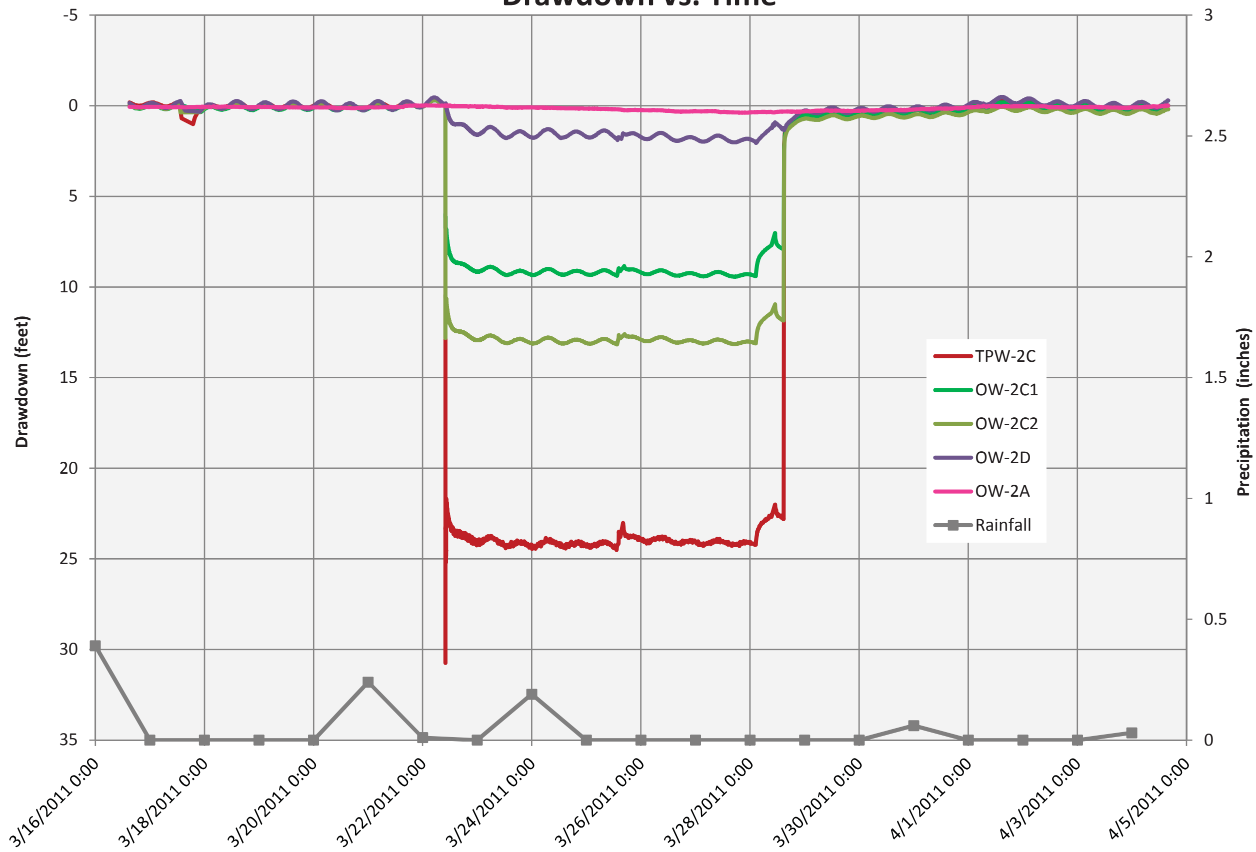


Figure 4-28: Combined APT - Zone C Wells Drawdown vs. Time

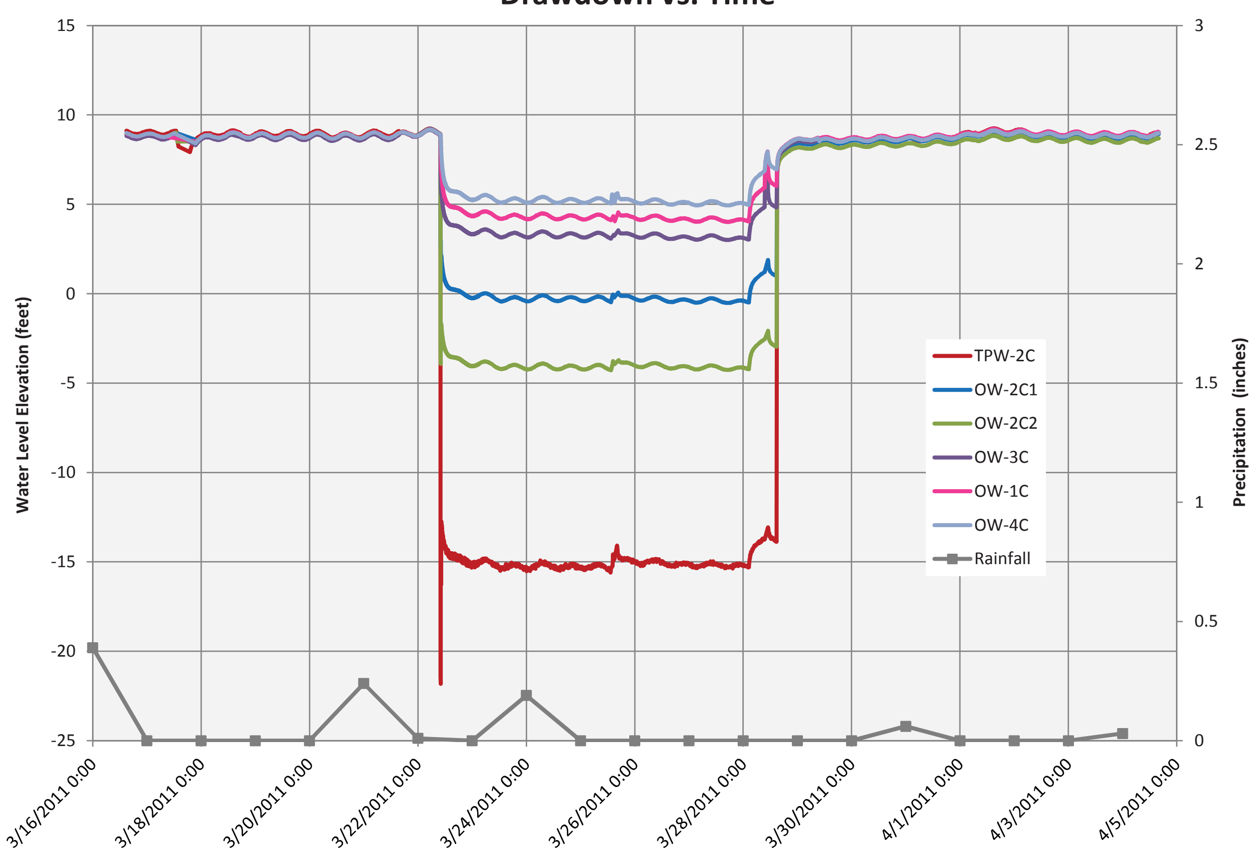


Figure 4-29: Combined APT TPW-2C and OW-2 Cluster Wells Drawdown vs. Time

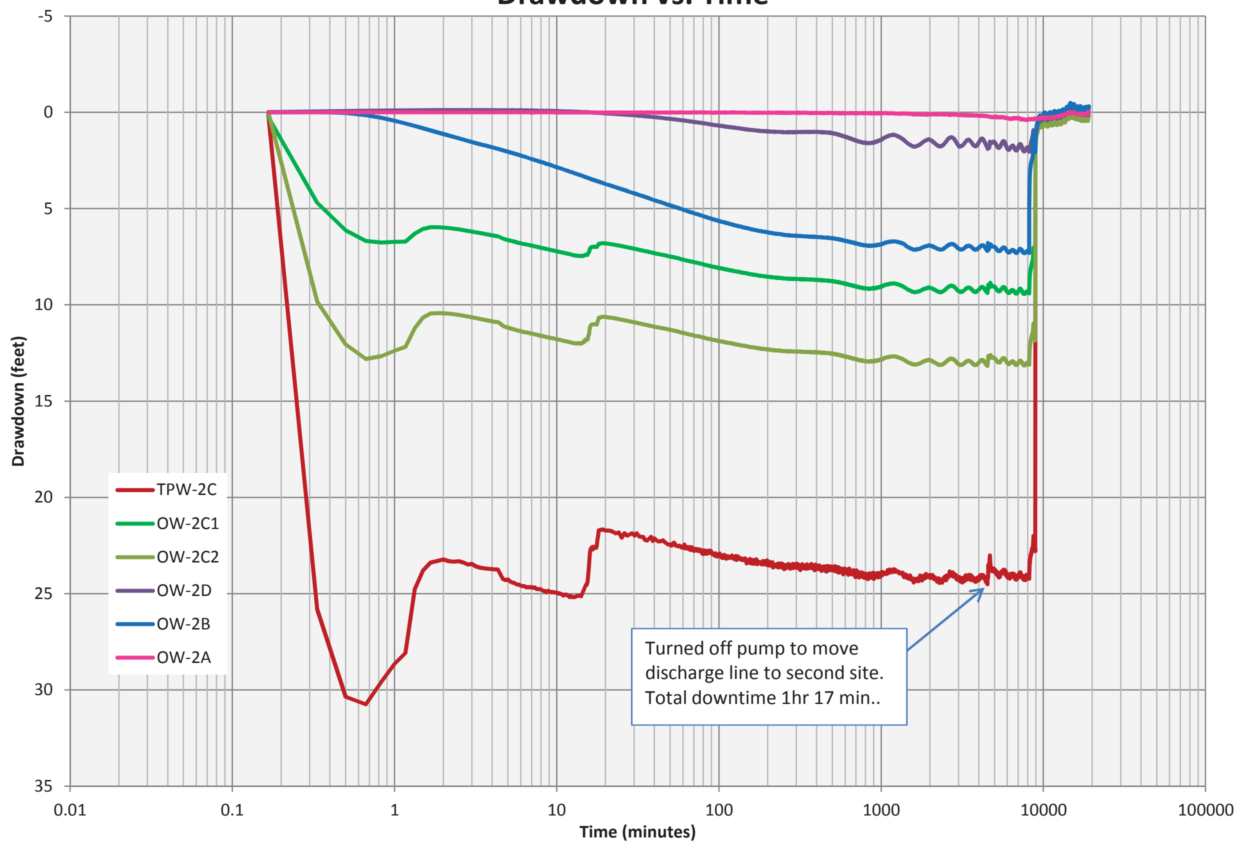


Figure 4-30: Combined APT Zone C Cluster Wells Drawdown vs. Time

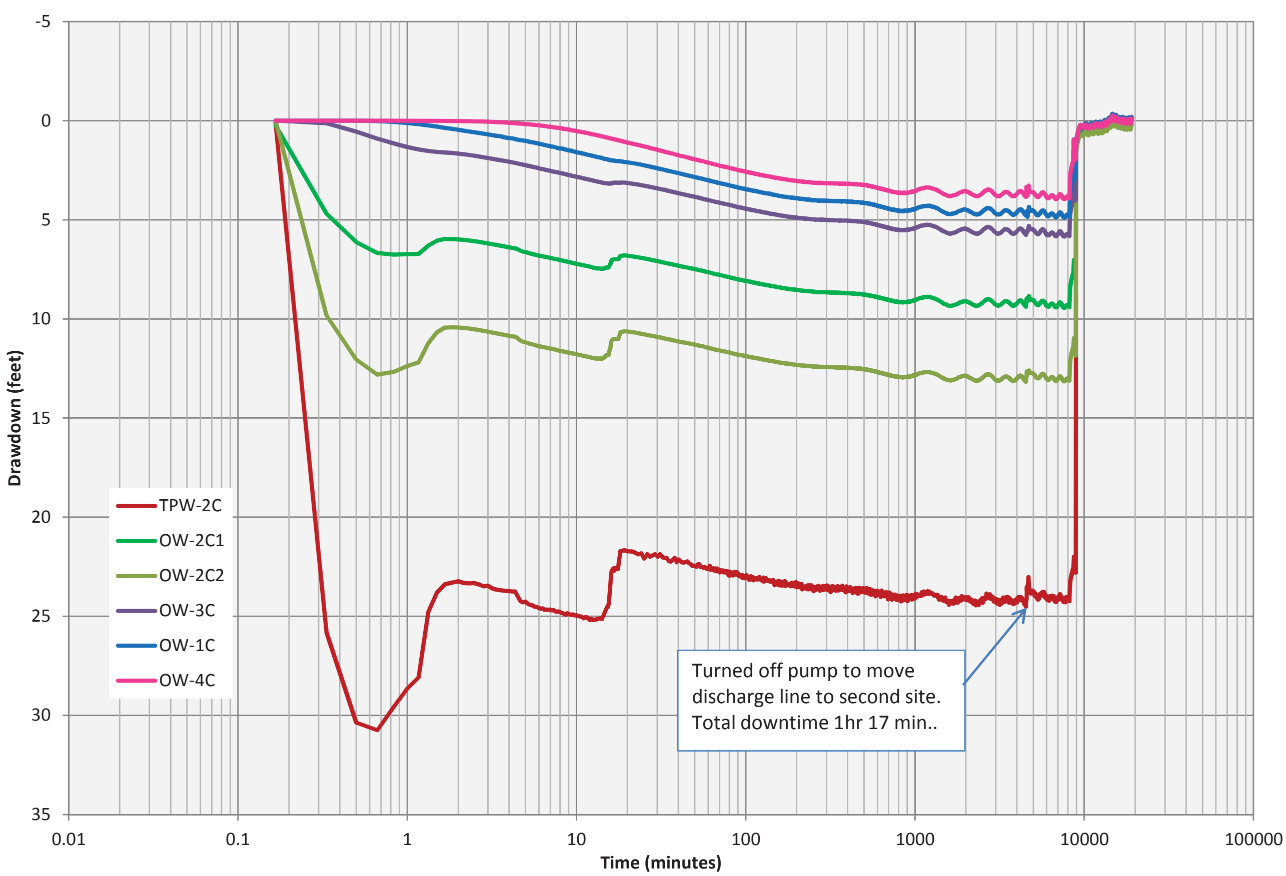


Figure 4-31: Combined APT - TPW-3B Last 30 hours
Drawdown vs. Time

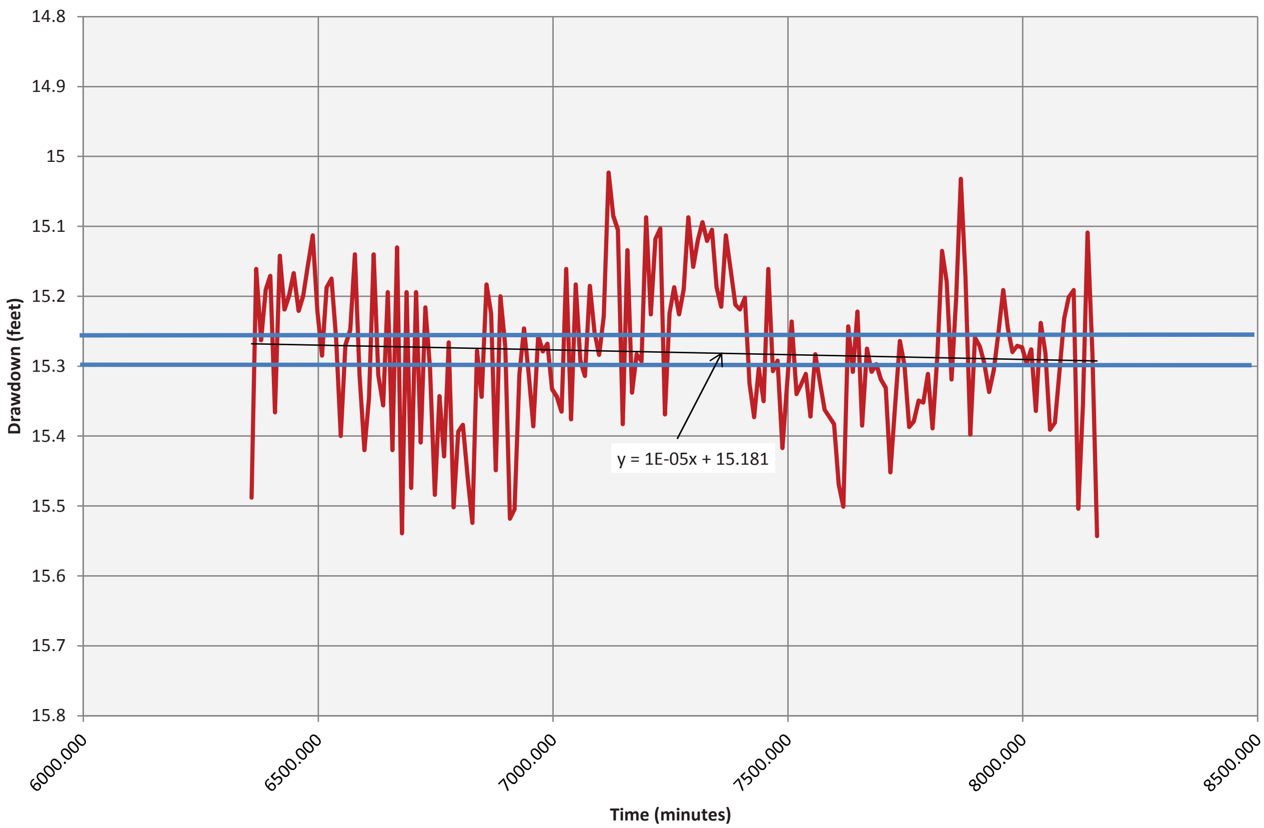


Figure 4-32: Combined APT - TPW-3B Last 30 hours
Drawdown vs. Time

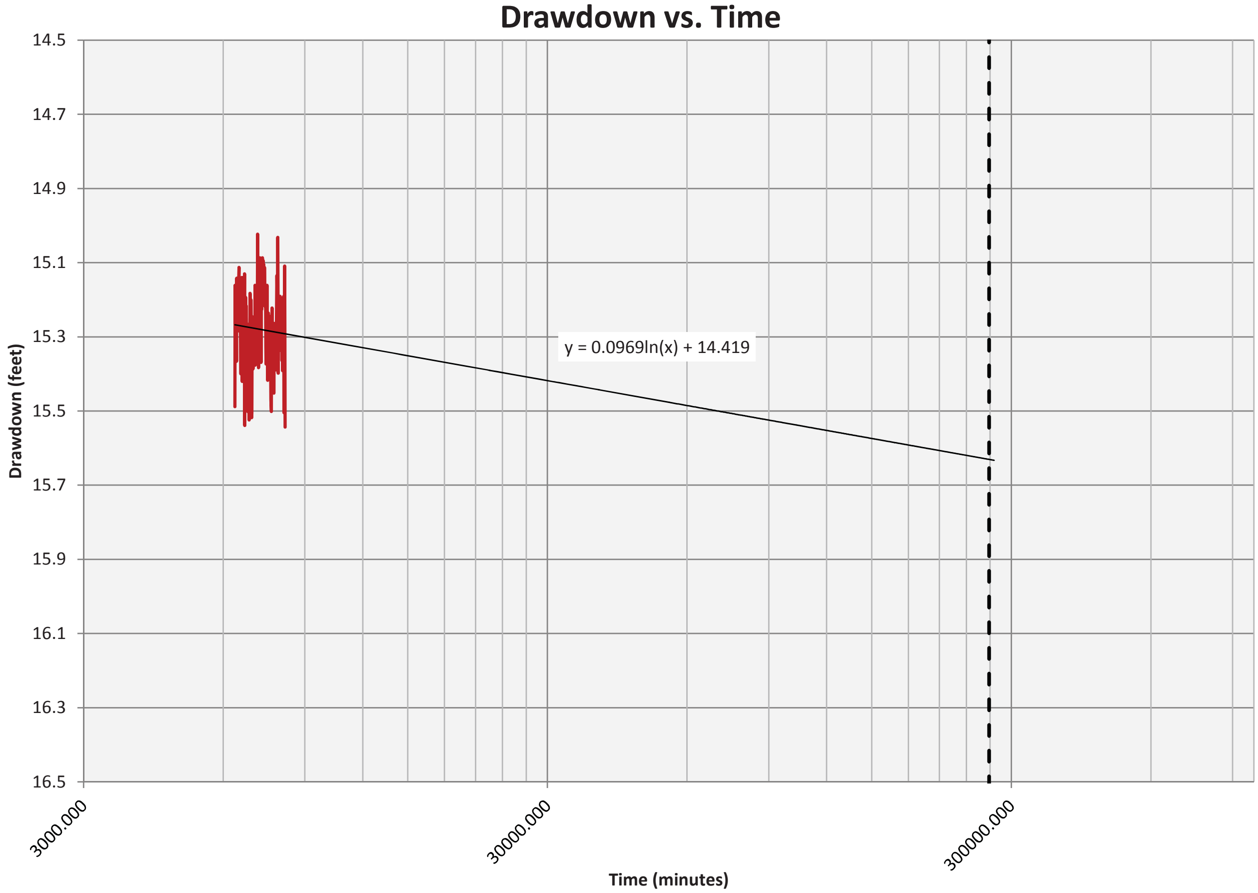


Figure 4-33: Combined APT - TPW-2C Last 30 hours Drawdown vs. Time

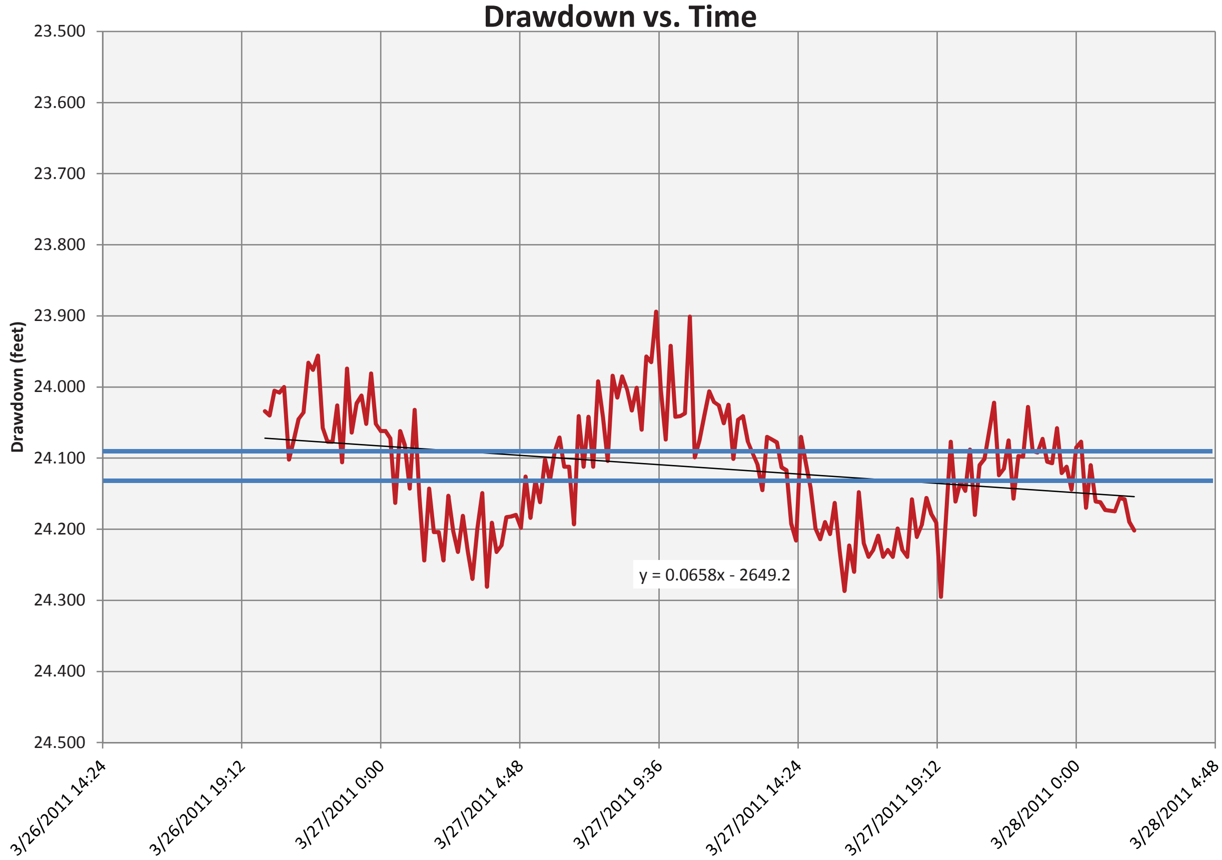
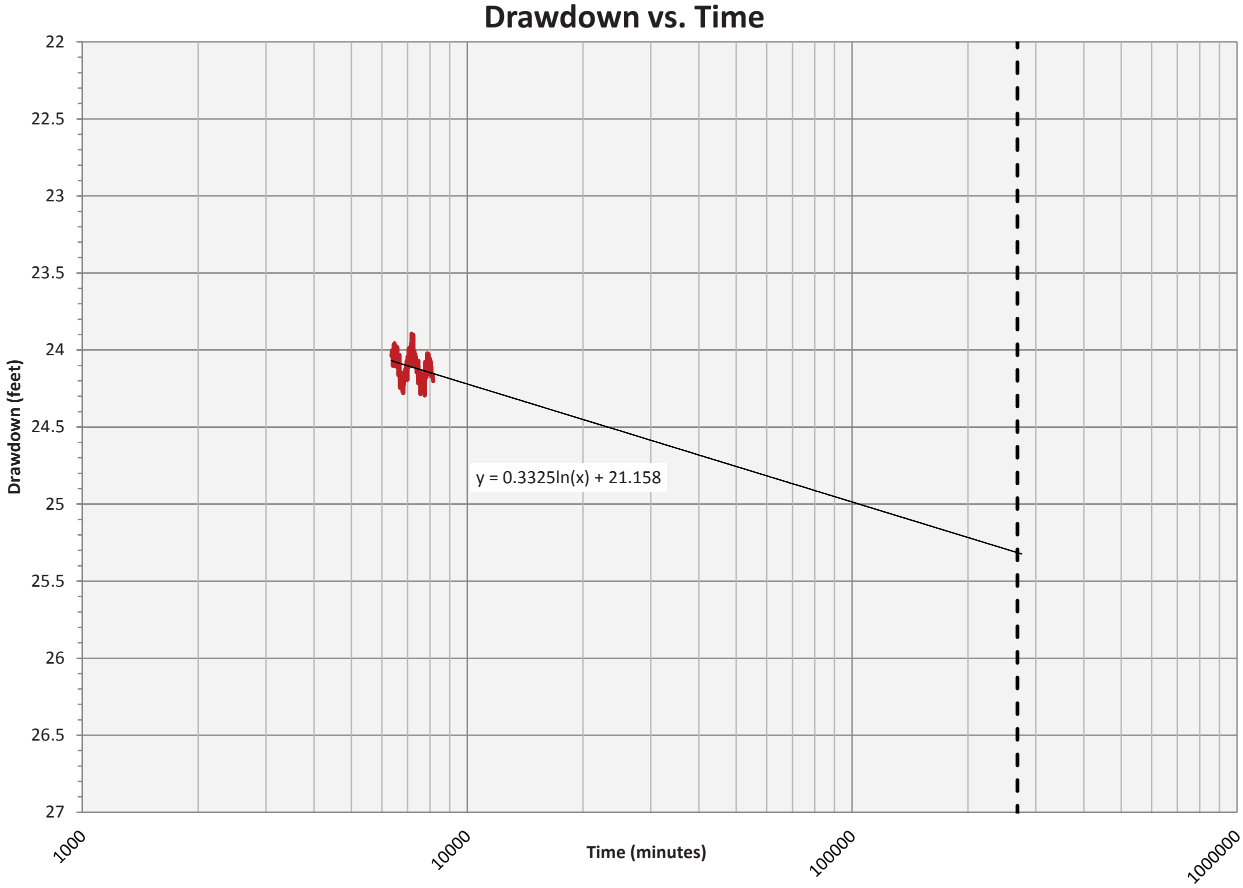


Figure 4-34: Combined APT - TPW-2C Last 30 hours Drawdown vs. Time



Drawing file: I:\Eastham.217\217-1001 Phase 2 New Source Development\6. District H\7. Source Final Report\Figures\FIGURE 4-35.dwg Plot Date: May 03,2013-12:03pm

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Combined Pump Test: Zone B
Pre-Test Water Level Elevation Map
March 21-22, 2011

DISTRICT H
NAUSET ROAD
EASTHAM, MA

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Figure 4-35

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DISTRICT H
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EASTHAM, MA

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Figure 4-36

Drawing file: I:\Eastham.217\217-1001 Phase 2 New Source Development\6. District H\7. Source Final Report\Figures\FIGURE 4-36.dwg Plot Date: May 03,2013-12:04pm

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			Date	
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			Checked by	AMP
			Approved by	MNW

Combined Pump Test: Zone C
Pre-Test Water Level Elevation Map
March 21-22, 2011

DISTRICT H
NAUSET ROAD
EASTHAM, MA

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Sheet No.

Figure 4-37

Drawing file: I:\Eastham.217\217-1001 Phase 2 New Source Development\6. District H\7. Source Final Report\Figures\FIGURE 4-37.dwg Plot Date: May 03,2013-12:04pm

NOTE:
1. THE LOCATIONS OF THE ACCESS ROAD AND VERNAL POOLS ARE APPROXIMATE AS THEY WERE DELINEATED FROM USGS TOPOGRAPHIC QUADRANGLES.

Combined Test Pump Rates
TPW-3B 1.0 MGD and TPW-2c 1.0 MGD

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Date	
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Combined Pump Test: Zone C
End of Test Drawdown Map
March 28, 2011

DISTRICT H
NAUSET ROAD
EASTHAM, MA

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Figure 4-38

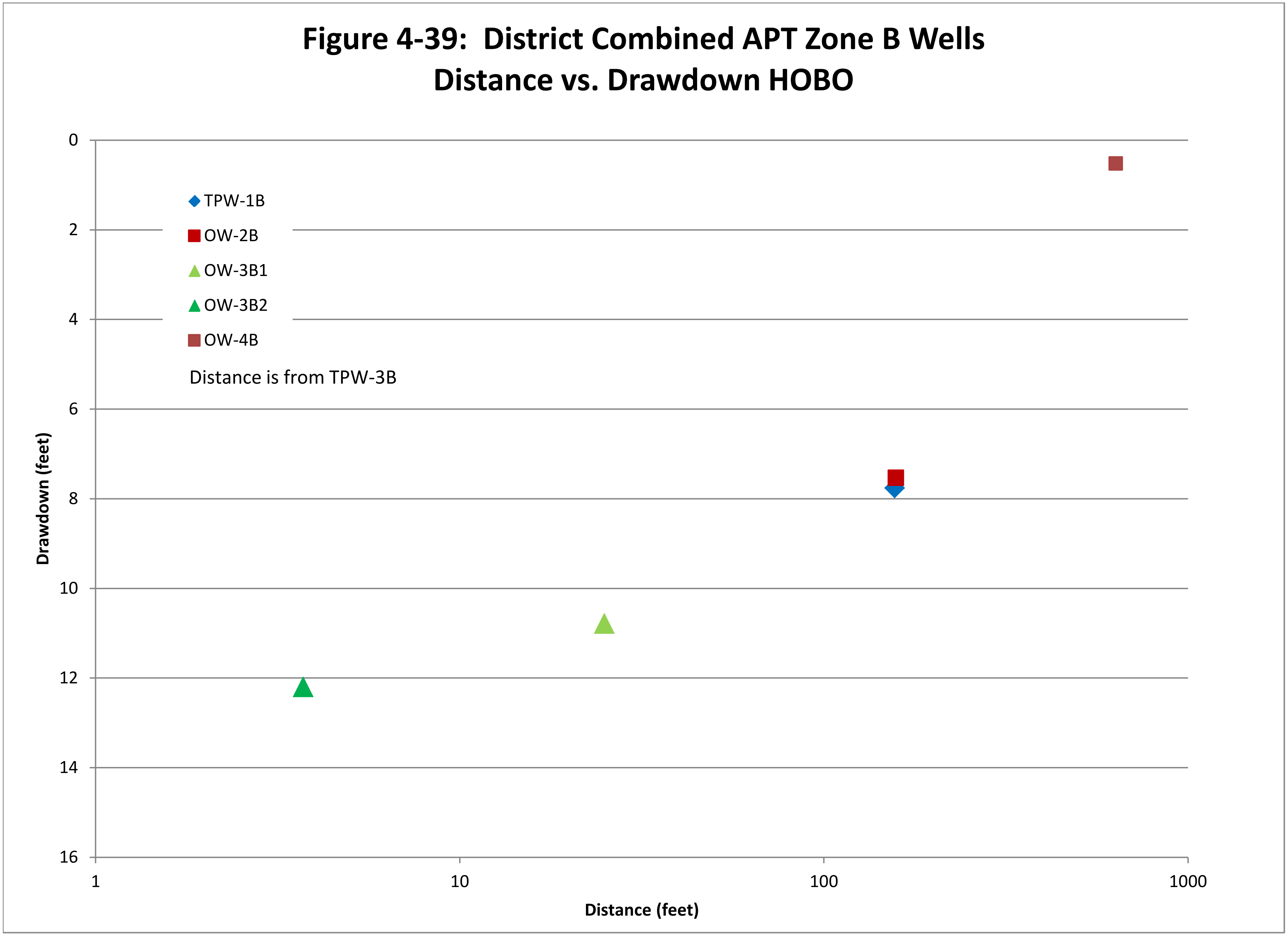


Figure 4-39: District Combined APT Zone B Wells
Distance vs. Drawdown HOBO
TPW-1B
OW-2B
OW-3B1
OW-3B2
OW-4B
Distance is from TPW-3B
Drawdown (feet)
Distance (feet)
0
2
4
6
8
10
12
14
16
1
10
100
1000

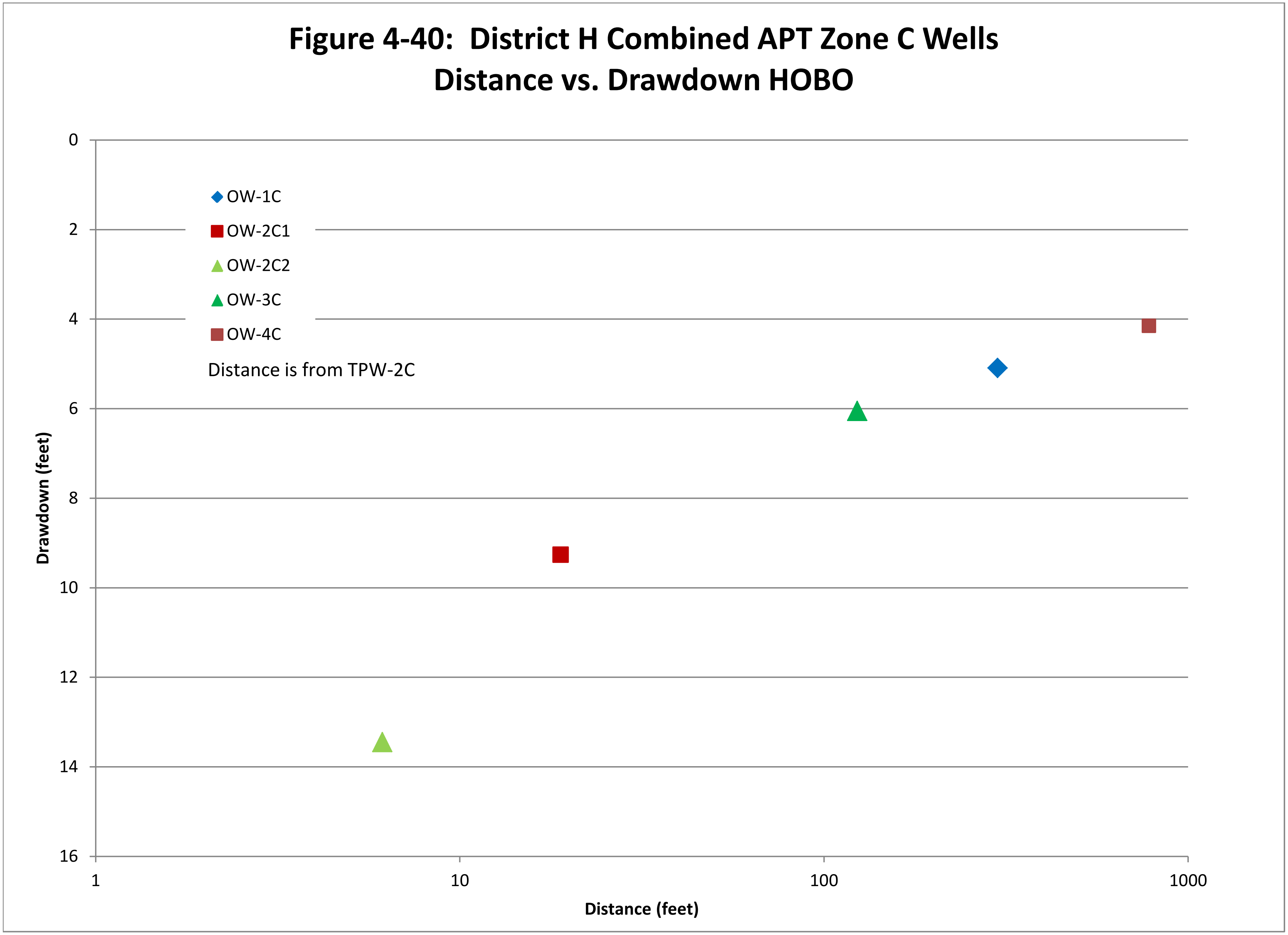


Figure 4-40: District H Combined APT Zone C Wells
Distance vs. Drawdown HOBO
OW-1C
OW-2C1
OW-2C2
OW-3C
OW-4C
Distance is from TPW-2C
Drawdown (feet)
0
2
4
6
8
10
12
14
16
1
10
100
1000
Distance (feet)

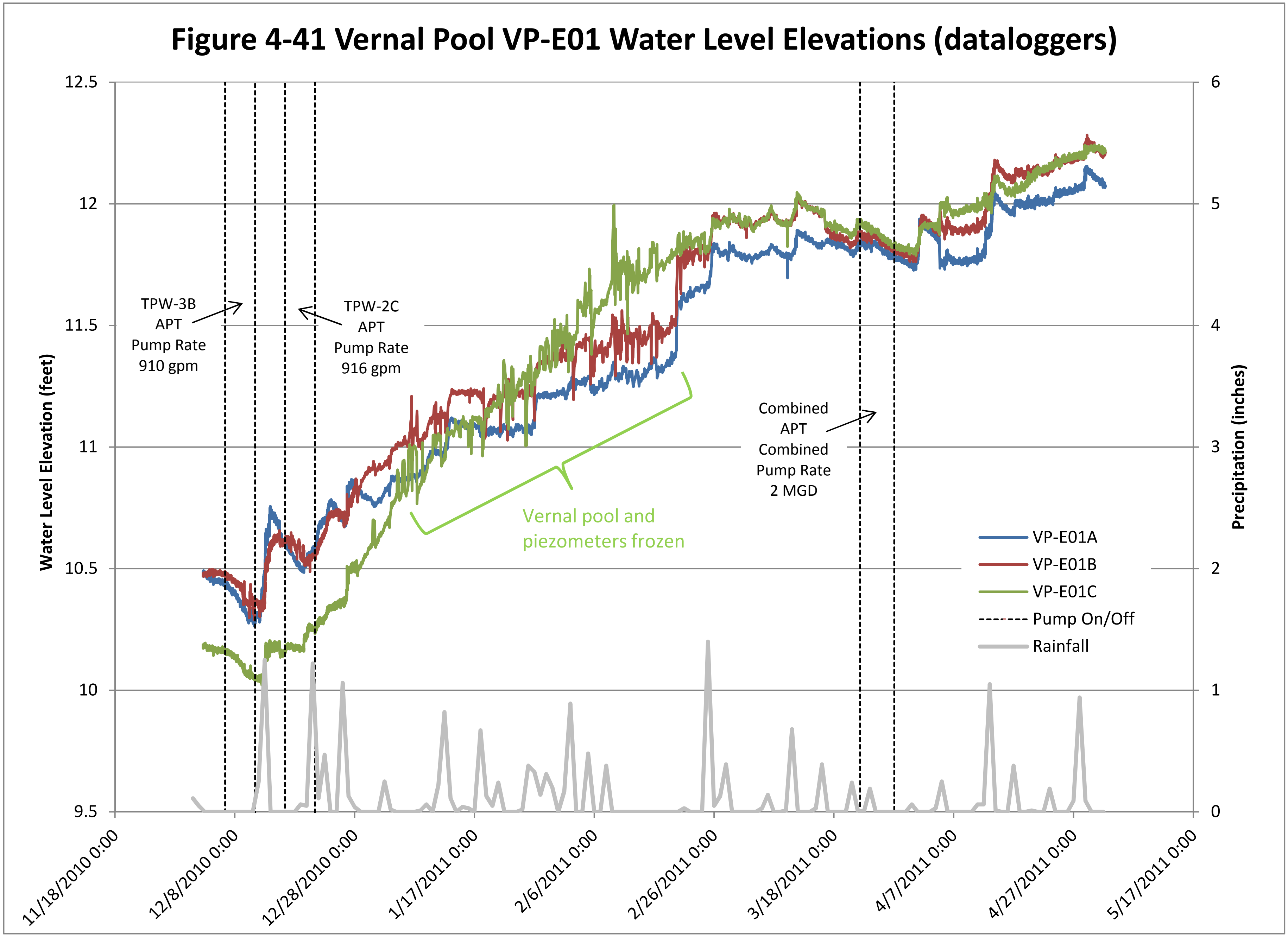


Figure 4-41 Vernal Pool VP-E01 Water Level Elevations (dataloggers)
Water Level Elevation (feet)
Precipitation (inches)
12.5
12
11.5
11
10.5
10
9.5
6
5
4
3
2
1
0
11/18/2010 0:00
12/8/2010 0:00
12/28/2010 0:00
1/17/2011 0:00
2/6/2011 0:00
2/26/2011 0:00
3/18/2011 0:00
4/7/2011 0:00
4/27/2011 0:00
5/17/2011 0:00
TPW-3B APT Pump Rate 910 gpm
TPW-2C APT Pump Rate 916 gpm
Vernal pool and piezometers frozen
Combined APT Combined Pump Rate 2 MGD
VP-E01A
VP-E01B
VP-E01C
Pump On/Off
Rainfall

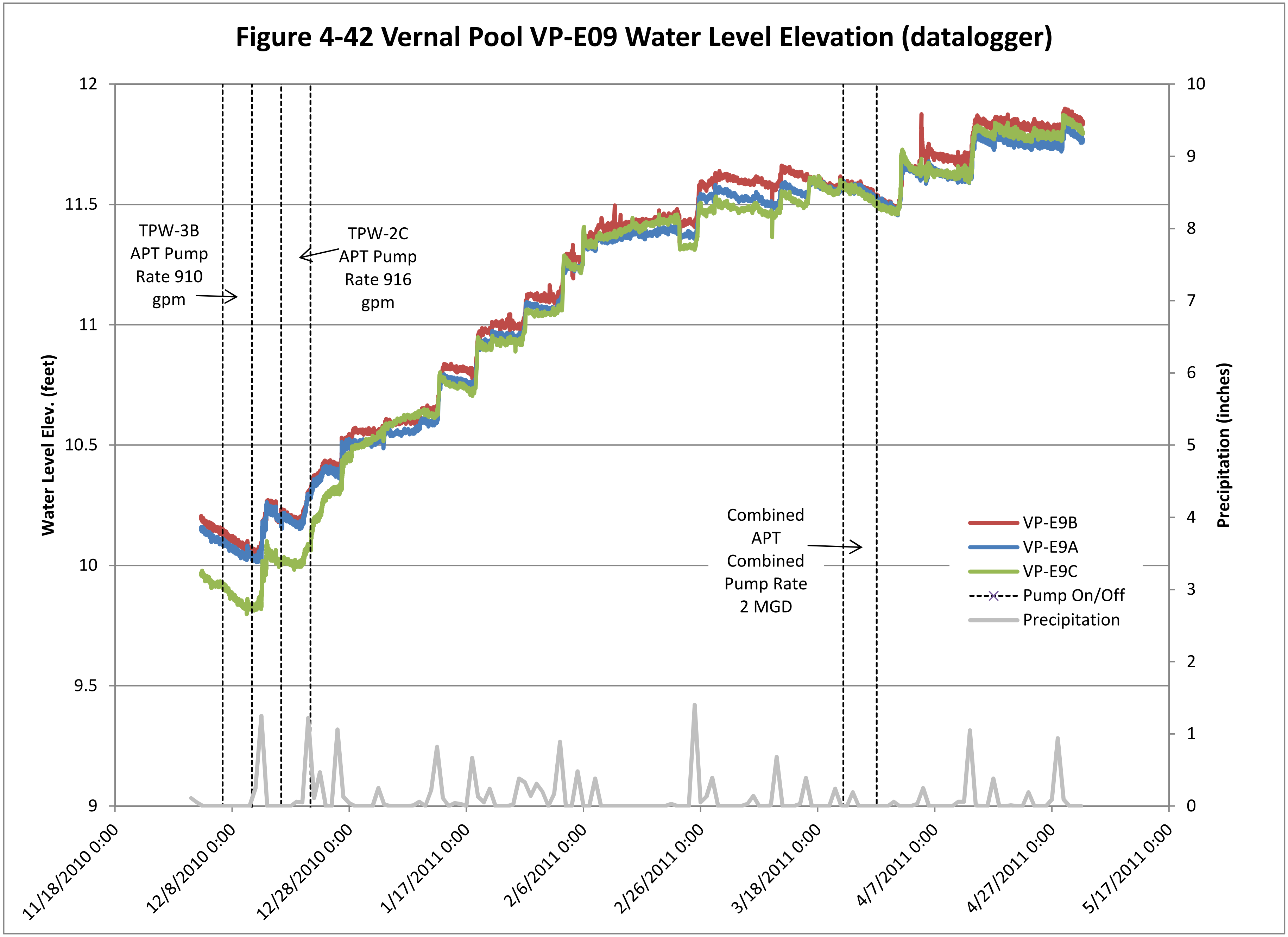


Figure 4-42 Vernal Pool VP-E09 Water Level Elevation (datalogger)
Water Level Elev. (feet)
Precipitation (inches)
12
11.5
11
10.5
10
9.5
9
10
9
8
7
6
5
4
3
2
1
0
TPW-3B APT Pump Rate 910 gpm
TPW-2C APT Pump Rate 916 gpm
Combined APT Combined Pump Rate 2 MGD
VP-E9B
VP-E9A
VP-E9C
Pump On/Off
Precipitation
11/18/2010 0:00
12/8/2010 0:00
12/28/2010 0:00
1/17/2011 0:00
2/6/2011 0:00
2/26/2011 0:00
3/18/2011 0:00
4/7/2011 0:00
4/27/2011 0:00
5/17/2011 0:00

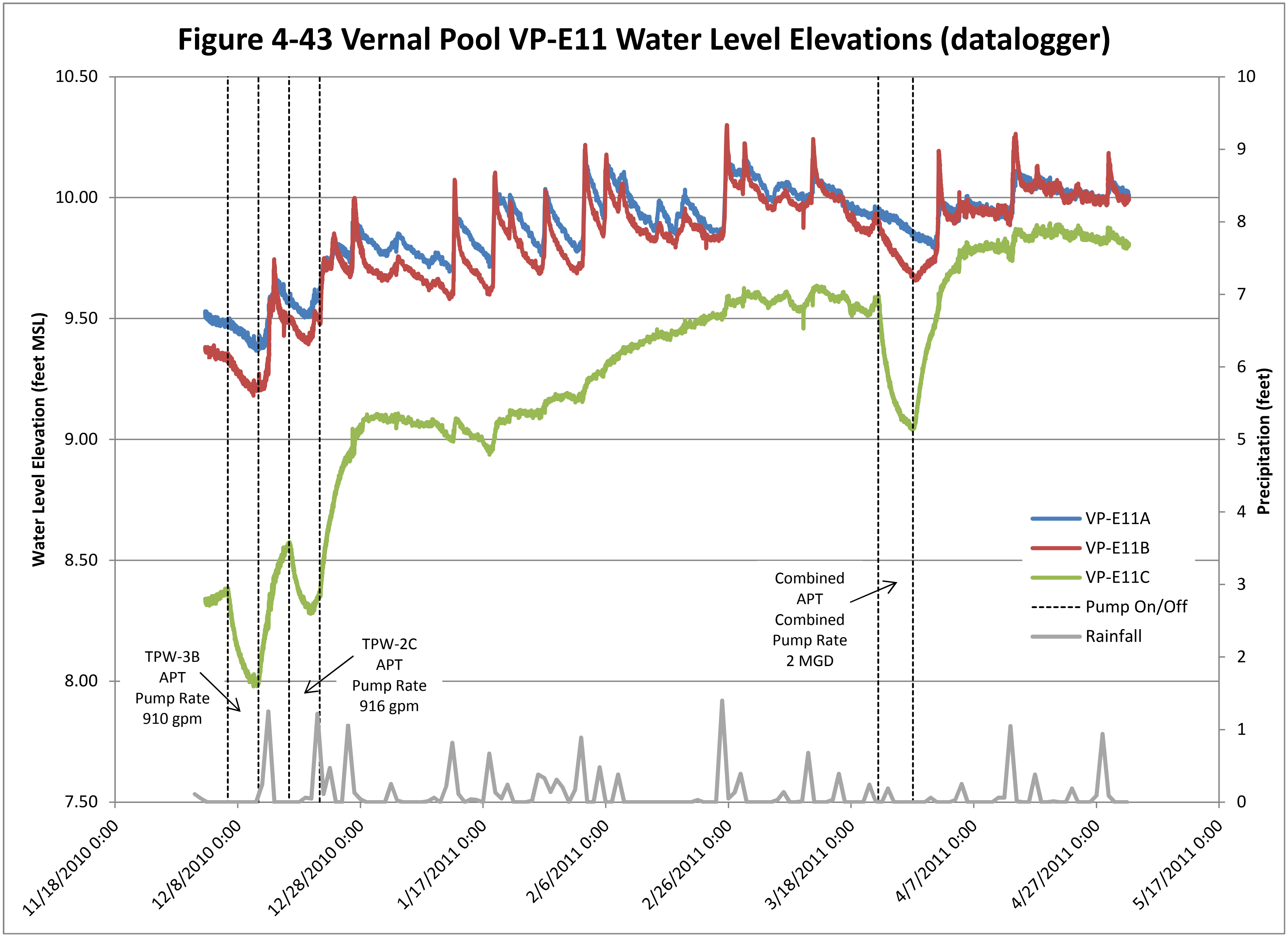
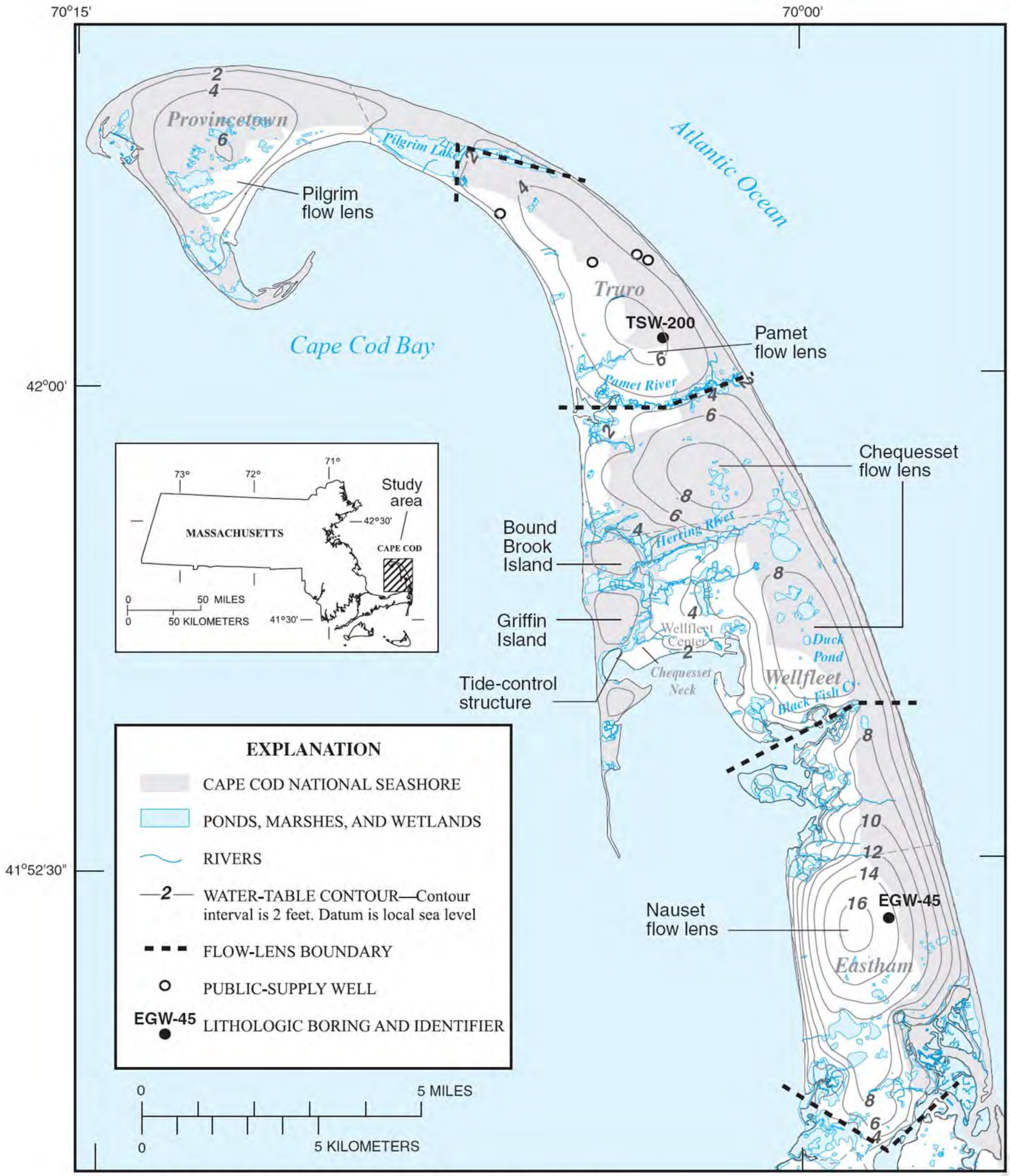


Figure 4-43 Vernal Pool VP-E11 Water Level Elevations (datalogger)
Water Level Elevation (feet MSL)
Precipitation (feet)
10.50
10.00
9.50
9.00
8.50
8.00
7.50
10
9
8
7
6
5
4
3
2
1
0
VP-E11A
VP-E11B
VP-E11C
Pump On/Off
Rainfall
TPW-3B
APT
Pump Rate
910 gpm
TPW-2C
APT
Pump Rate
916 gpm
Combined
APT
Combined
Pump Rate
2 MGD
11/18/2010 0:00
12/8/2010 0:00
12/28/2010 0:00
1/17/2011 0:00
2/6/2011 0:00
2/26/2011 0:00
3/18/2011 0:00
4/7/2011 0:00
4/27/2011 0:00
5/17/2011 0:00



Base from U.S. Geological Survey Digital Line Graphs, and topographic quadrangles, Provincetown, Wellfleet, and Orleans, Massachusetts, 1:25,000, Polyconic projection, NAD 1927, Zone 19

Source: Figure 1 from Masterson (2004)

Lower Cape Cod Freshwater Lens Aquifers

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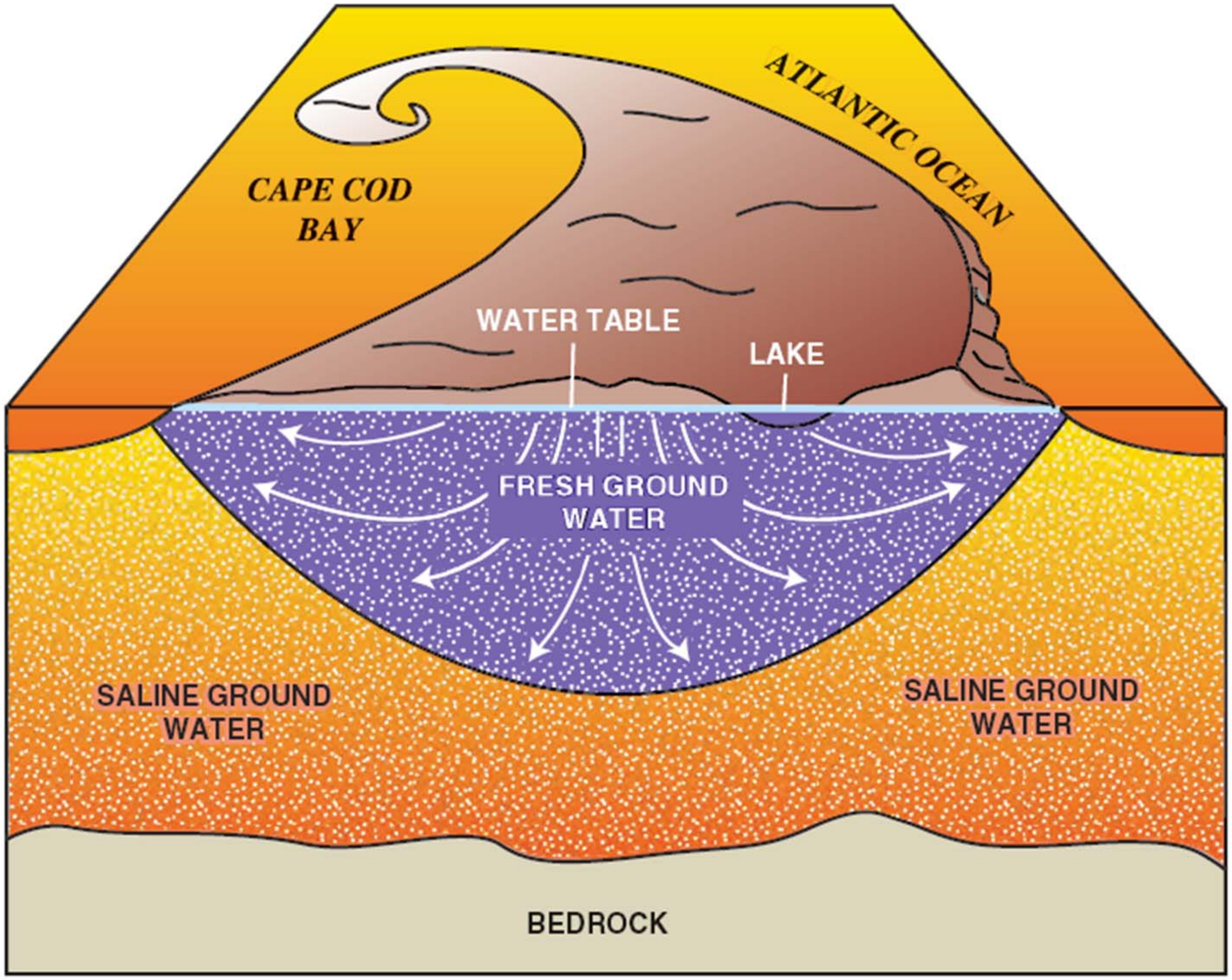
Figure 5-1



Source: Figure 5 from Masterson (2004)

Schematic diagram, not to scale

Graphic Depiction of Freshwater Lens and Saltwater Interface

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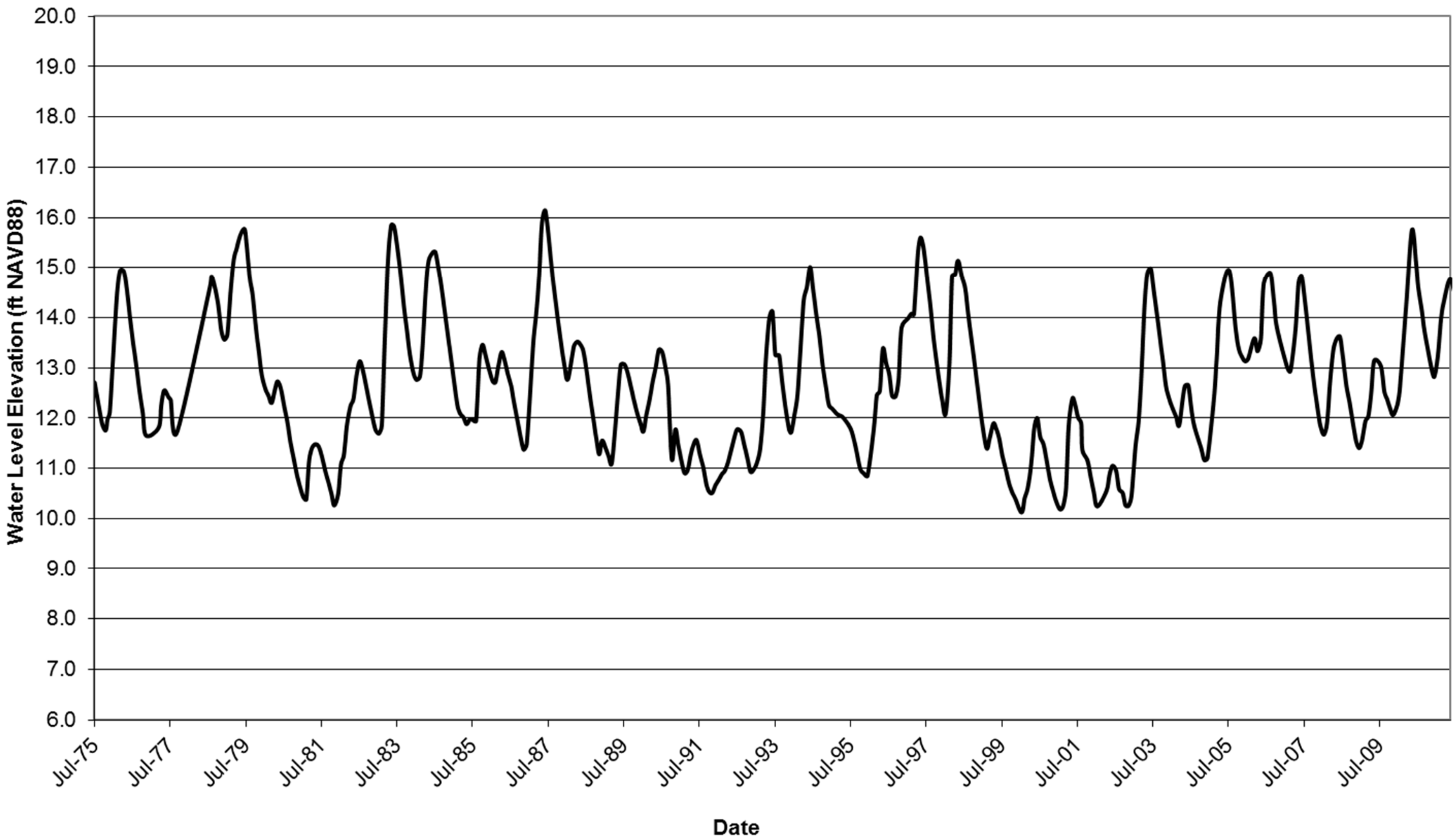
Figure 5-2



Long-term Hydrograph:
Monthly Water Level Elevation at EGW-36

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Figure 5-3

Basemap Sources: USGS, ESRI, TANA, AND, and MassGIS

General Site Map

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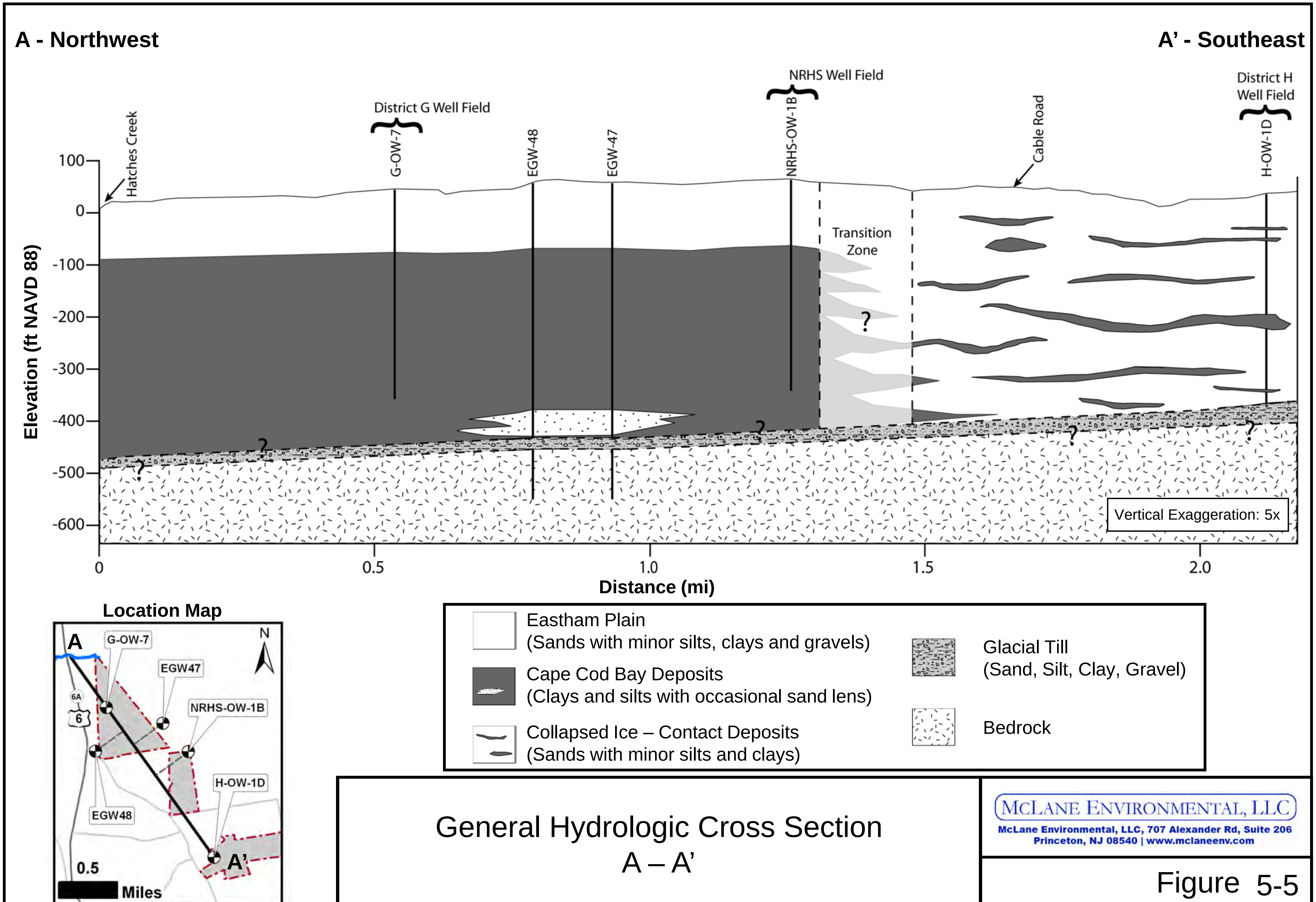
Figure 5-4



General Hydrologic Cross Section
A – A’

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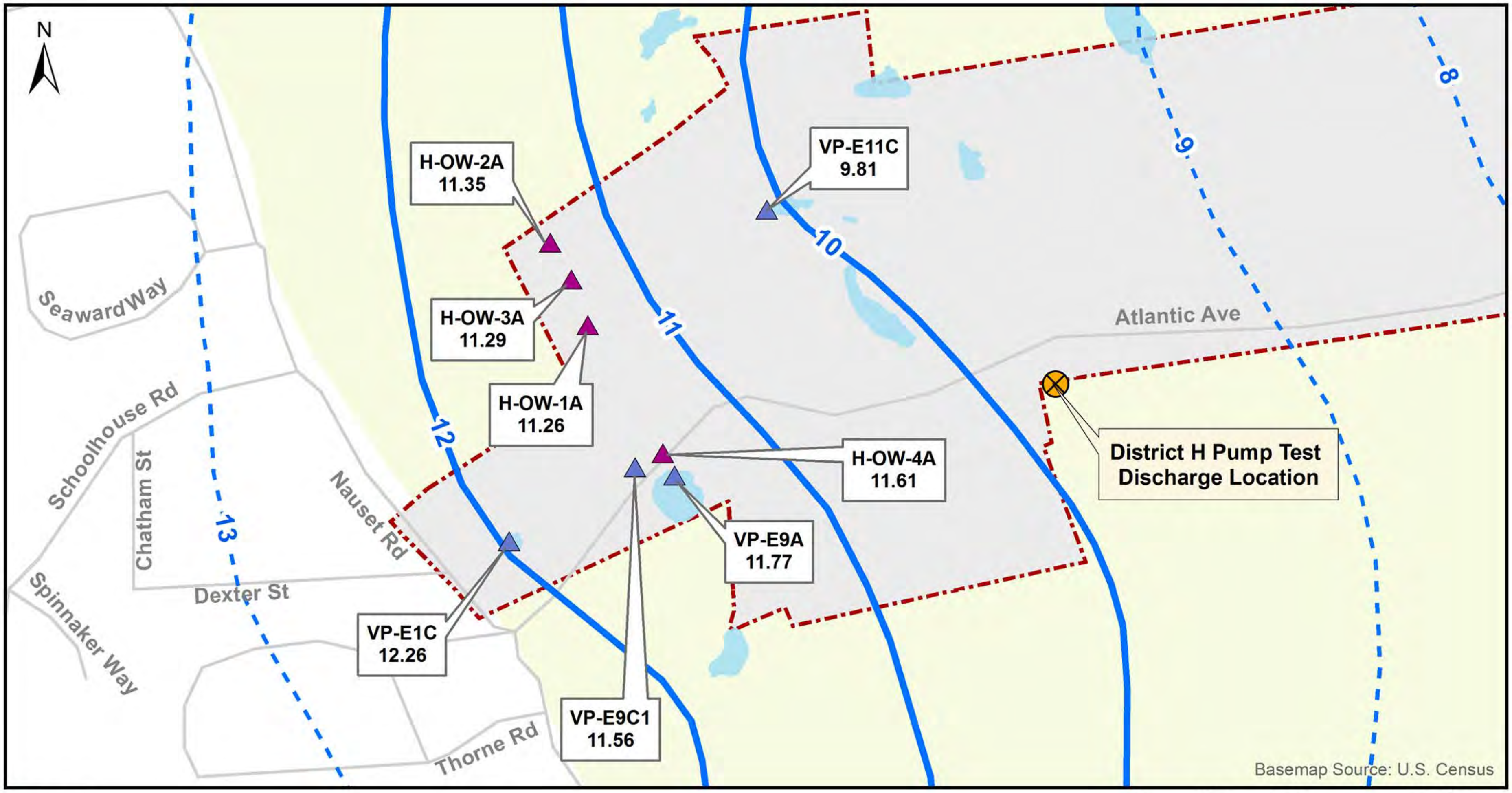
Figure 5-5



Legend

- Observation Well
- Vernal Pool Staff Gage/ Piezometer
- Discharge Locations
- Vernal Pools
- 13.59 Groundwater Elevation (ft NAVD 88)
- 12 Groundwater Contour
- Site Boundaries
- Roads

District H Water Level Elevation Contours
May 02, 2011

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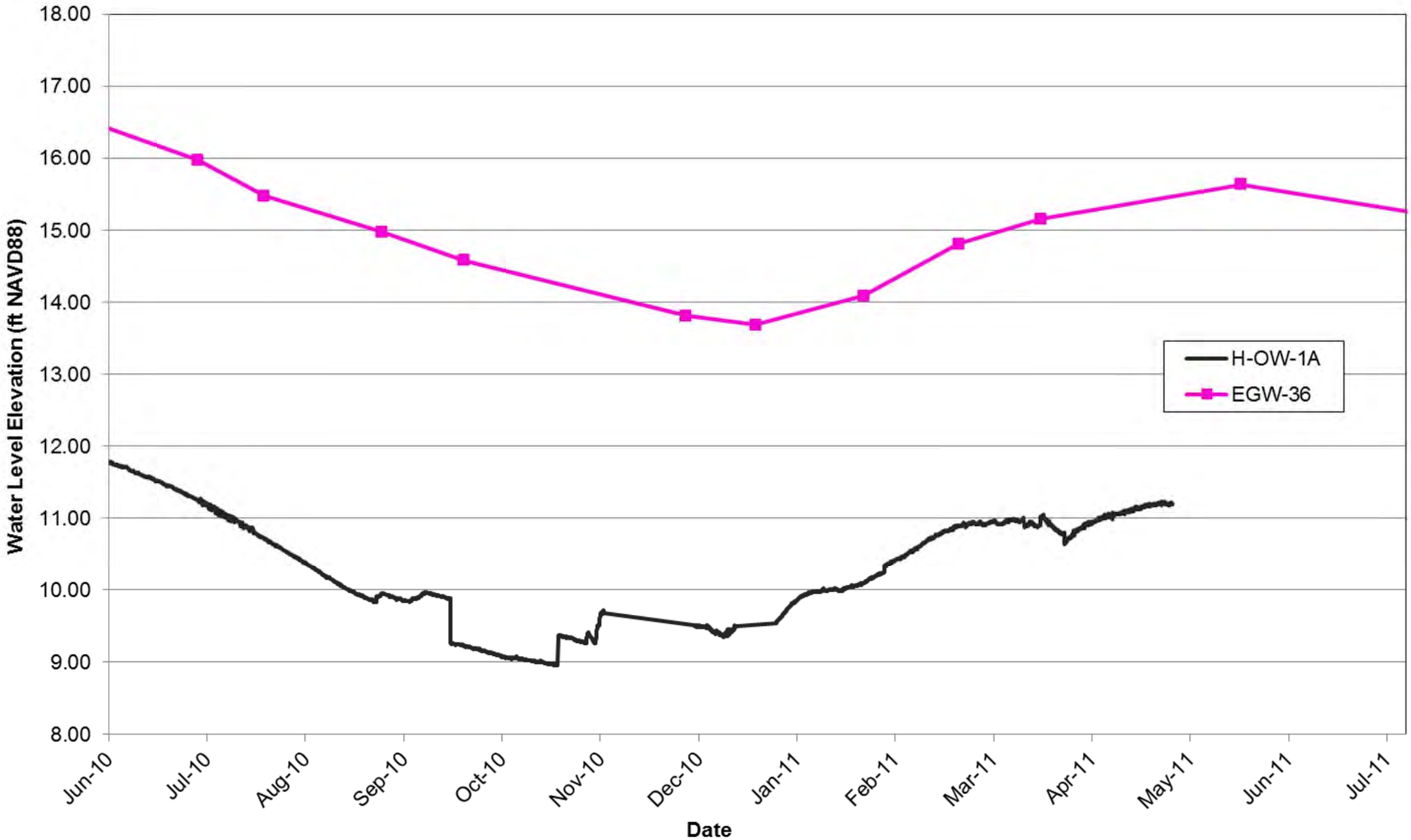
Figure 5-6



Long-term Hydrograph: H-OW-1A

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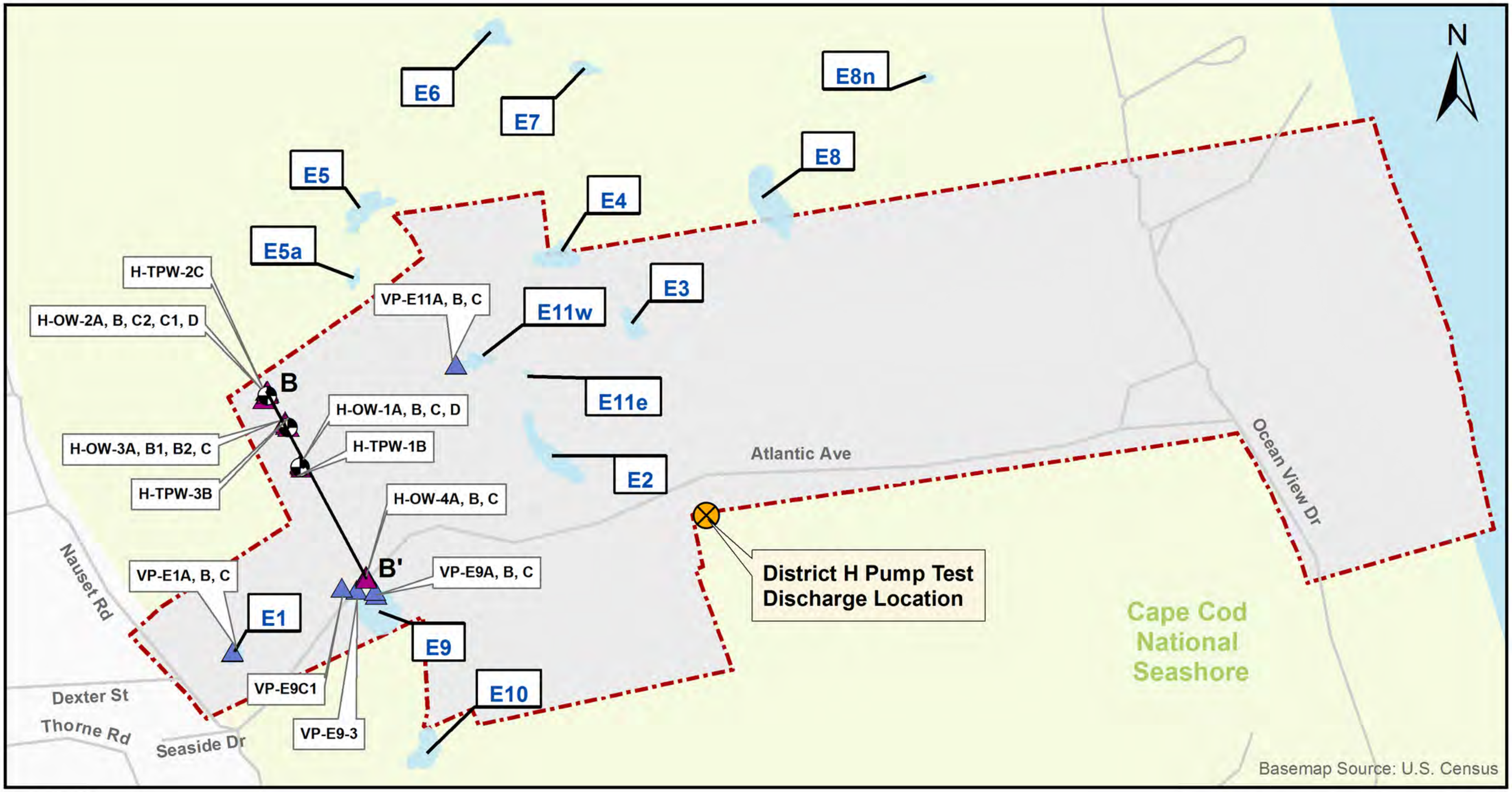
Figure 5-7



Legend

- Pumping Wells
- Observation Wells
- Vernal Pool Staff Gages/ Piezometers
- Discharge Location
- E2 Vernal Pools
- Site Boundaries
- B-B' Cross Section Transect
- Roads

0 250 500 1,000 Feet

District H Well Field Site Map

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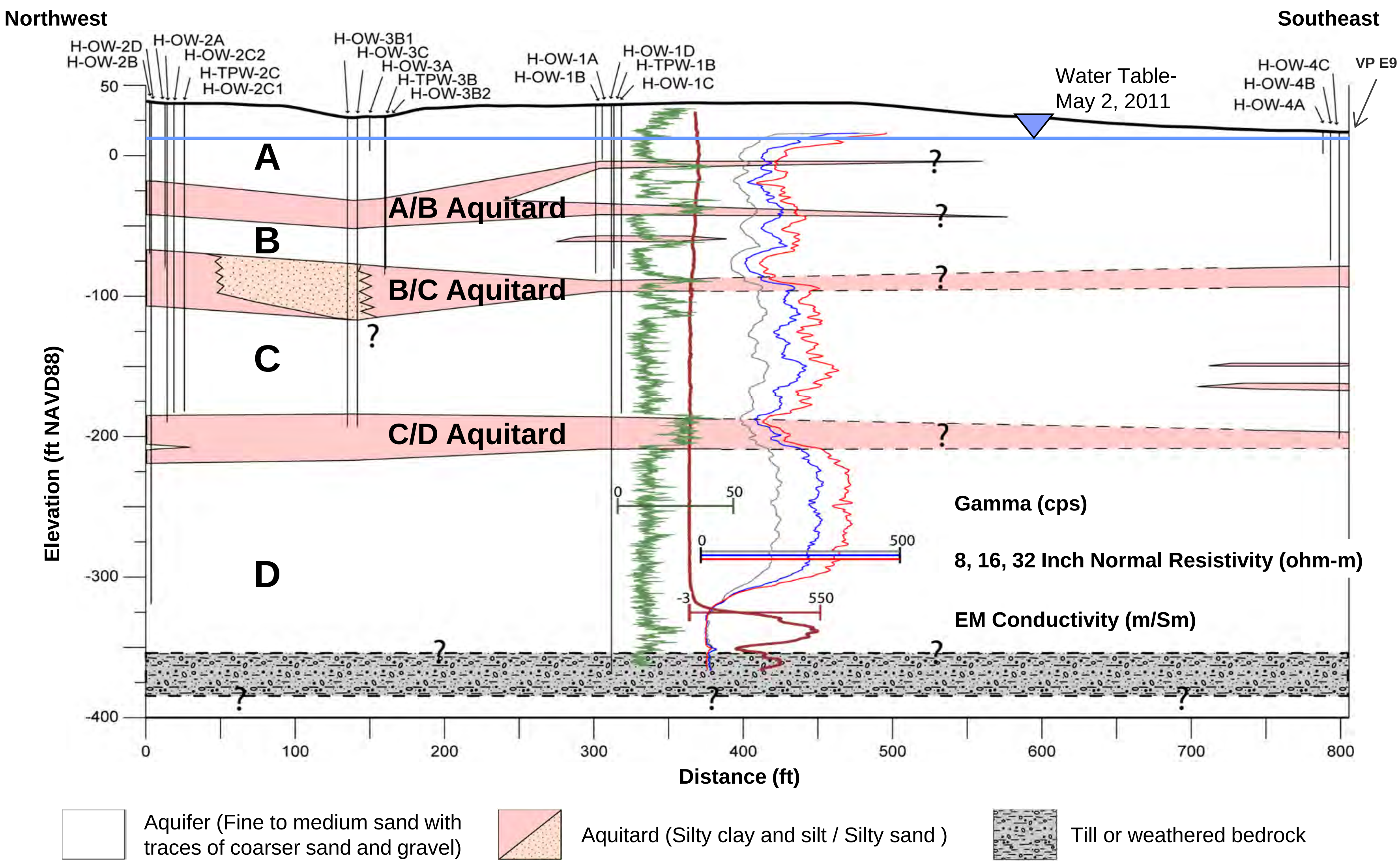
Figure 5-8



District H Well Field Hydrologic
Cross Section B–B'

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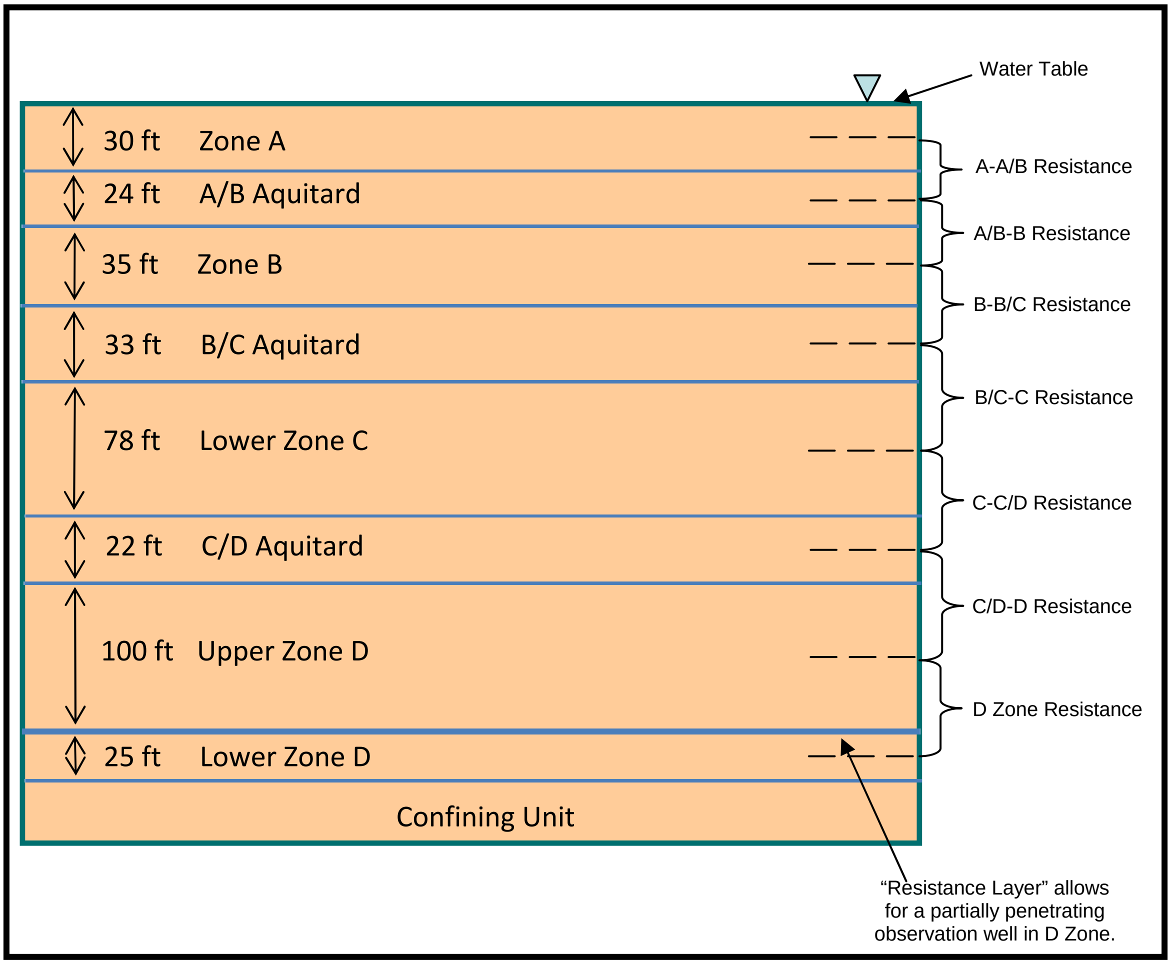
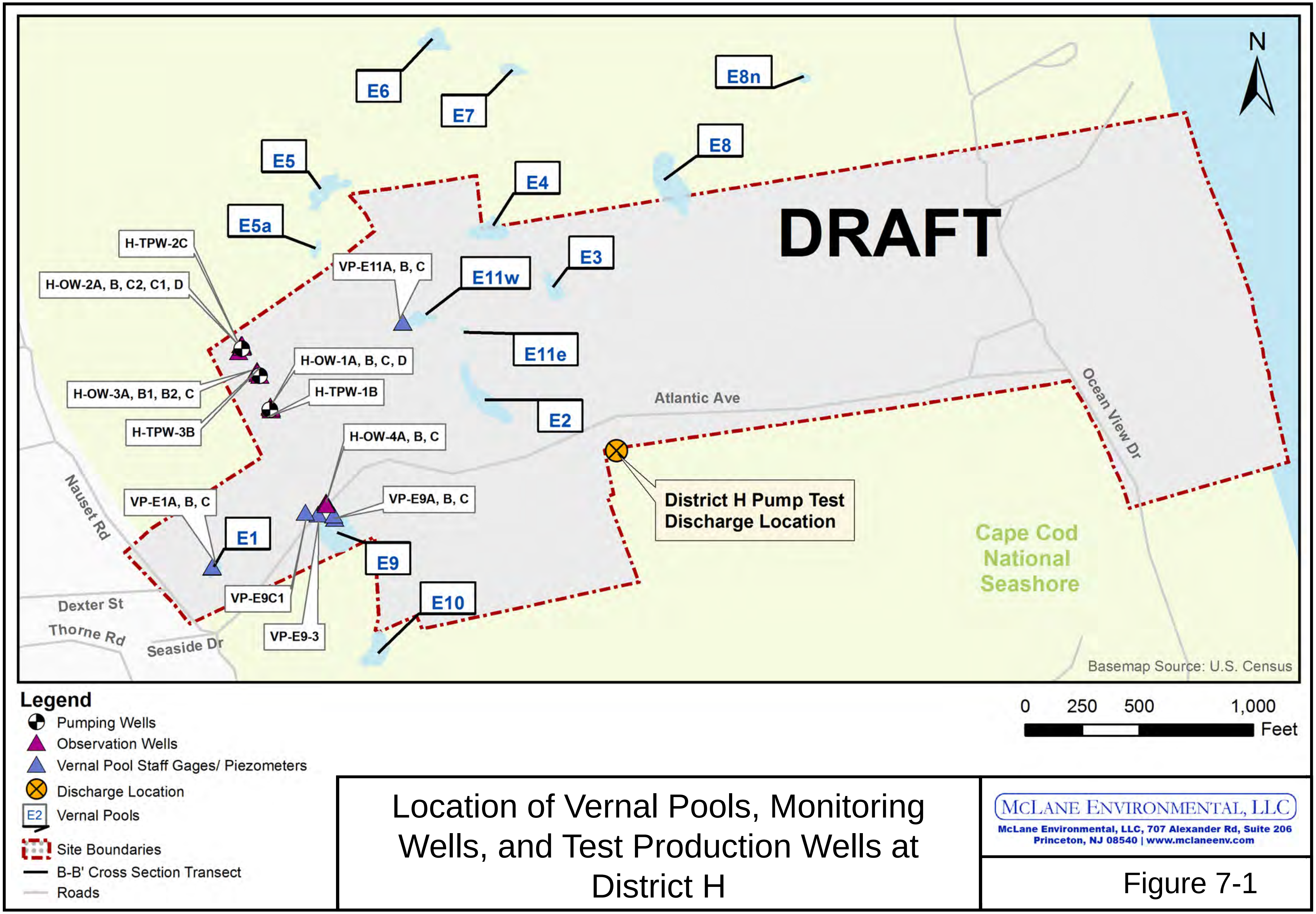
Figure 5-9

Figure 6-1
Cross Section of MLU Conceptual Model





Location of Vernal Pools, Monitoring Wells, and Test Production Wells at District H

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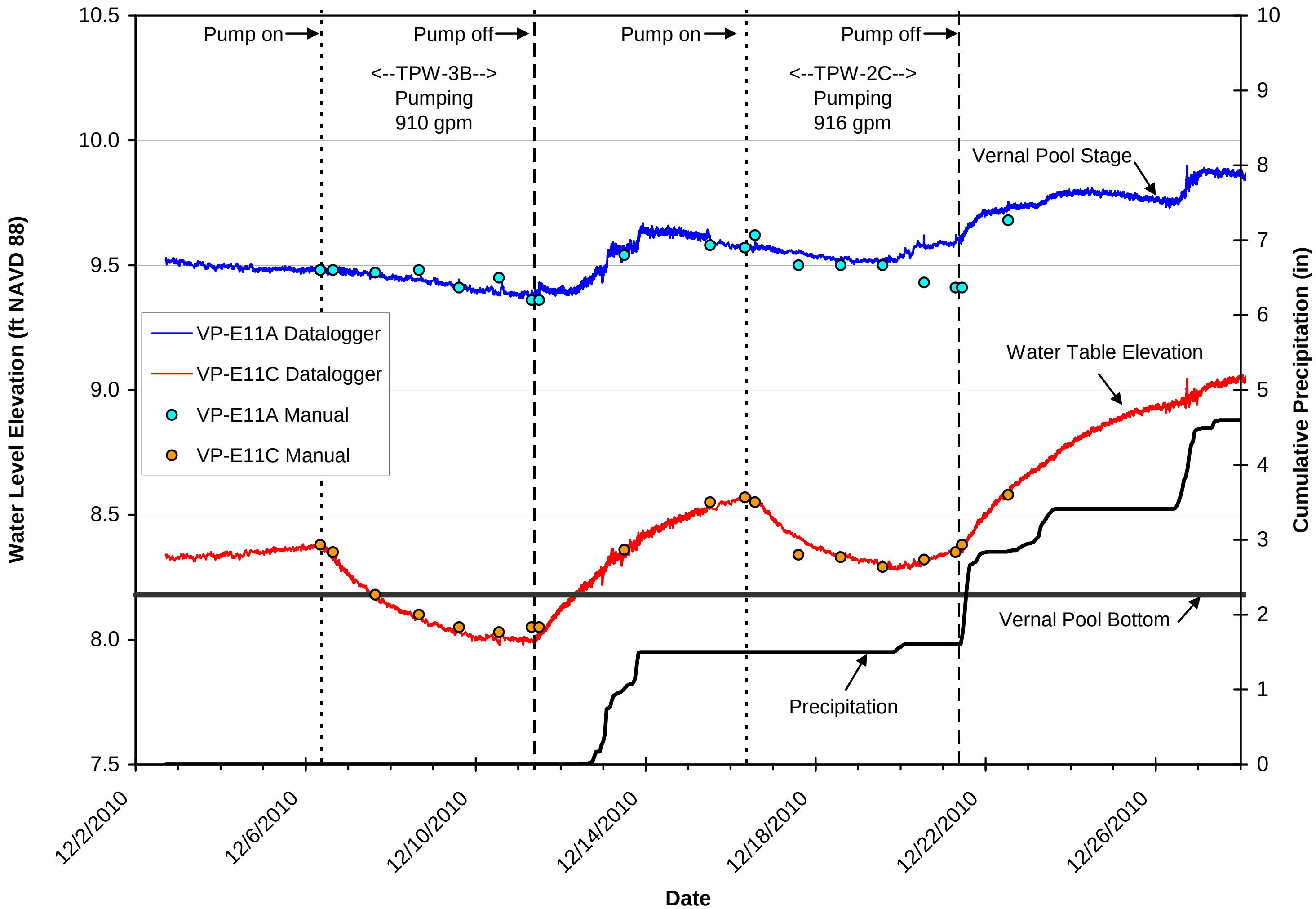
Figure 7-1



Groundwater and Stage Levels for Vernal Pool E11 during Aquifer Test 1 (TPW-3B) and Aquifer Test 2 (TPW-2C)

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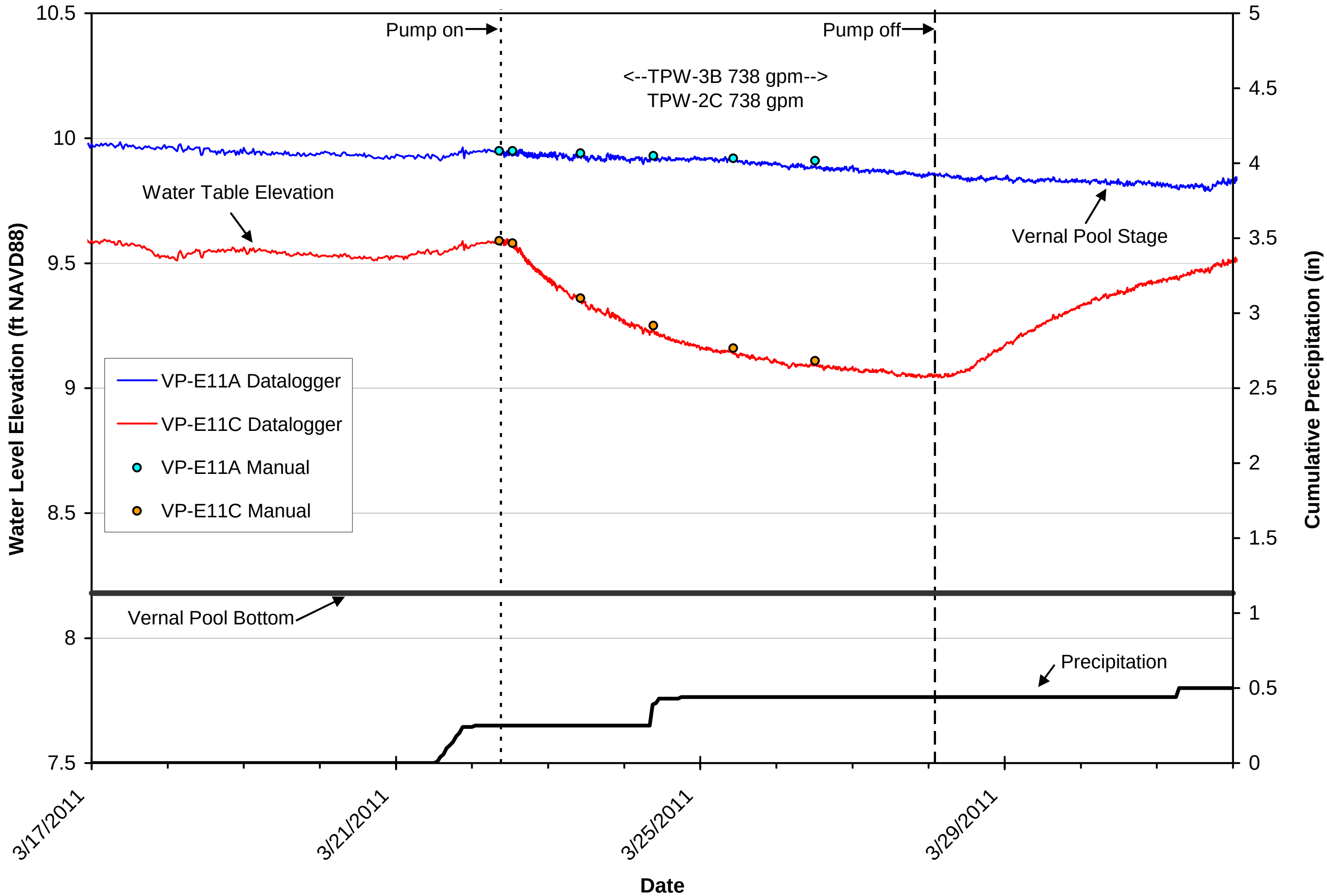
Figure 7-2



Groundwater and Stage Levels for Vernal Pool E11 during Aquifer Test 3 (TPW-3B & TPW-2C)

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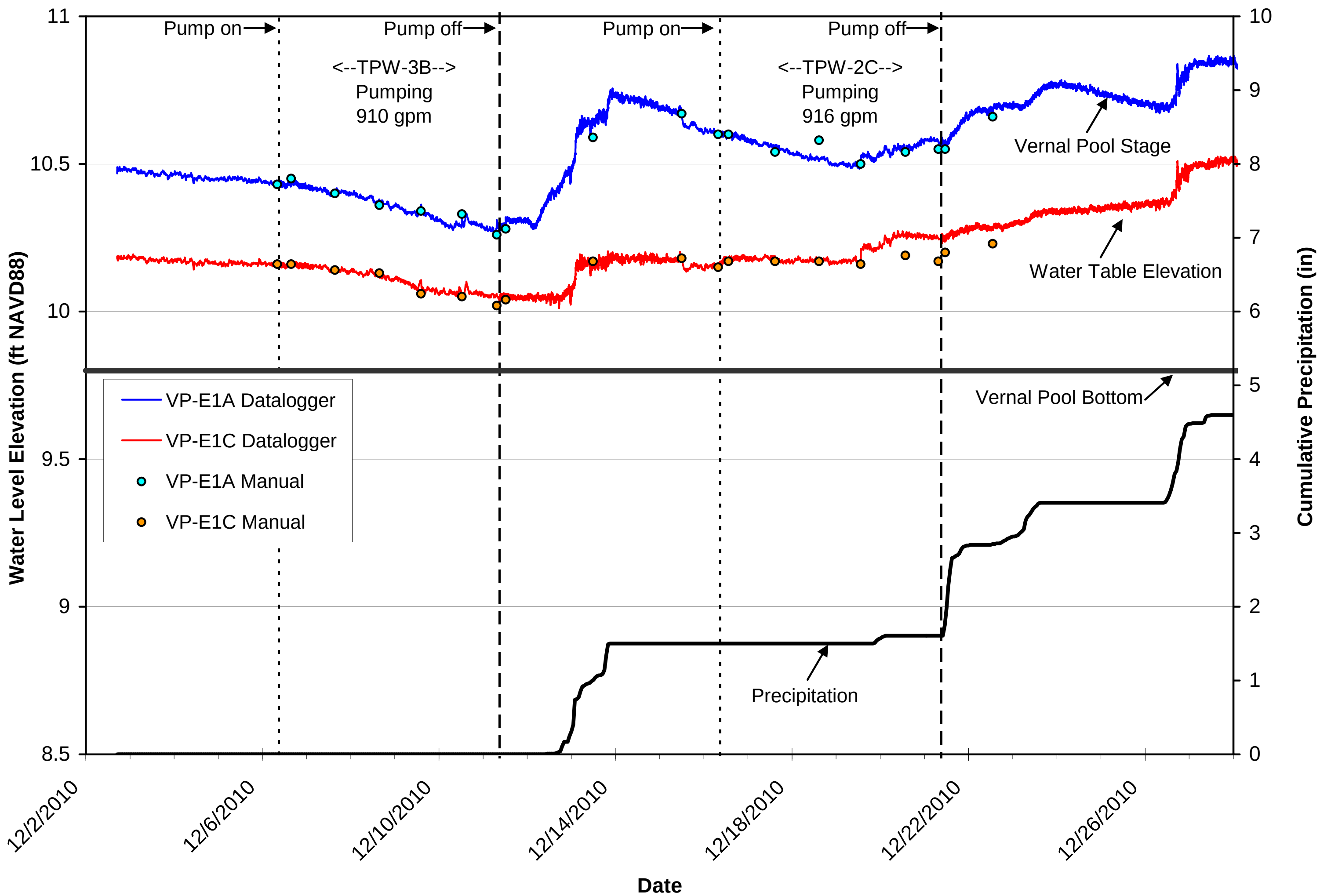
Figure 7-3



Groundwater and Stage Levels for Vernal Pool E1 during Aquifer Test 1 (TPW-3B) and Aquifer Test 2 (TPW-2C)

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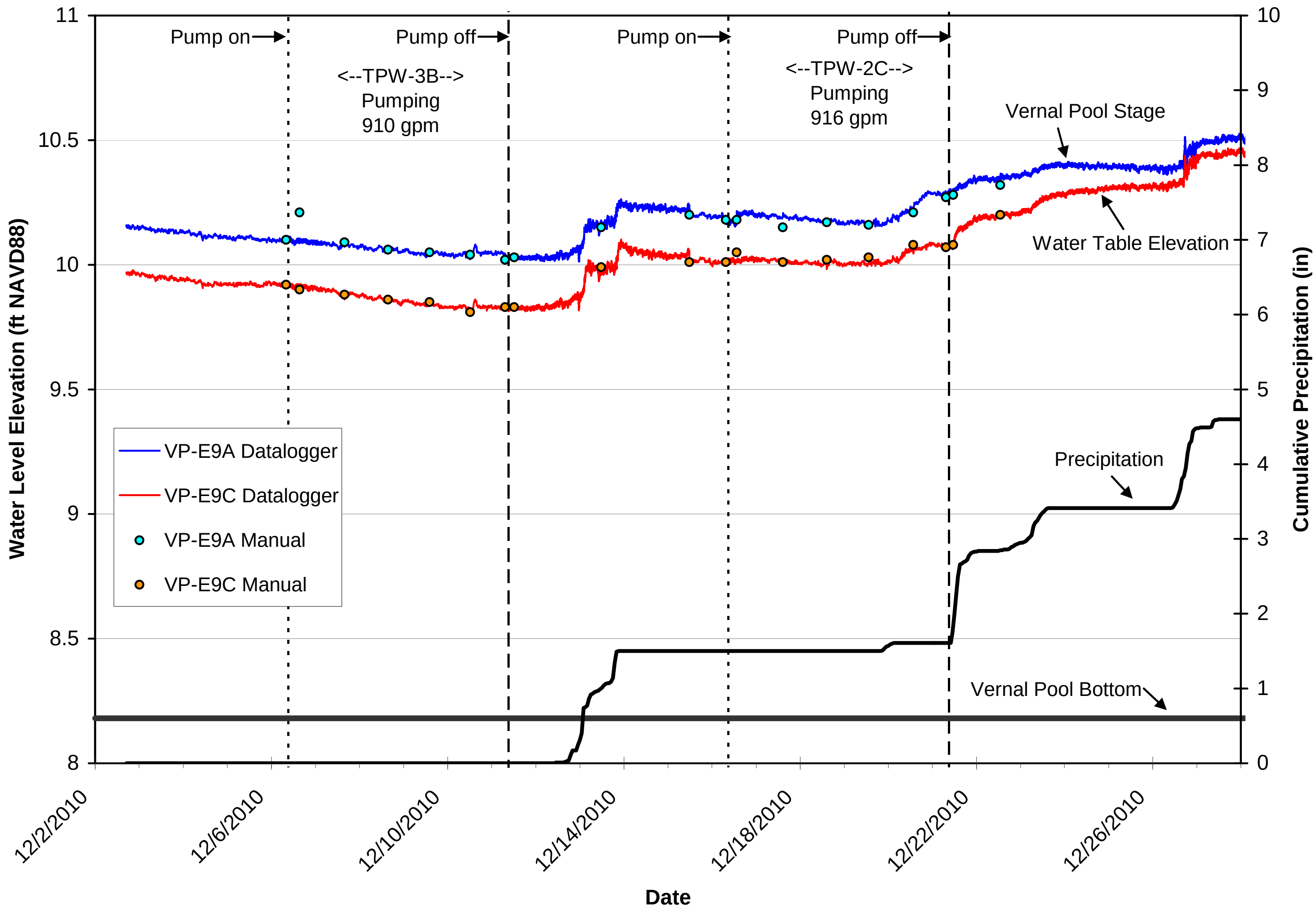
Figure 7-4



Groundwater and Stage Levels for Vernal Pool E9 during Aquifer Test 1 (TPW-3B) and Aquifer Test 2 (TPW-2C)

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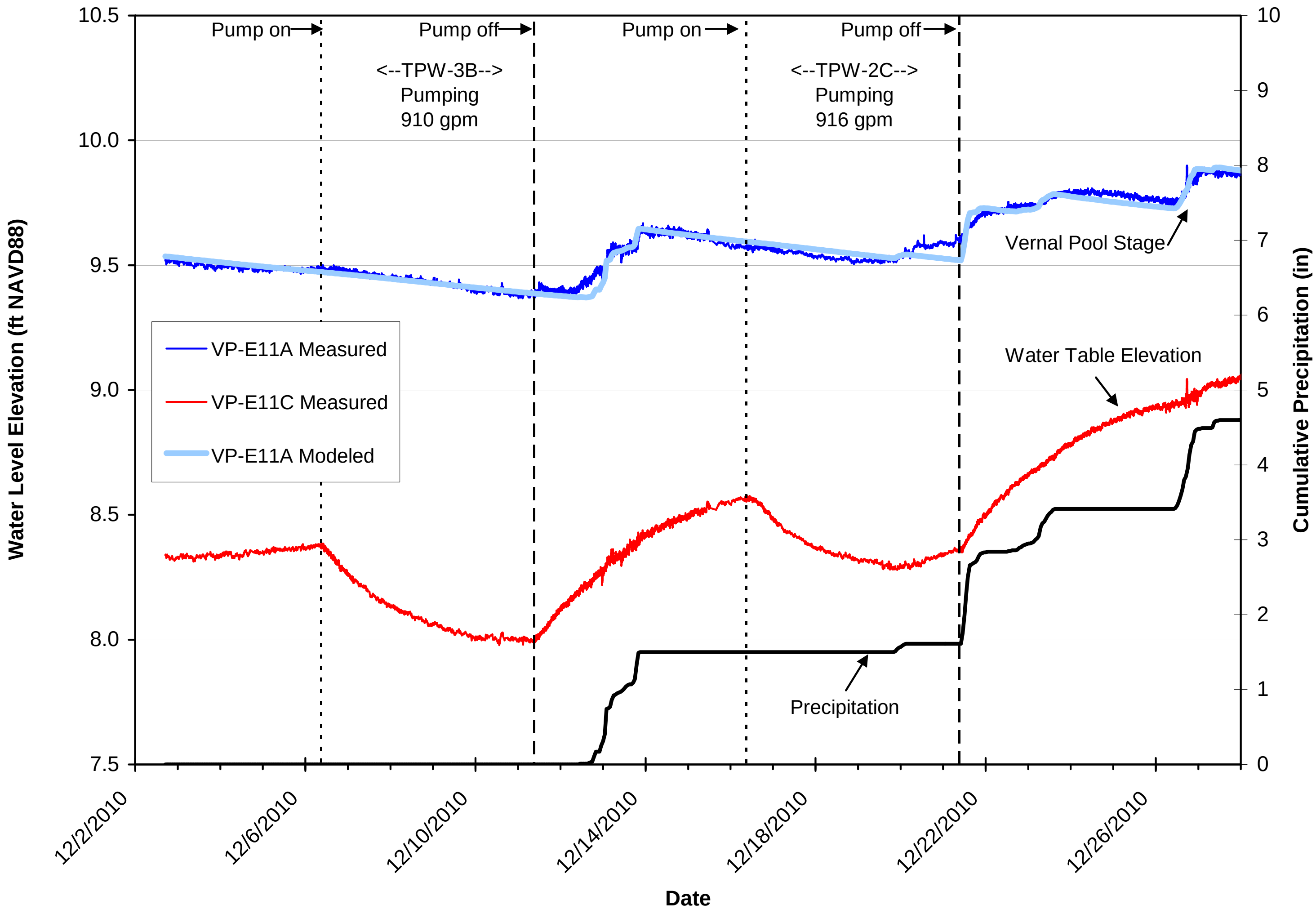
Figure 7-5



Calibration Results for TPW-3B & TPW-2C Constant Rate Aquifer Tests

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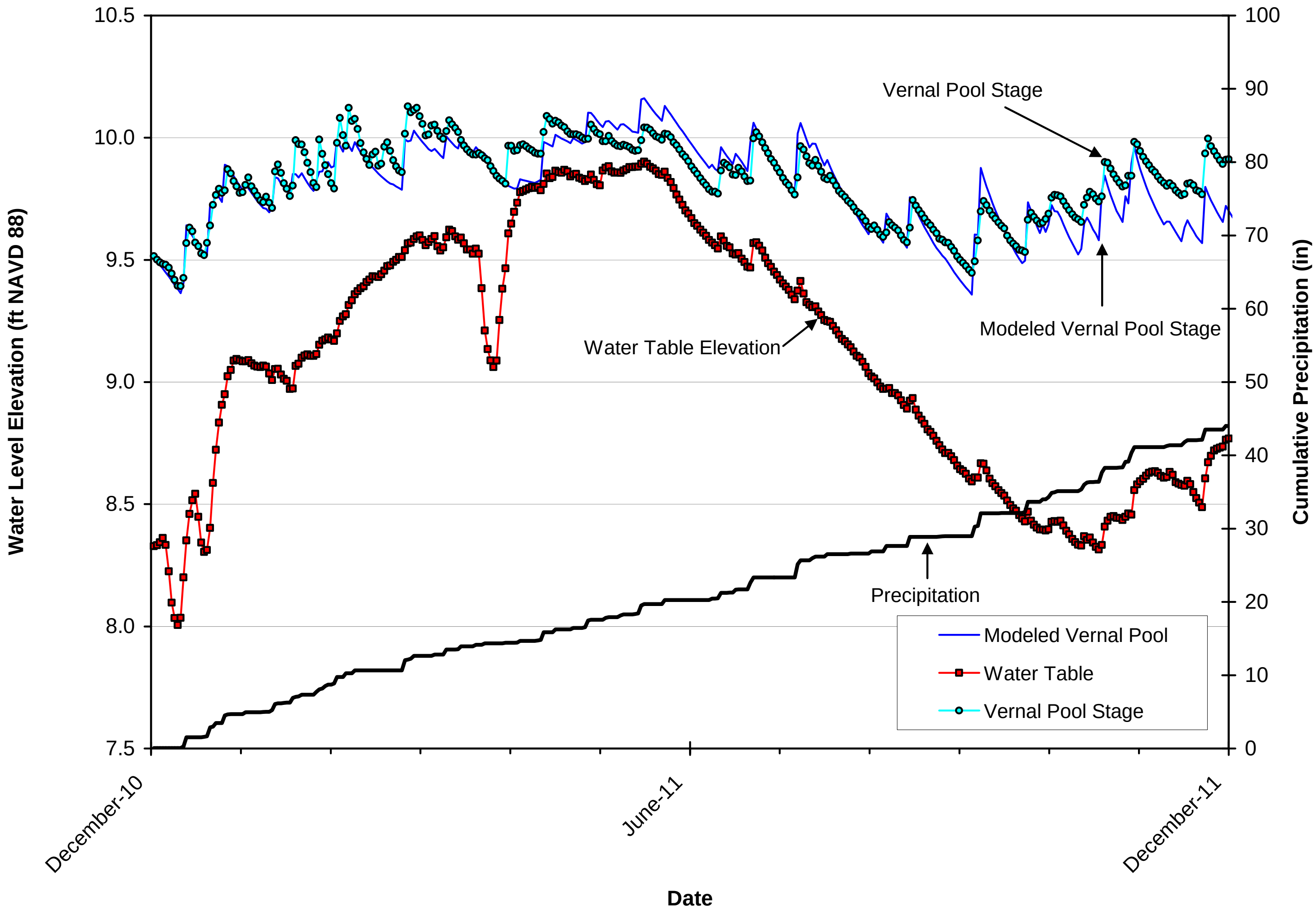
Figure 7-6



Modeled Vernal Pool Stage for E11 from December 2010 to December 2011

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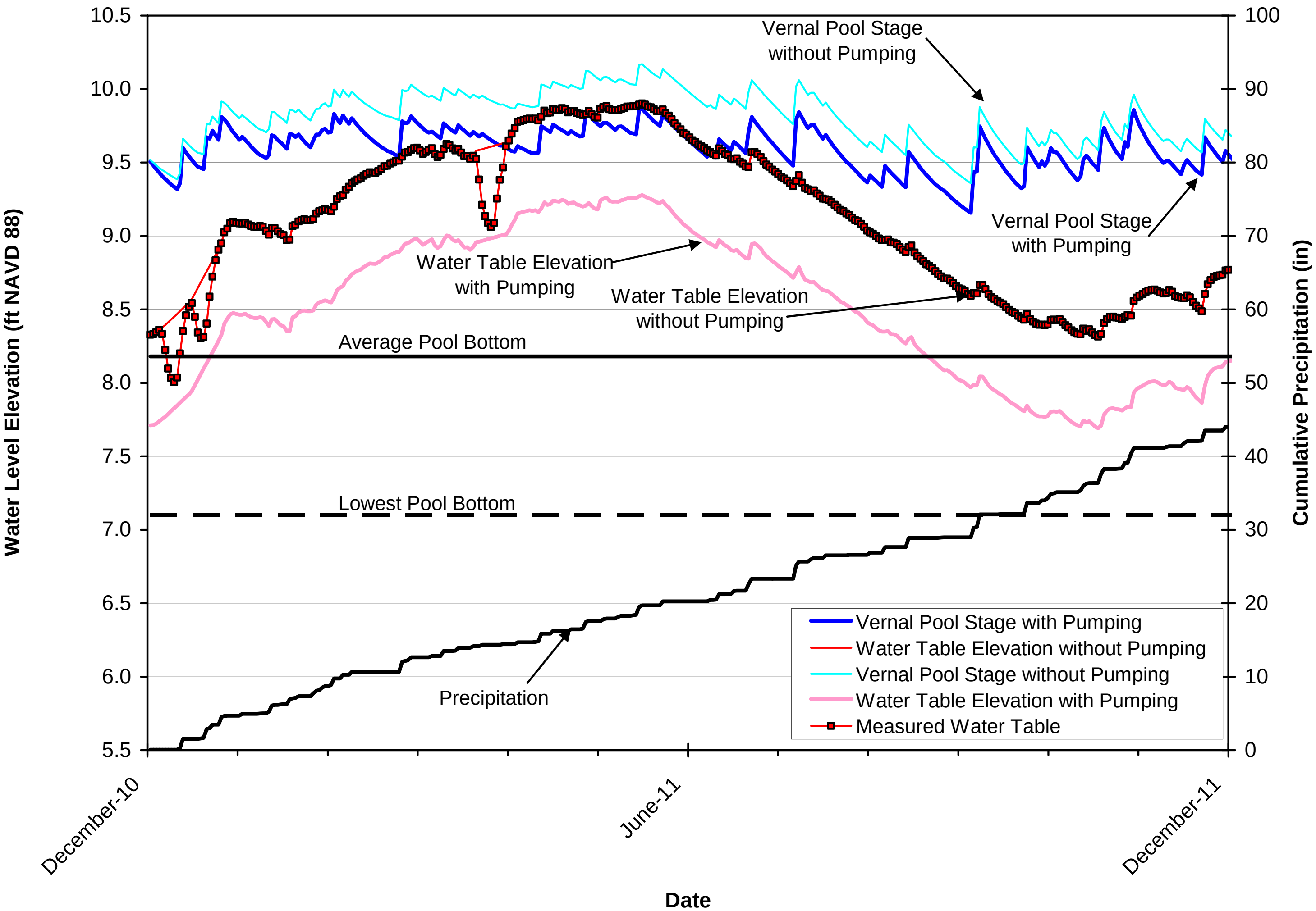
Figure 7-7



Predicted Vernal Pool Stage with and without TPW-3B Pumping at 0.5 MGD from December 2010 to December 2011

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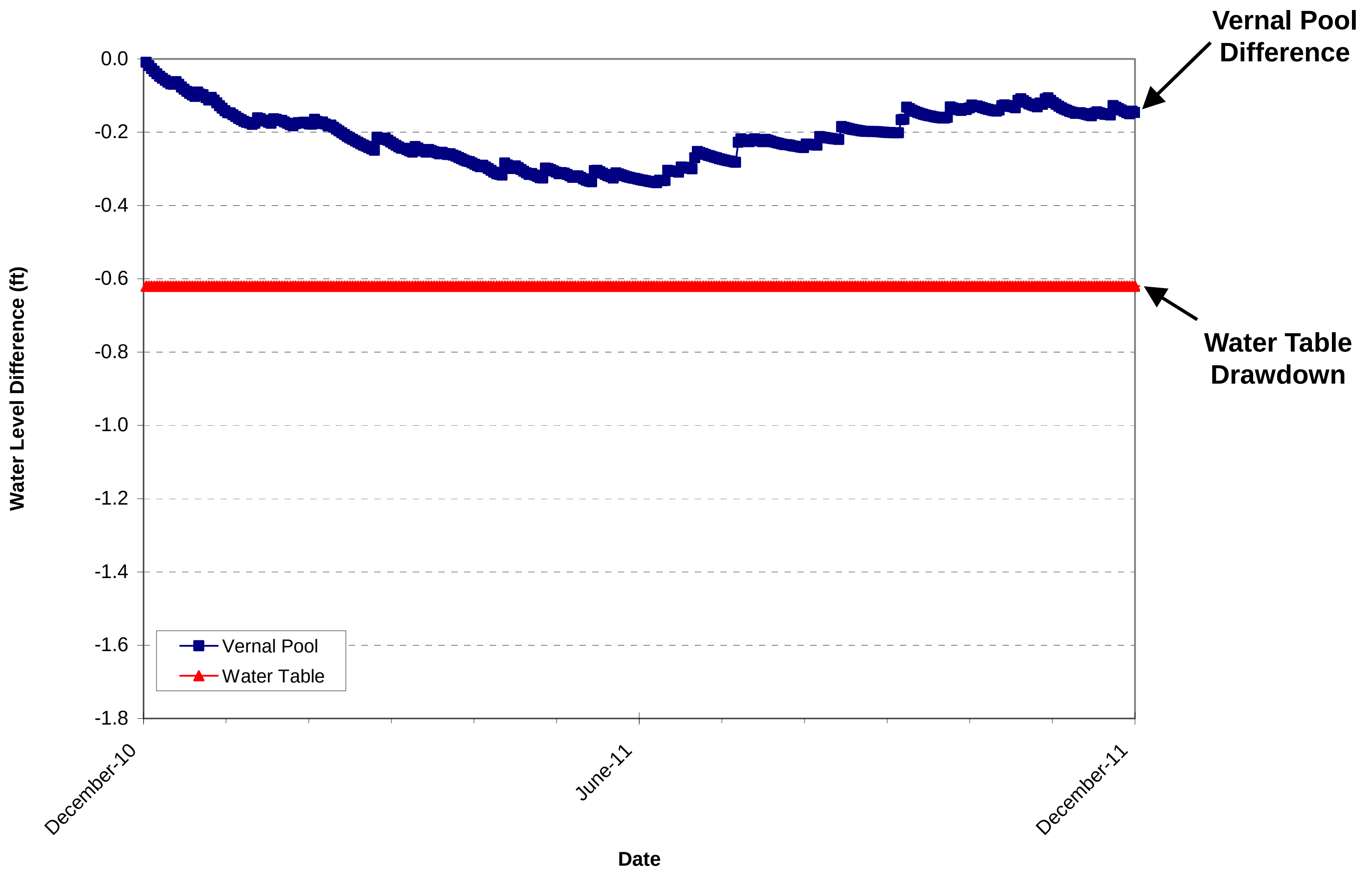
Figure 7-8



Difference between Predicted Vernal Pool Stage with and without Pumping at 0.5 MGD

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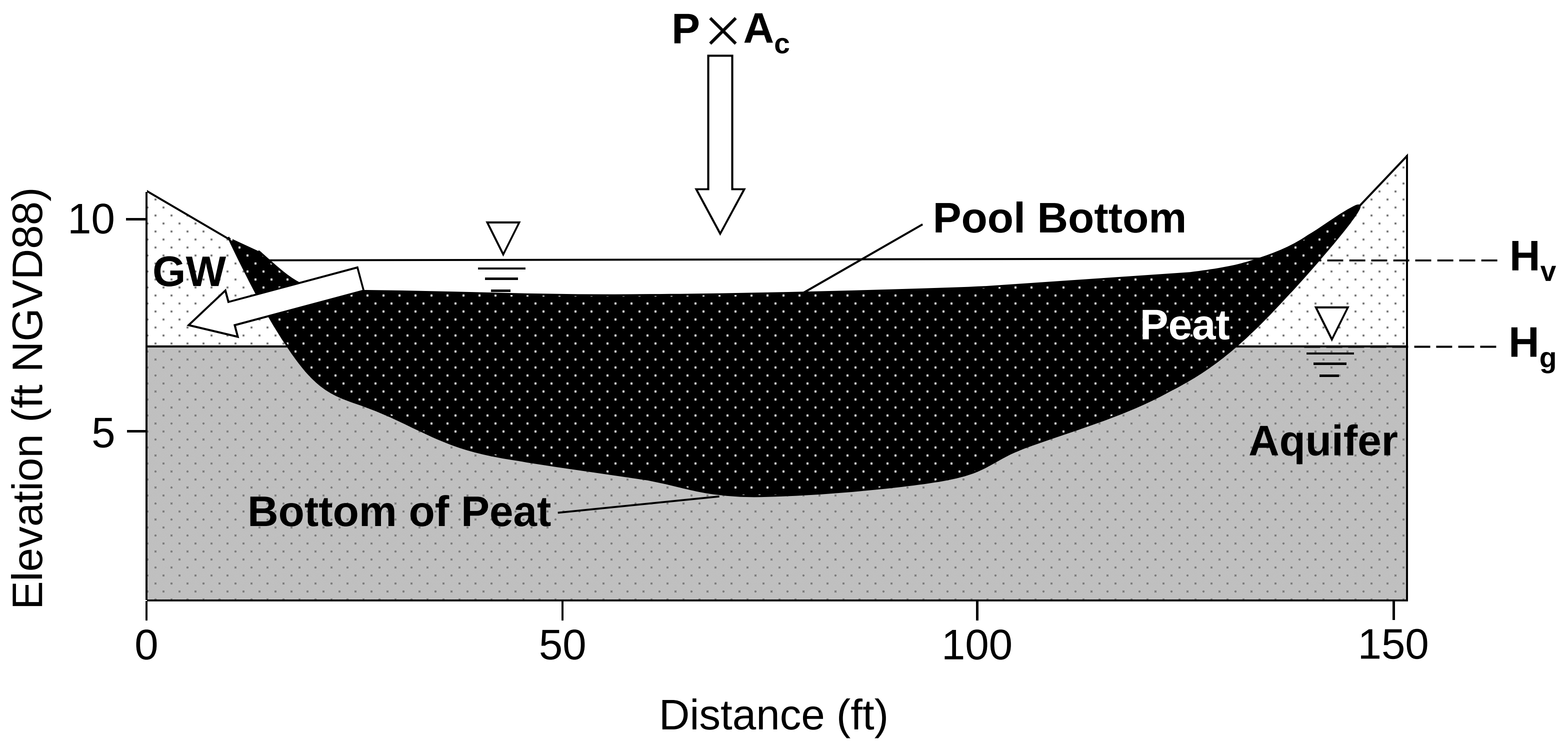
Figure 7-9



P = precipitation
GW = discharge to groundwater
H_v = vernal pool water elevation
H_g = groundwater elevation
A_c = vernal pool catchment area

Components of the Water Budget for Vernal Pool E11

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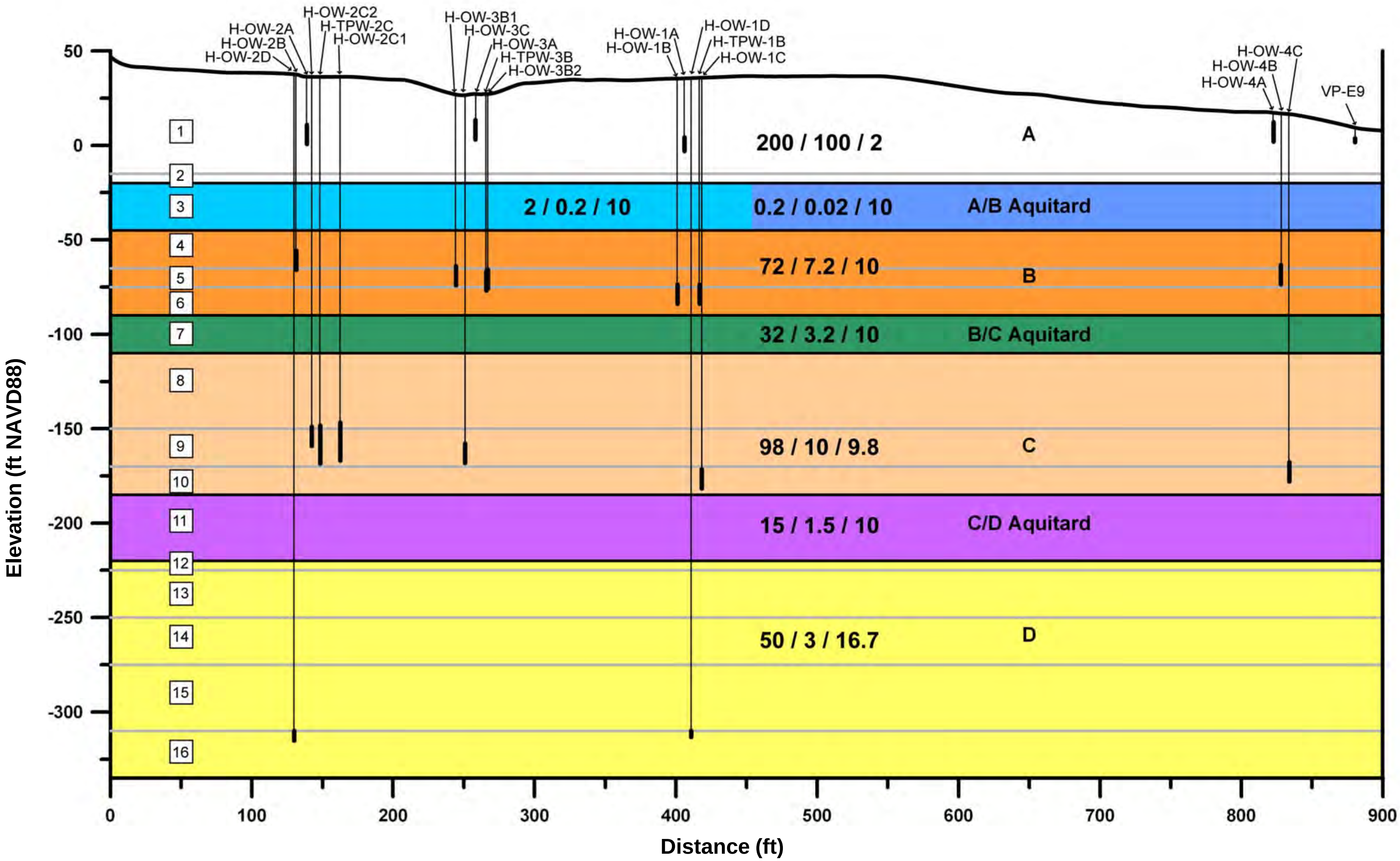
Figure 7-10



District H Model Cross-Section:
North-South

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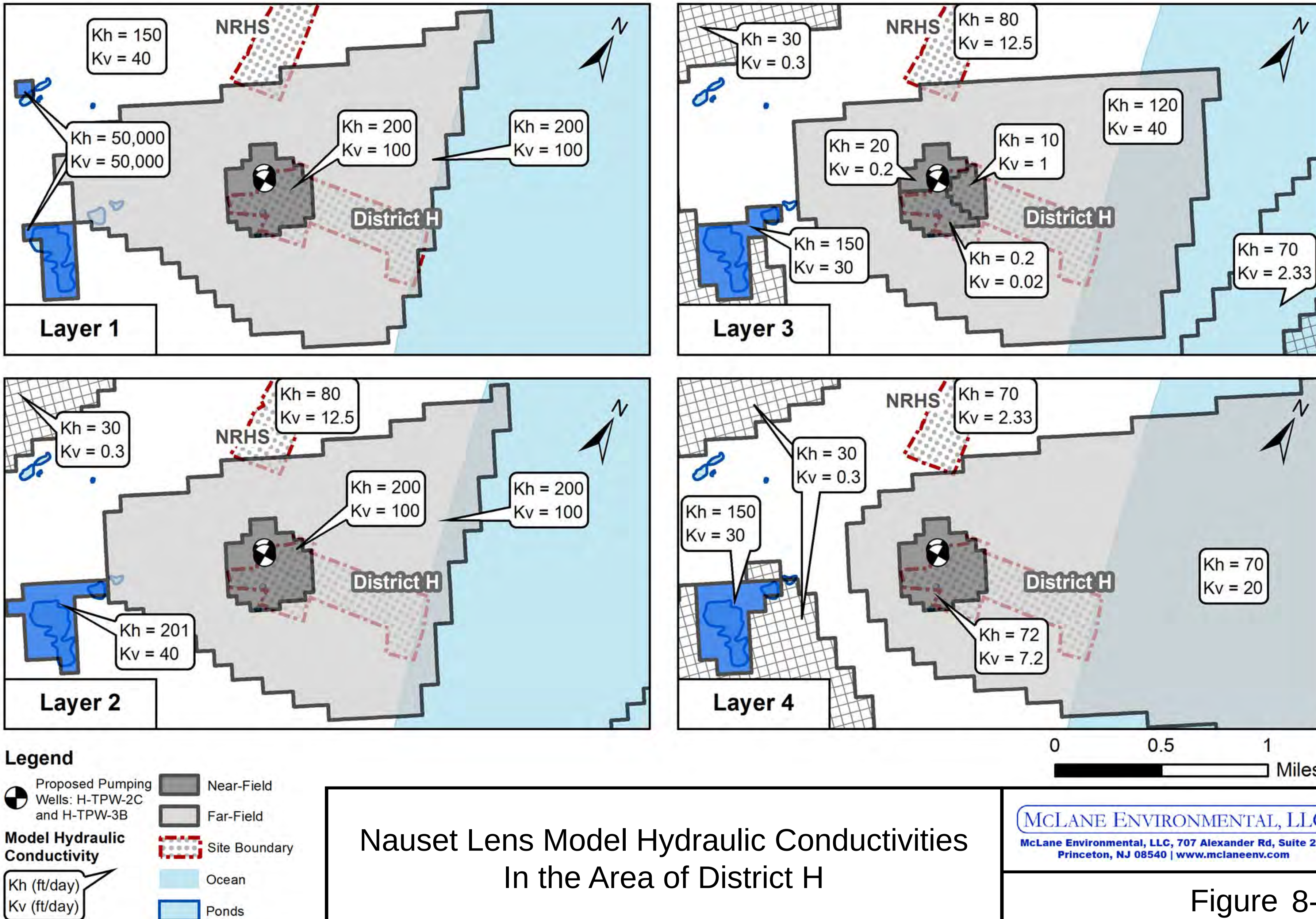
Figure 8-1



Nauset Lens Model Hydraulic Conductivities
In the Area of District H

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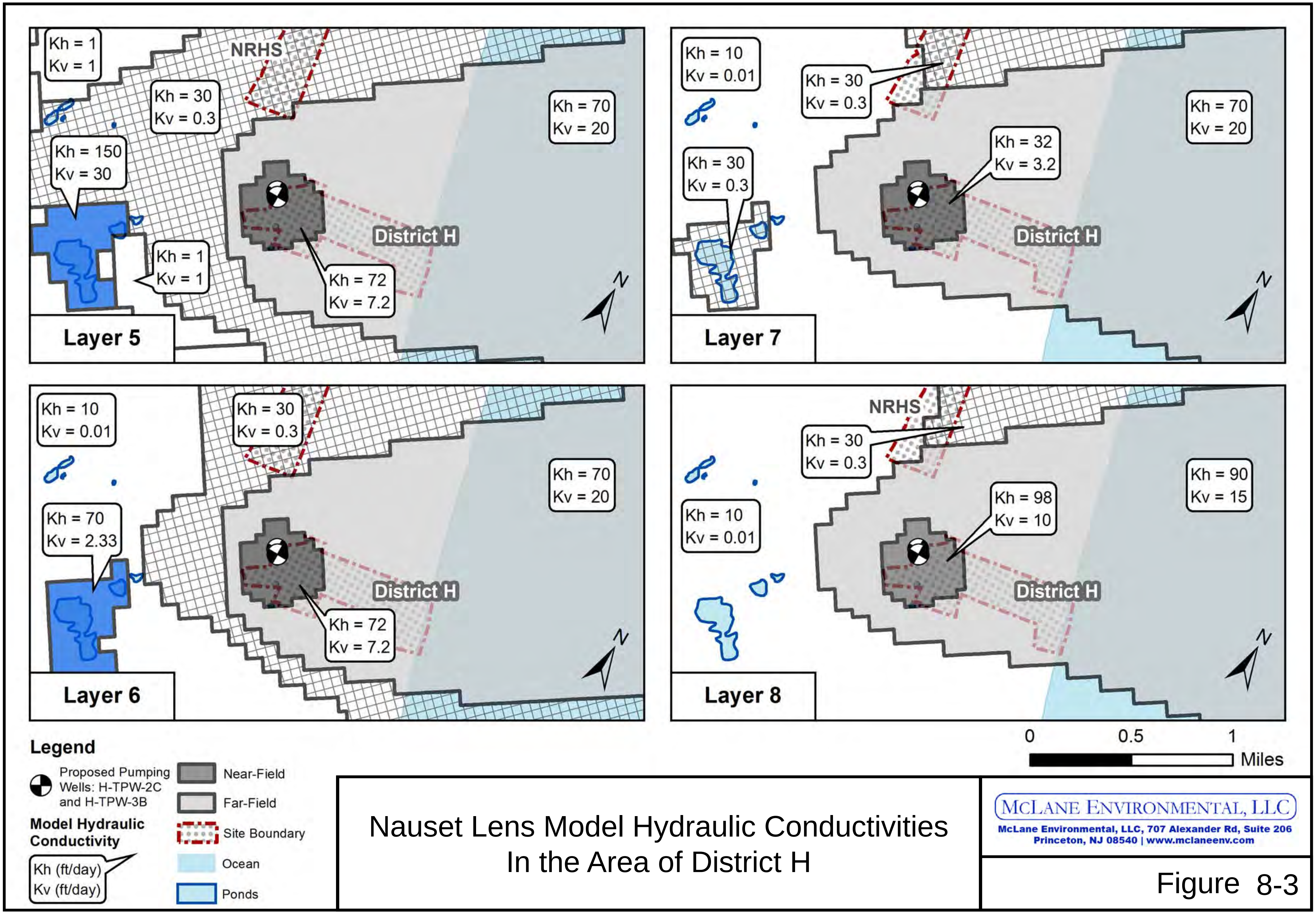
Figure 8-2



Nauset Lens Model Hydraulic Conductivities
In the Area of District H

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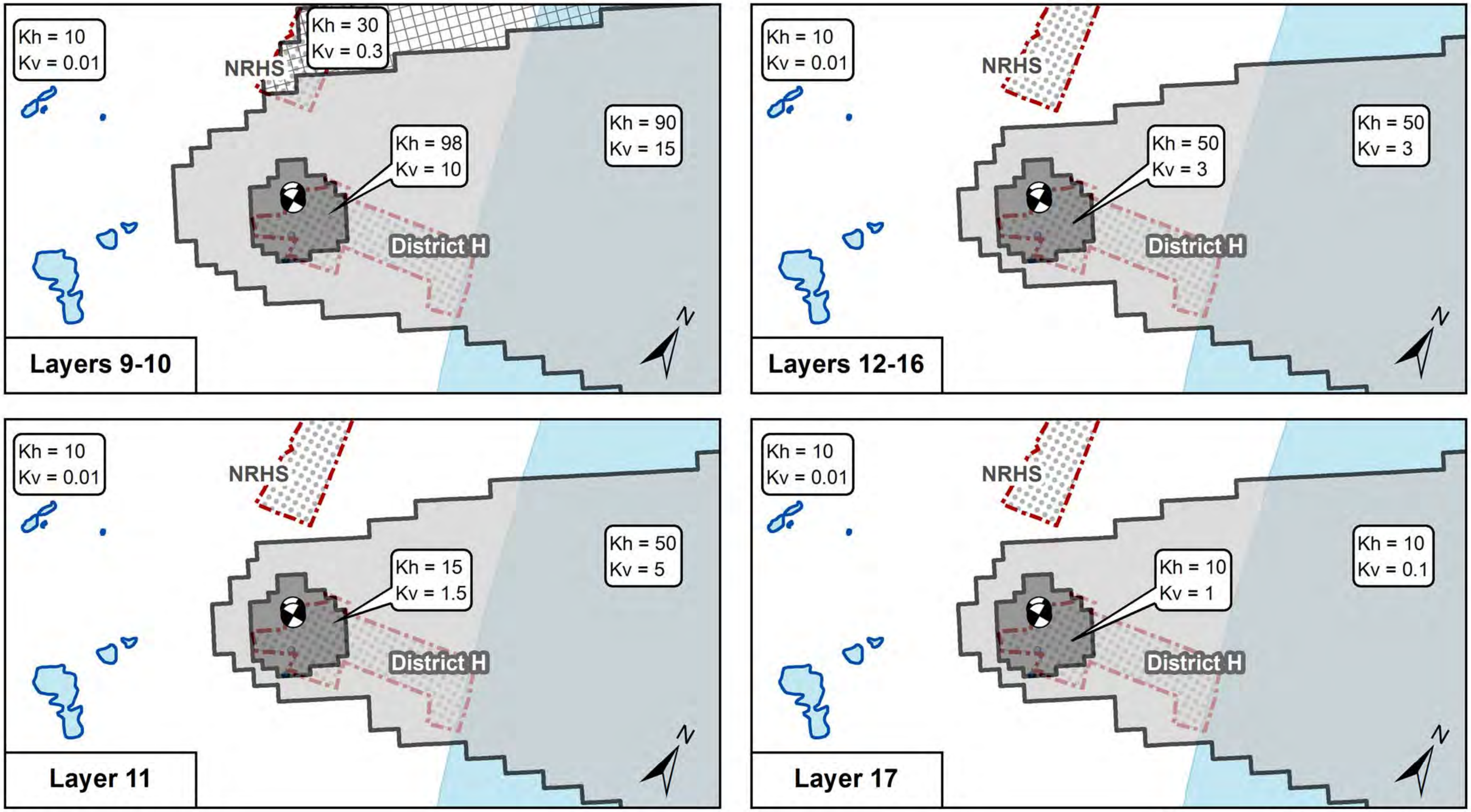
Figure 8-3



Legend

Proposed Pumping Wells: H-TPW-2C and H-TPW-3B

Model Hydraulic Conductivity

Kh (ft/day)
Kv (ft/day)

Near-Field
Far-Field
Site Boundary
Ocean
Ponds

0 0.5 1 Miles

Nauset Lens Model Hydraulic Conductivities
In the Area of District H

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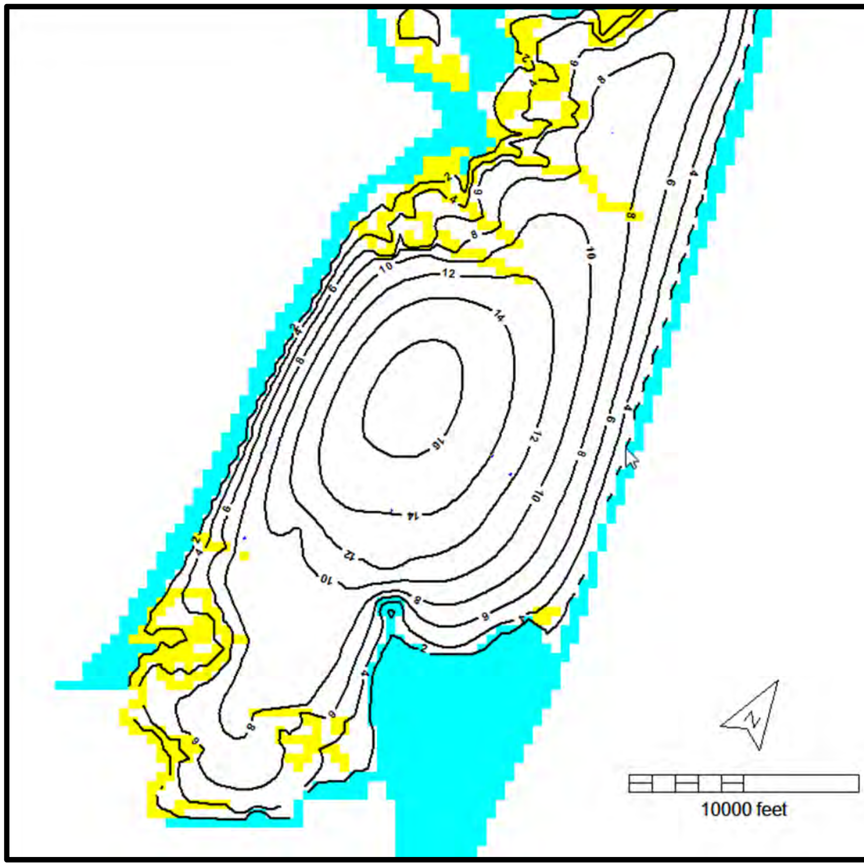
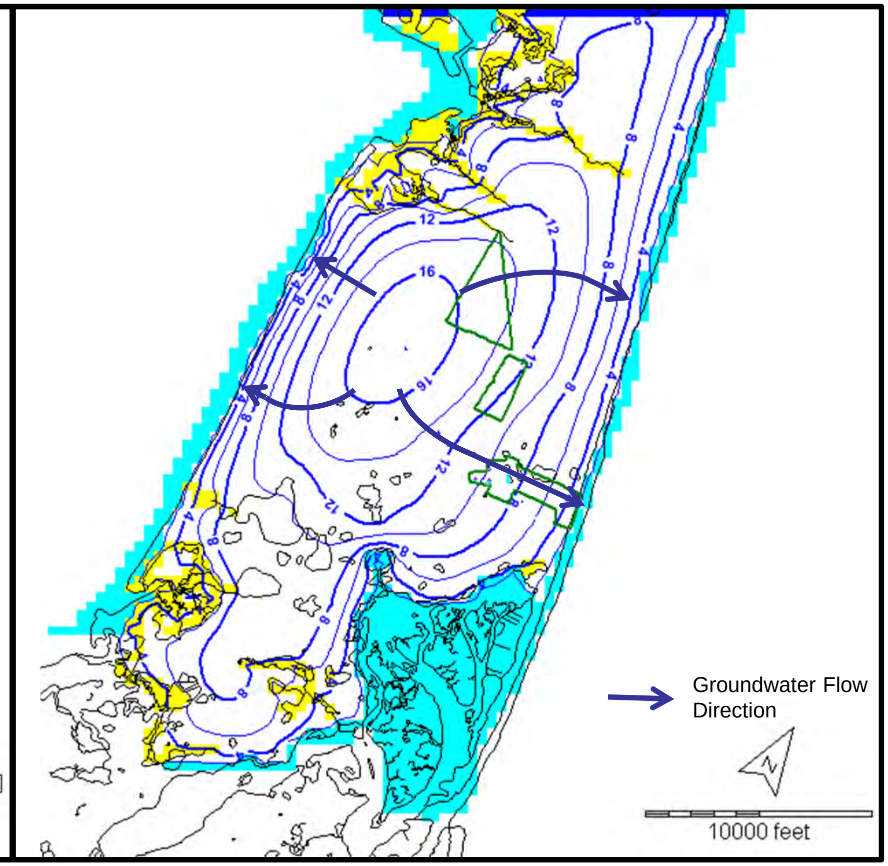
Figure 8-4

Lower Cape Model
Water Table Contours



Nauset Lens Model
Water Table Contours



Lower Cape Model and Nauset Lens Model Contours

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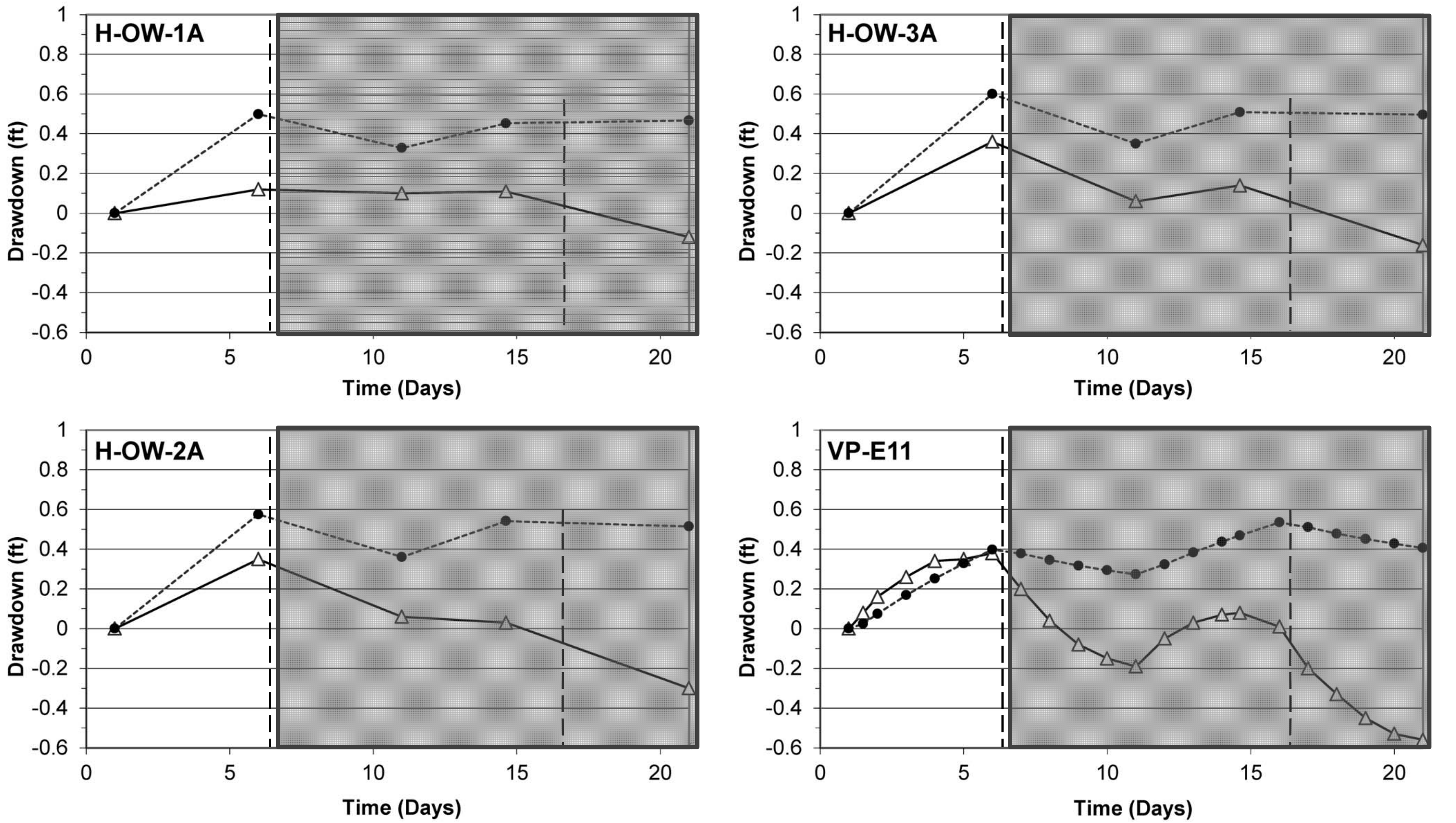
Figure 8-5



- Observed
- Simulated
- Pump Turned Off
- Data not used in calibration due to the influence of seasonal recharge

Observed vs. Simulated Drawdown in Observation Wells – Zone A

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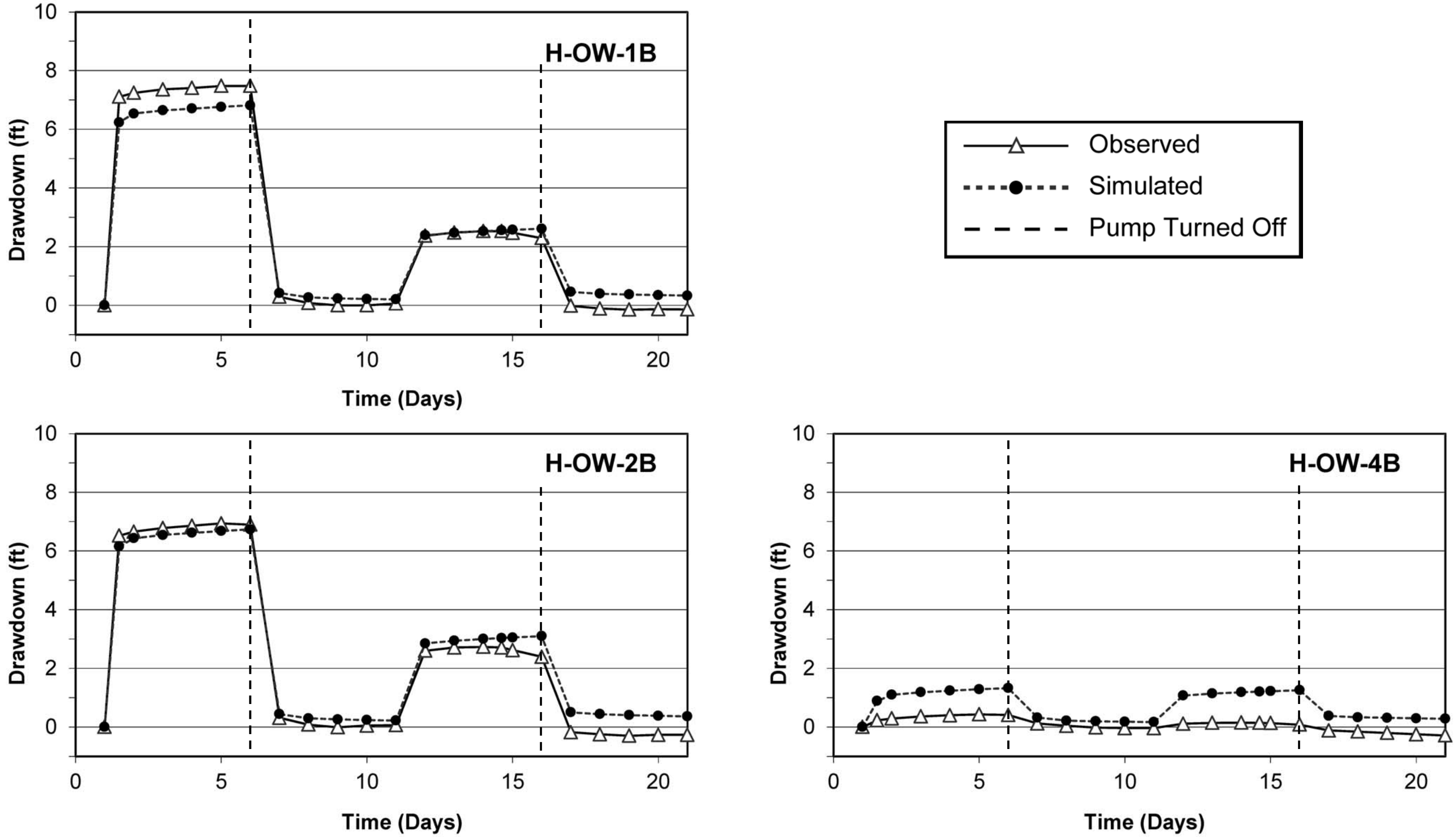
Figure 8-6



Observed vs. Simulated Drawdown in Observation Wells – Zone B

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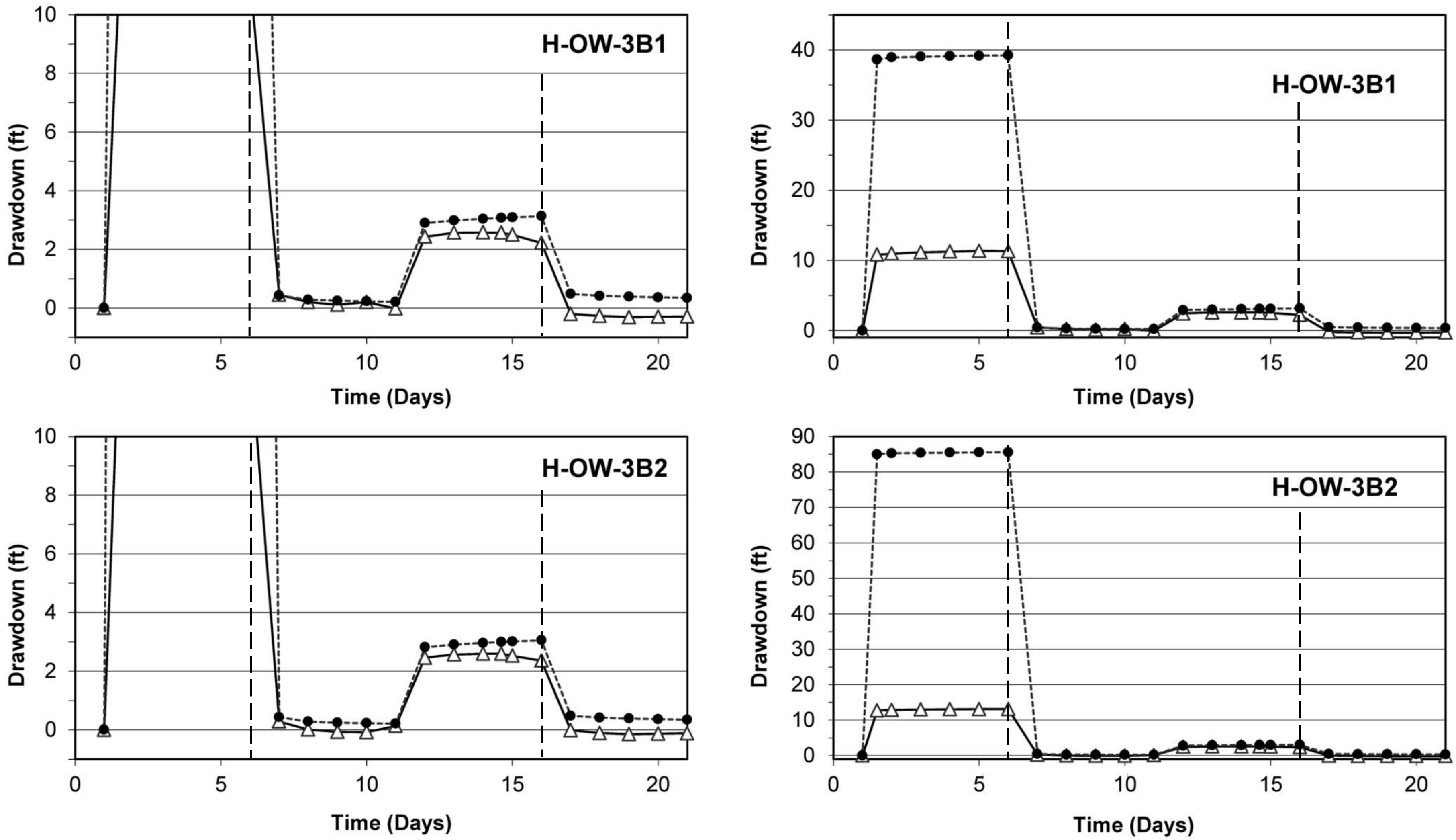
Figure 8-7



Observed
Simulated
Pump Turned Off

Observed vs. Simulated Drawdown in Observation Wells – Zone B

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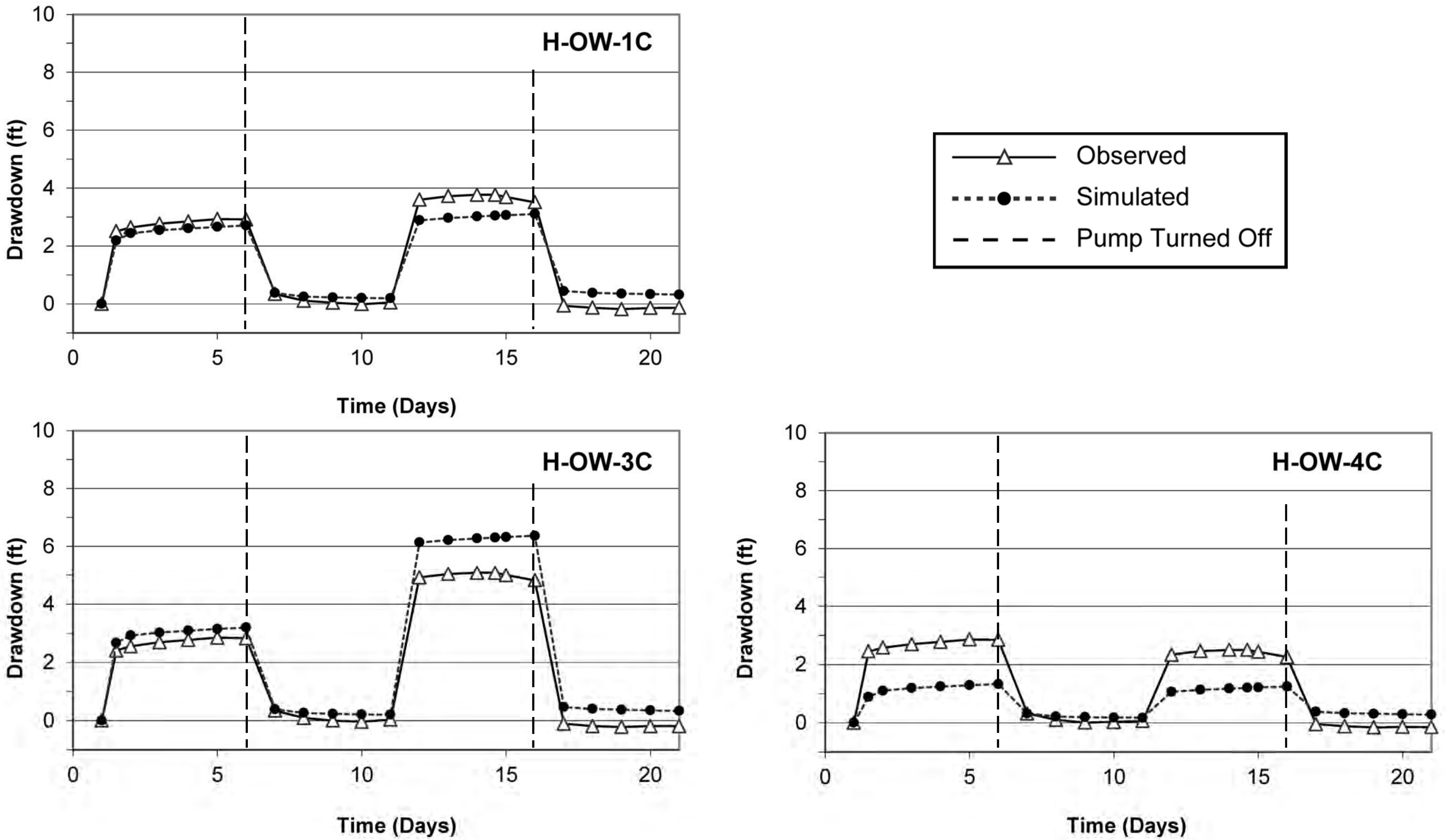
Figure 8-8



Observed vs. Simulated Drawdown in Observation Wells – Zone C

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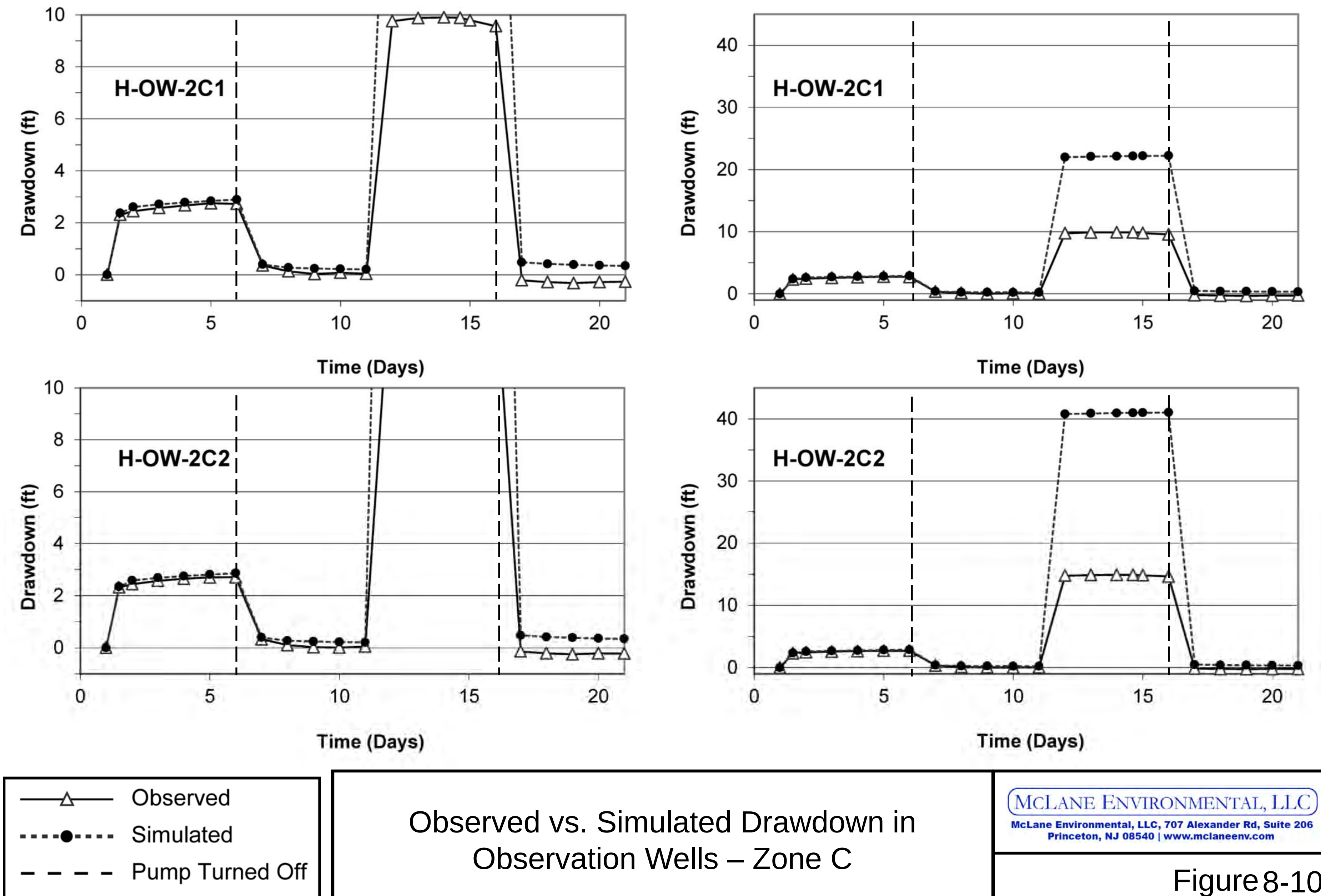
Figure 8-9



Observed vs. Simulated Drawdown in Observation Wells – Zone C

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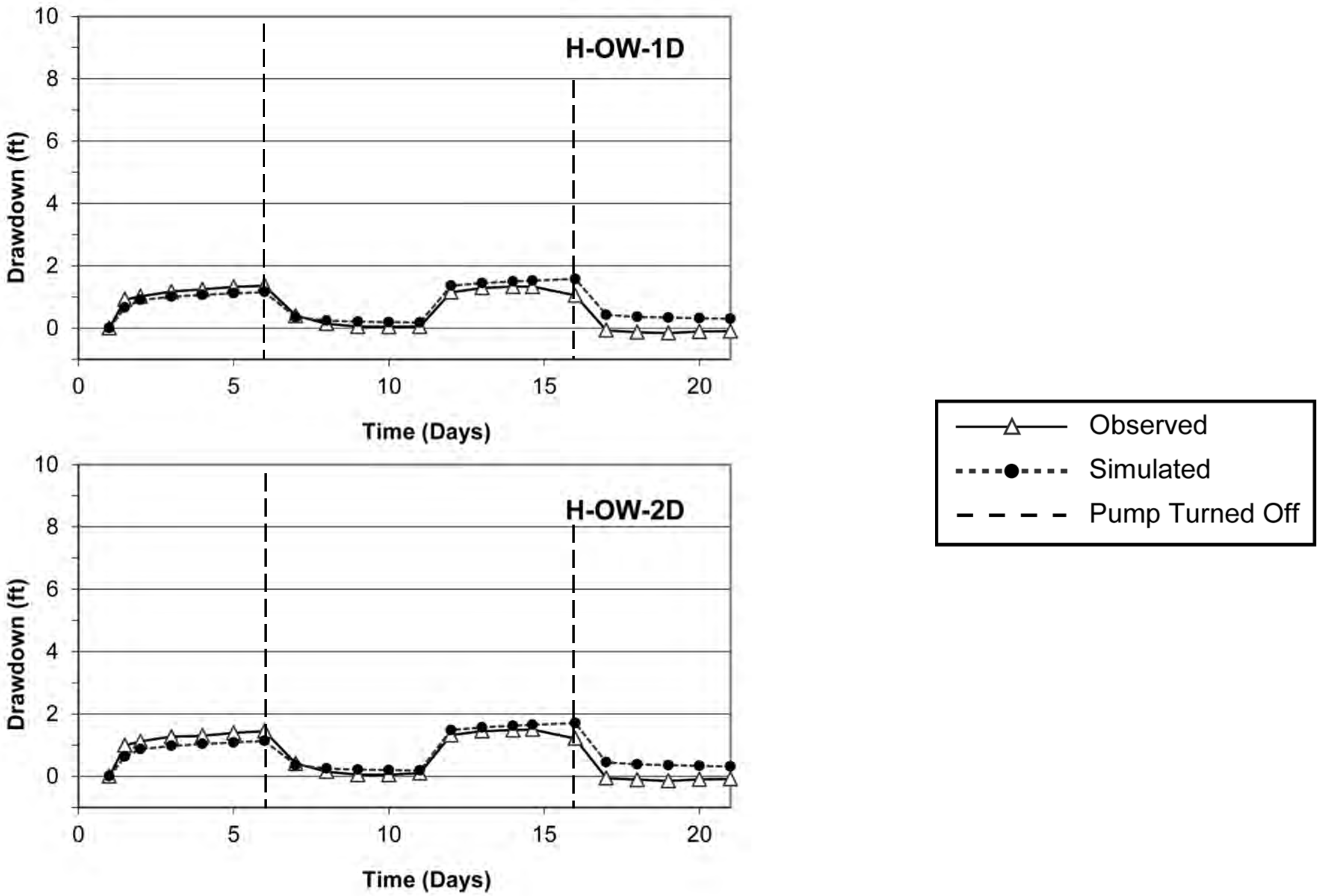
Figure 8-10



Observed vs. Simulated Drawdown in Observation Wells – Zone D

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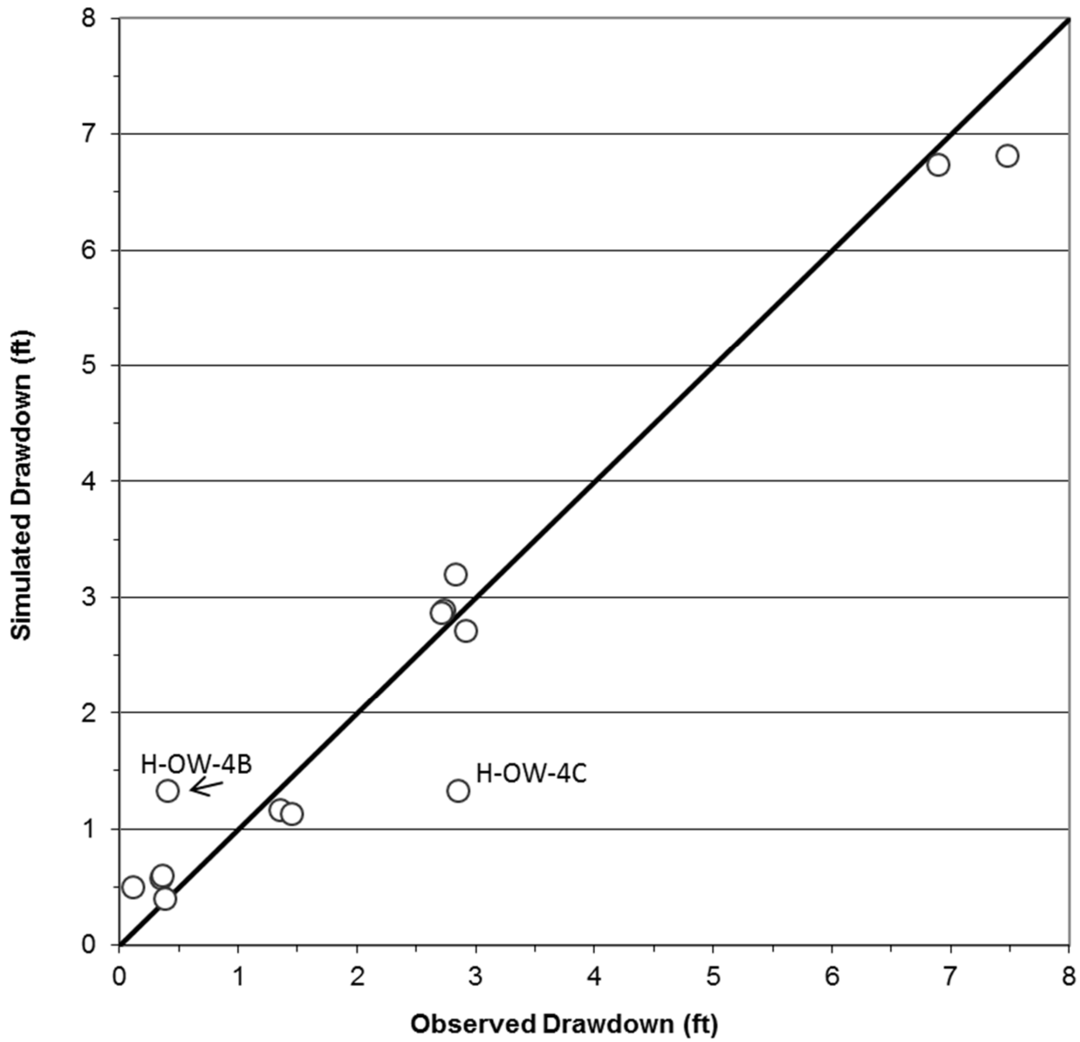
Figure 8-11



RMSE = 0.30 ft

MAE = 0.26 ft

12 observations points

Calibration Results- Observed vs. Simulated Drawdown for TPW-3B

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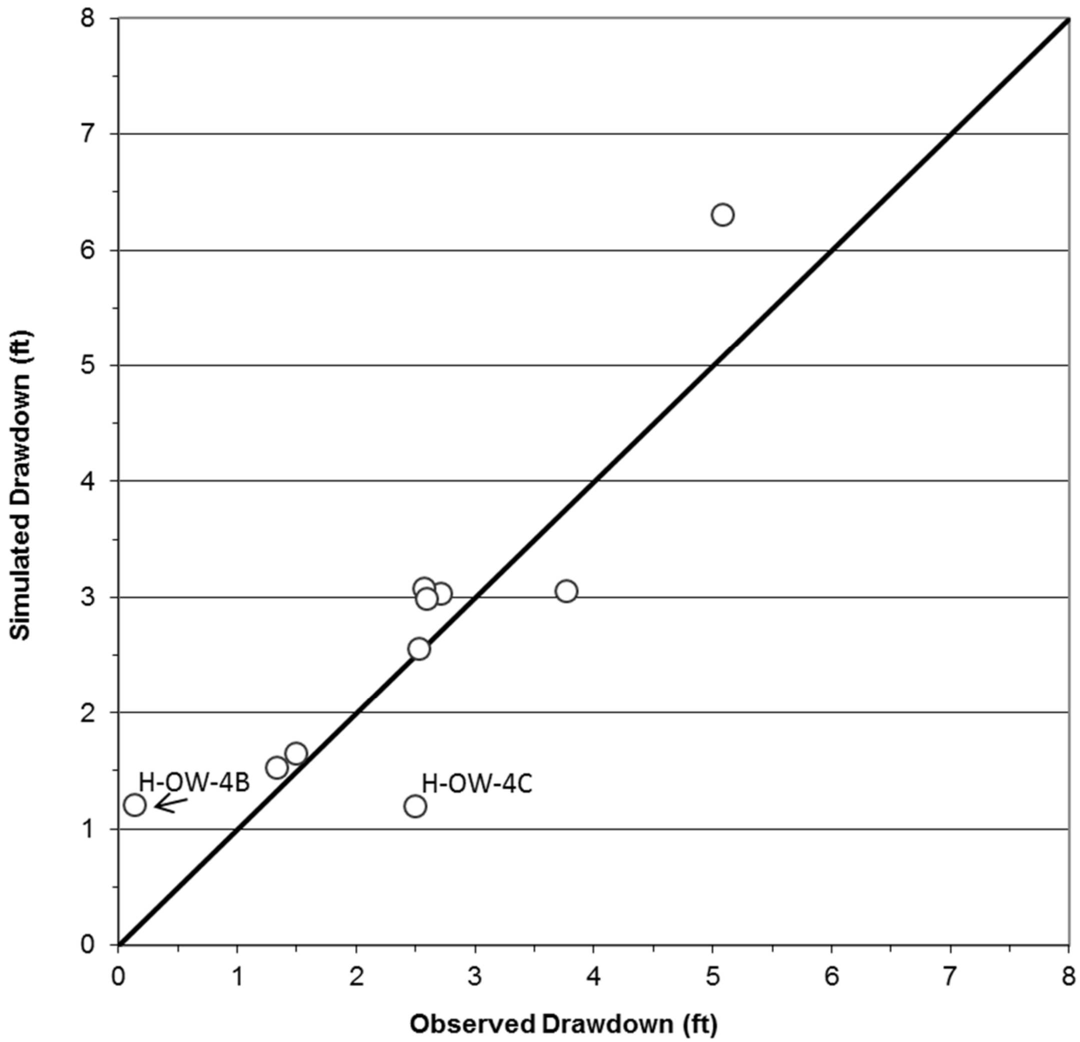
Figure 8-12



RMSE = 0.57 ft

MAE = 0.44 ft

8 observations points

Calibration Results- Observed vs. Simulated Drawdown for TPW-2C

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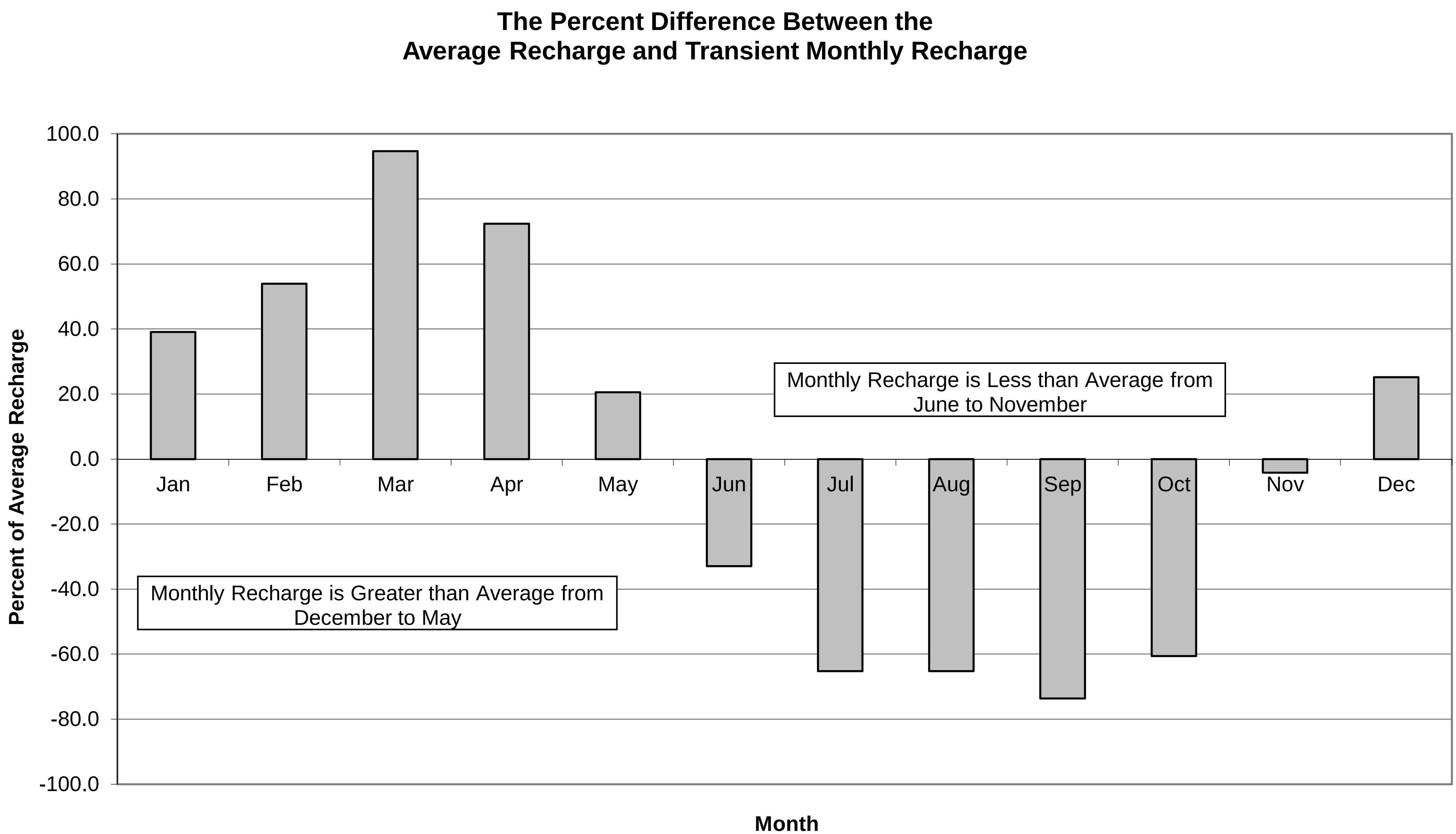
Figure 8-13



Percent Difference Between Transient Monthly Recharge and Average Monthly Recharge

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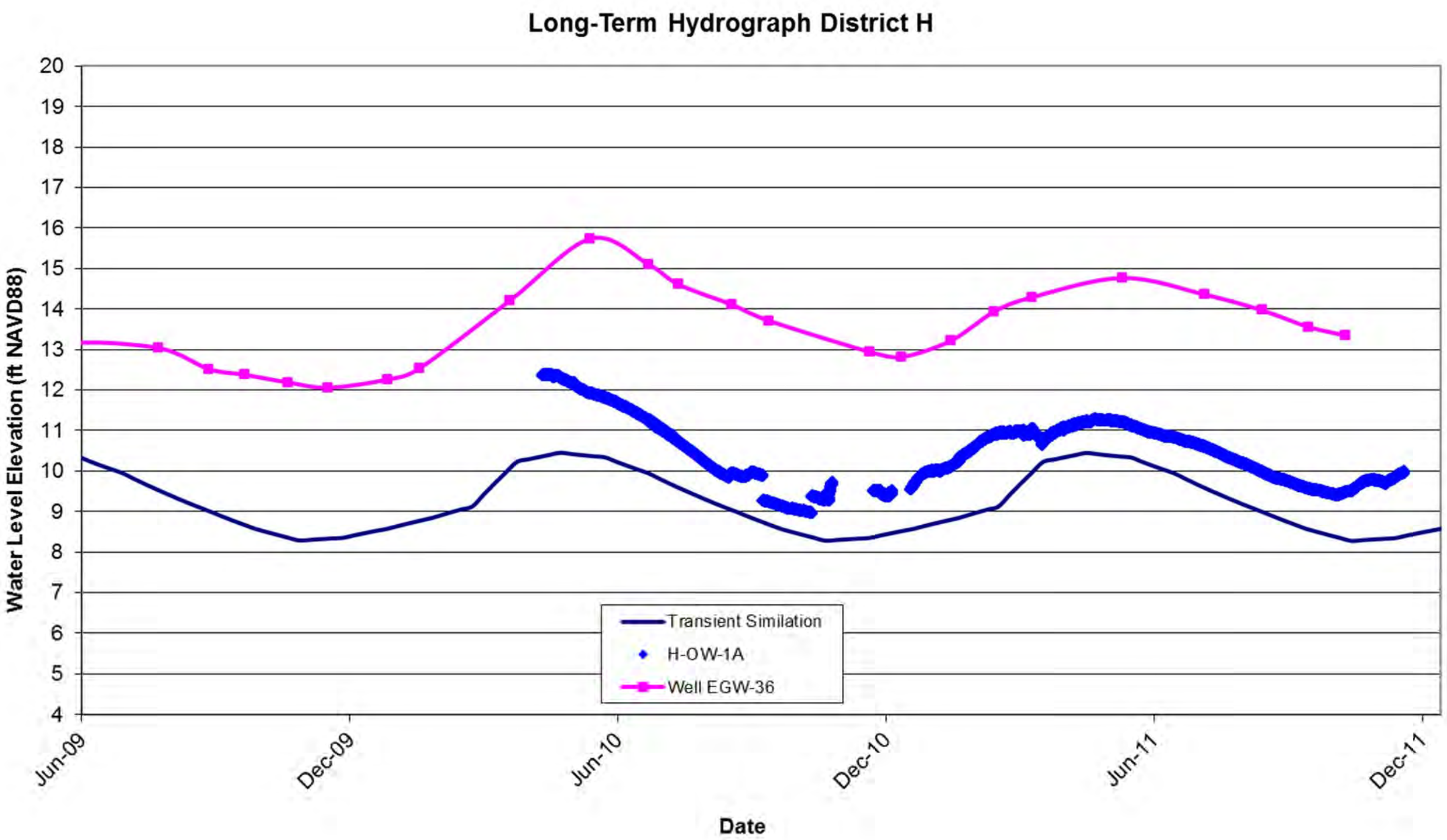
Figure 8-14



Simulated Groundwater Levels at the District H Well Field

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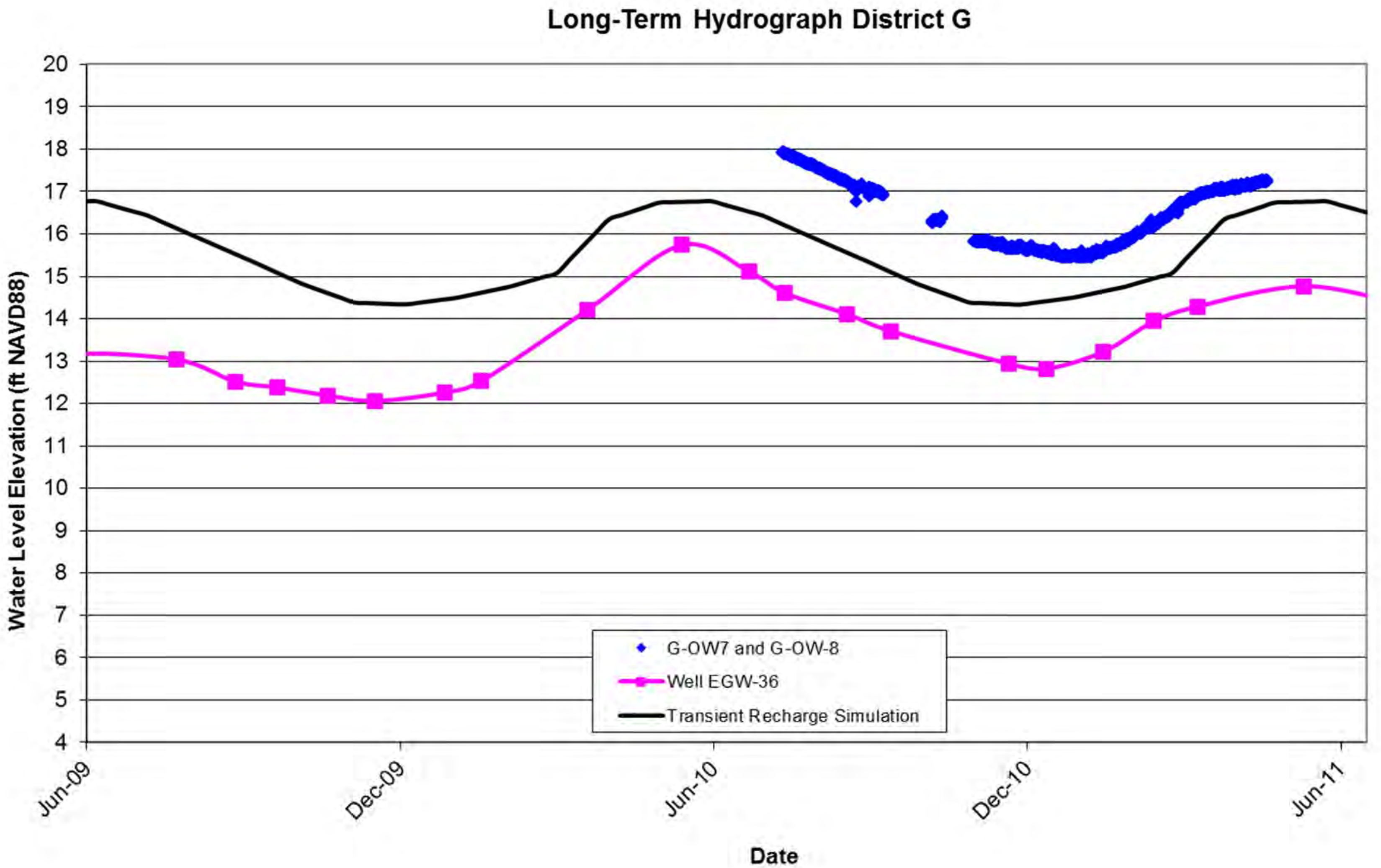
Figure 8-15



Simulated Groundwater Levels at the District G Well Field

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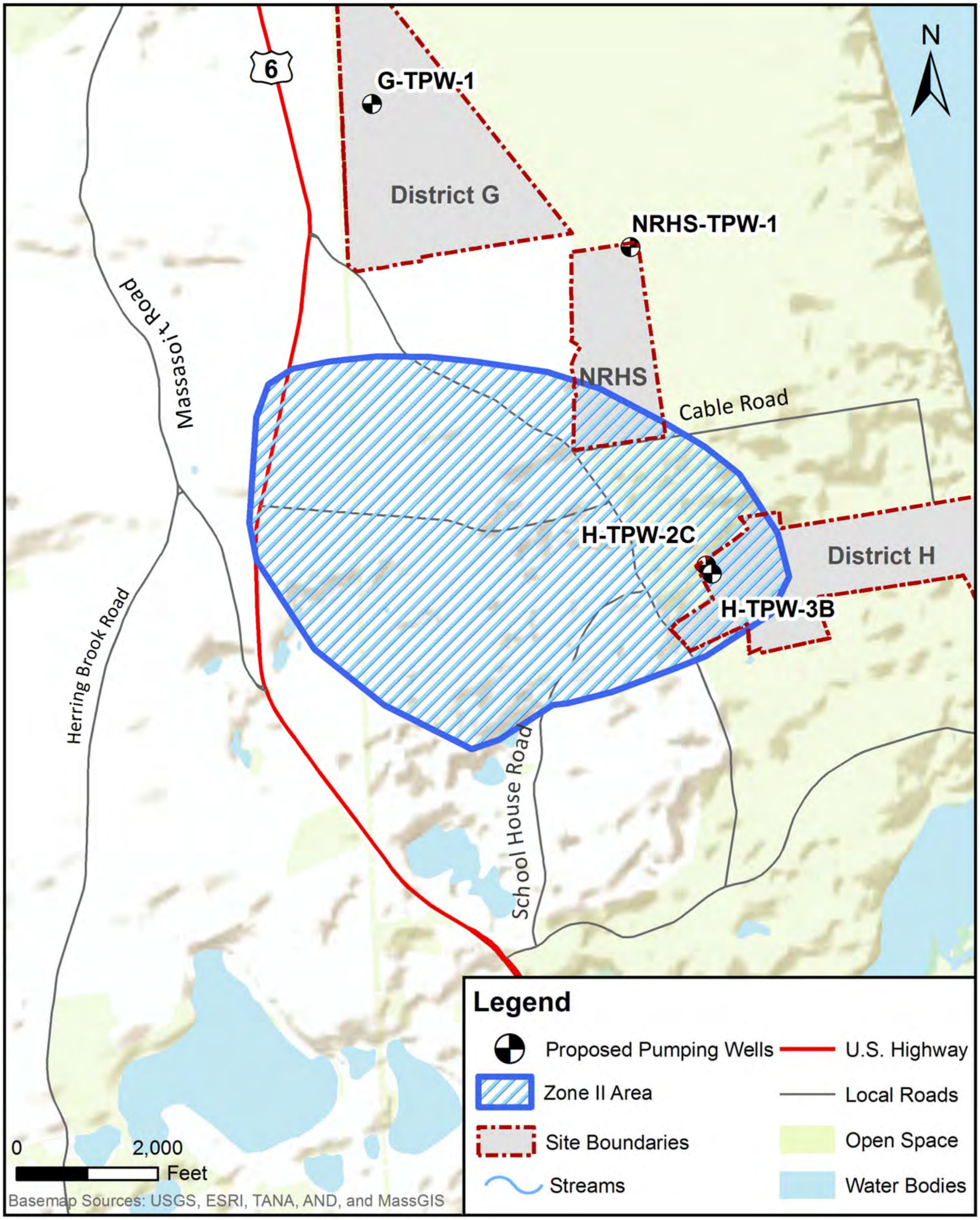
Figure 8-16



District H Zone II Area –
Pumping H-TPW-3B at 1.31 MGD

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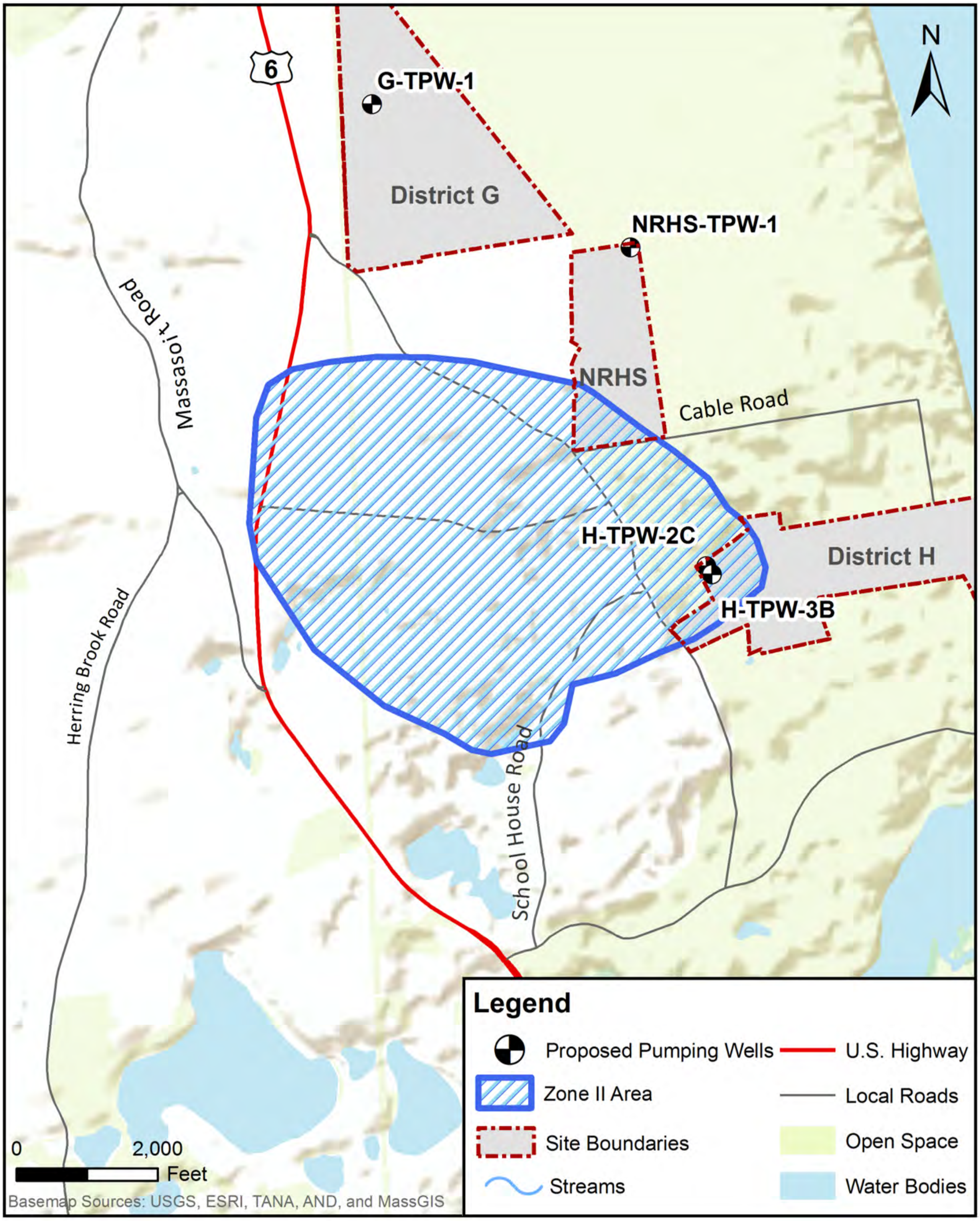
Figure 10-1



District H Zone II Area –
Pumping H-TPW-2C at 1.31 MGD

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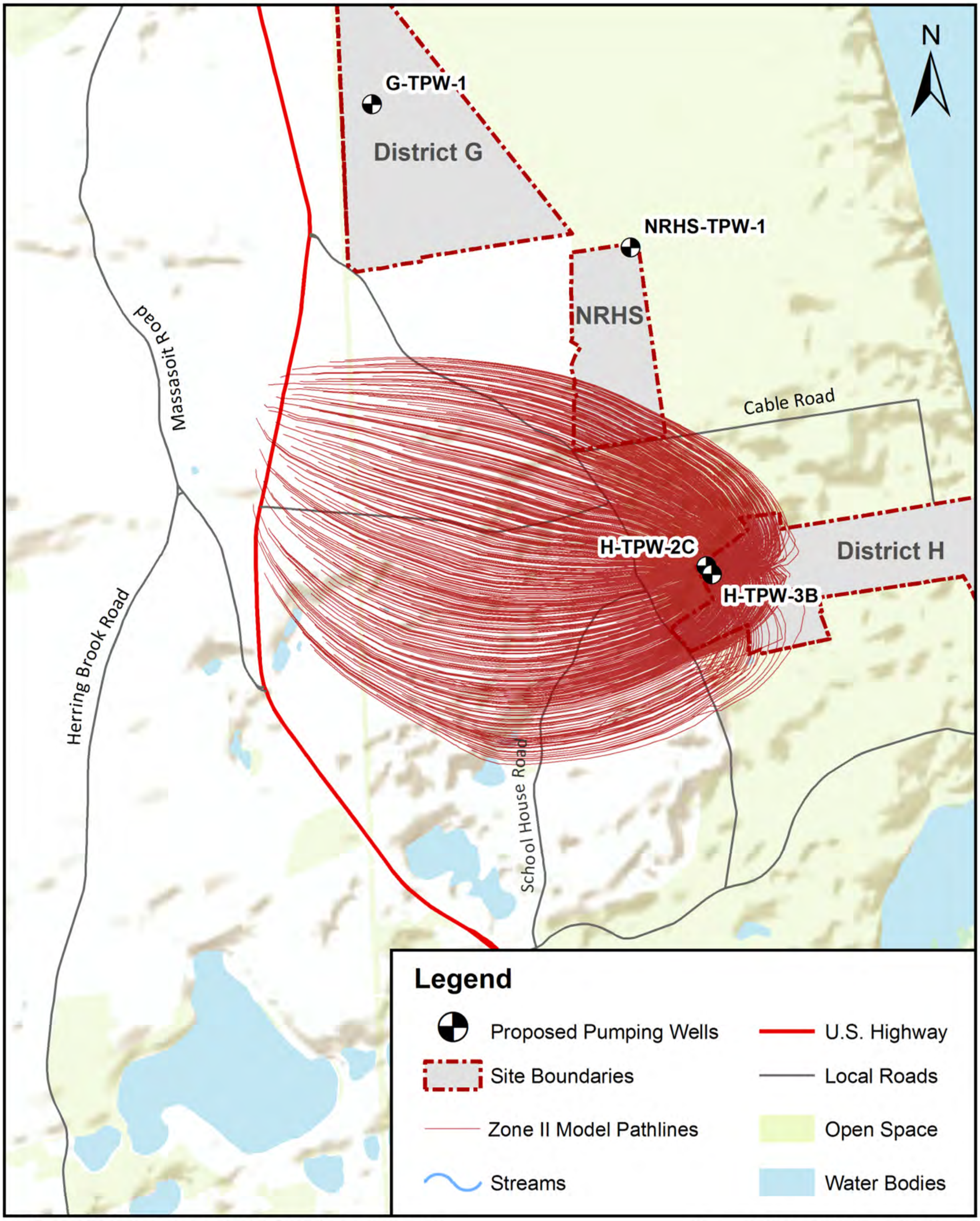
Figure 10-2



Basemap Sources: USGS, ESRI, TANA, AND, and MassGIS

District H Model Pathlines - Pumping H-TPW-3B at 1.31 MGD

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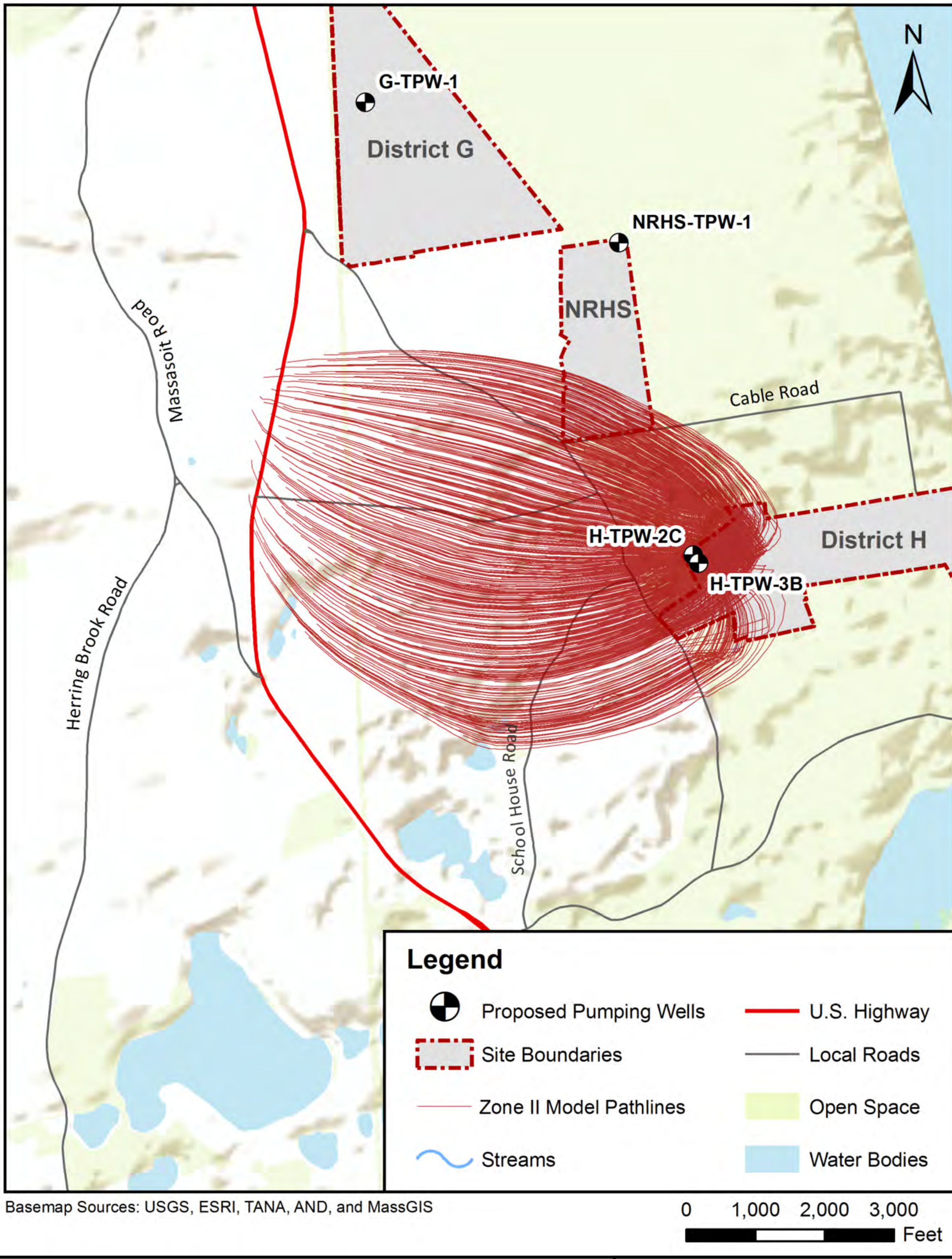
Figure 10-3



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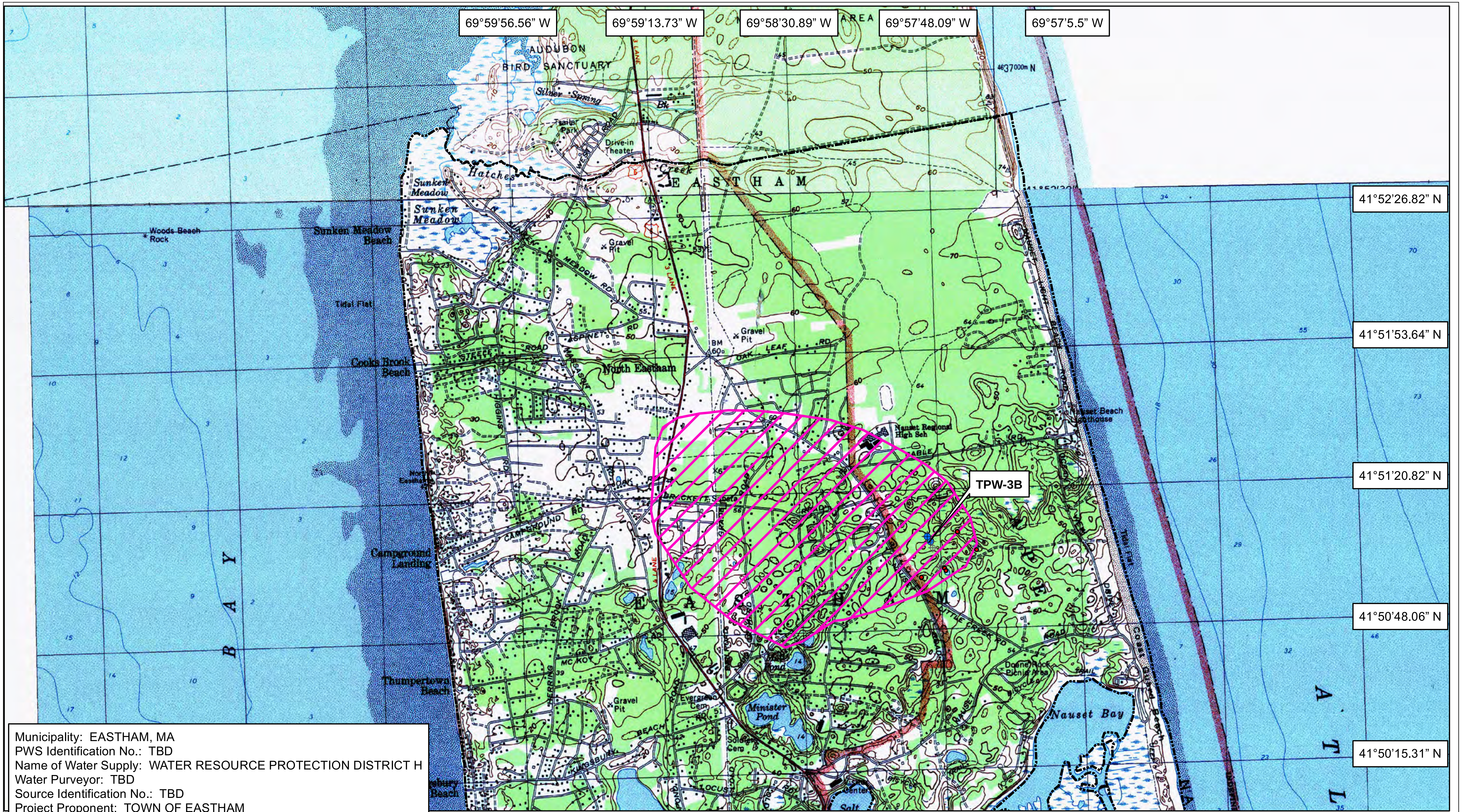
District H Model Pathlines -
Pumping H-TPW-2C at 1.31 MGD

Figure 10-4



Municipality: EASTHAM, MA
PWS Identification No.: TBD
Name of Water Supply: WATER RESOURCE PROTECTION DISTRICT H
Water Purveyor: TBD
Source Identification No.: TBD
Project Proponent: TOWN OF EASTHAM
Title of Study/Purpose of Delineation: ZONE II
Base Map Source: USGS
Date of Study Submittal: TBD

Latitude/Longitude of Source:

TPW-3B: 41 51' 9.108" N, 69 57' 50.422" W

0 0.25 0.5 1 Miles

Map Scale 1:25,000

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N W E S

Legend

Well Type

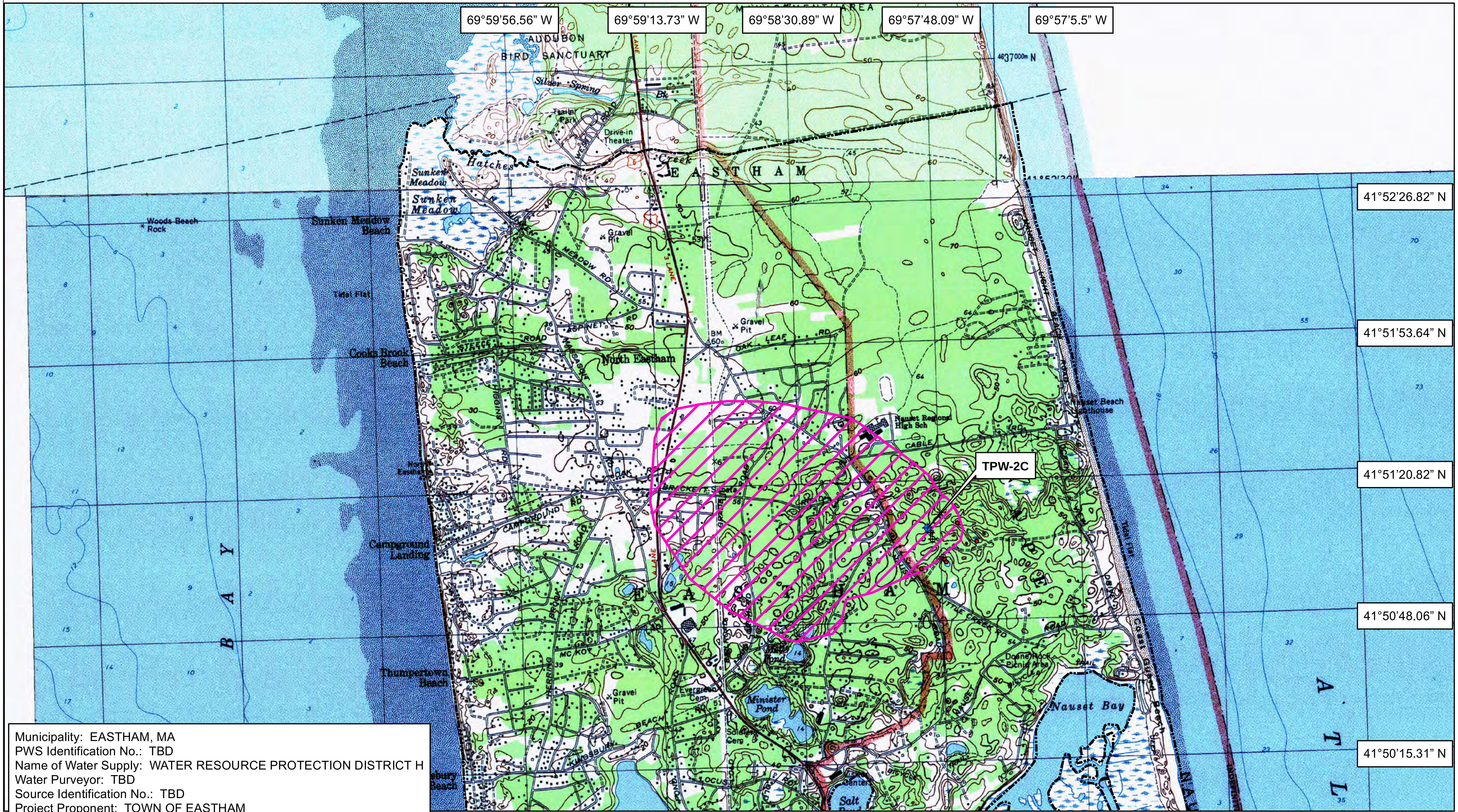
Test Production Well

Observation Well

Piezometer

Zone 2 TPW-3B (1.31 MGD)

Figure 10-5
District H Zone II Area - Pumping H
TPW-3B at 1.31 MGD on USGS Map
Eastham, MA



Municipality: EASTHAM, MA
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Water Purveyor: TBD
Source Identification No.: TBD
Project Proponent: TOWN OF EASTHAM
Title of Study/Purpose of Delineation: ZONE II
Base Map Source: USGS
Date of Study Submittal: TBD

Latitude/Longitude of Source:

TPW-2C: 41 51' 10.292" N, 69 57' 51.419" W

0 0.25 0.5 1 Miles

Map Scale 1:25,000

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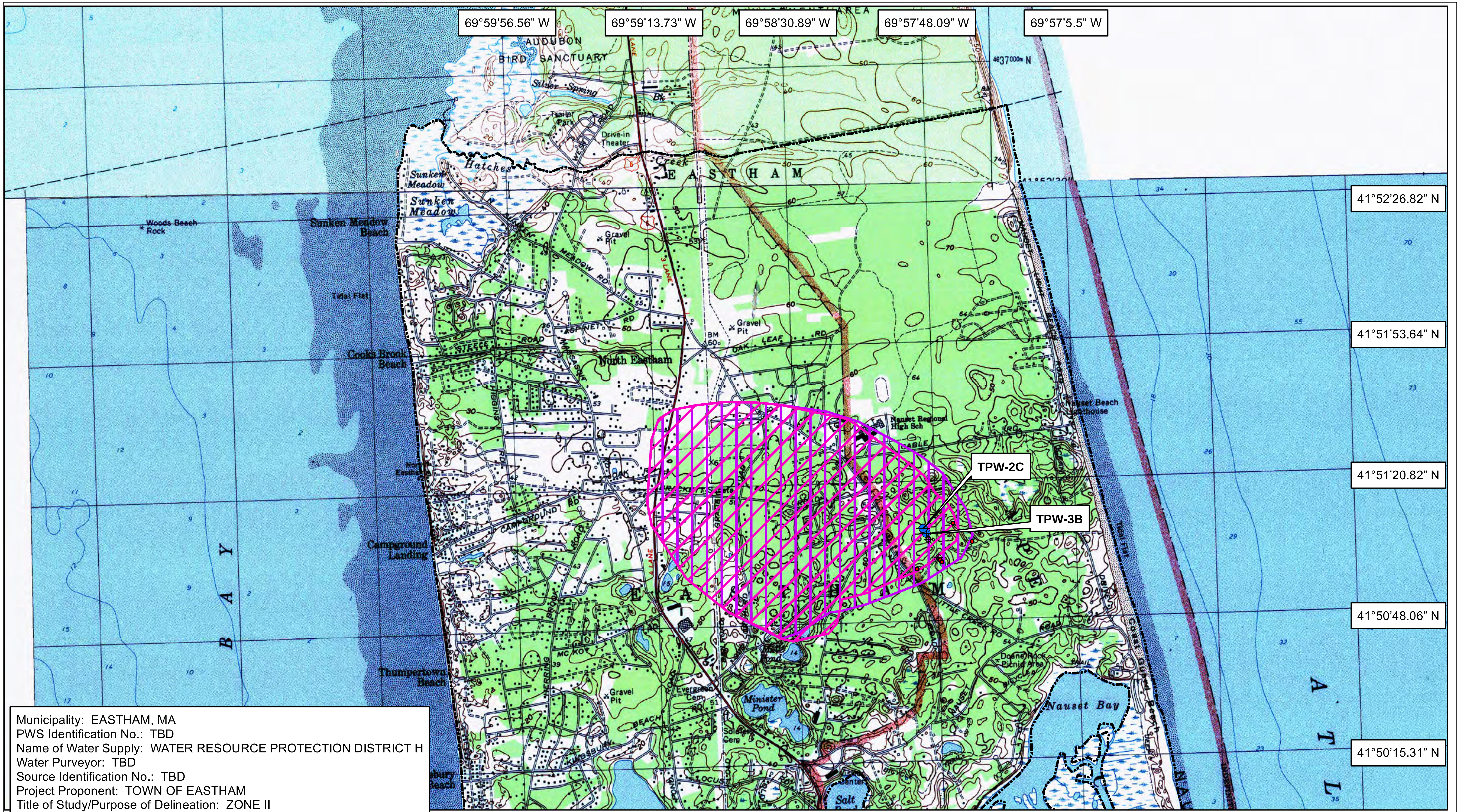
N
W E
S

Legend

Well_ID
- Production Well
- Observation Wells
- Piezometers
- Zone 2 TPW-2C (1.31 MGD)

Figure 10-6
District H Zone II Area - Pumping H
TPW-2C at 1.31 MGD on USGS Map
Eastham, MA



Municipality: EASTHAM, MA
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Latitude/Longitude of Source:

TPW-2C: 41 51' 10.292" N, 69 57' 51.419" W
TPW-3B: 41 51' 9.108" N, 69 57' 50.422" W

0 0.25 0.5 1 Miles

Map Scale 1:25,000

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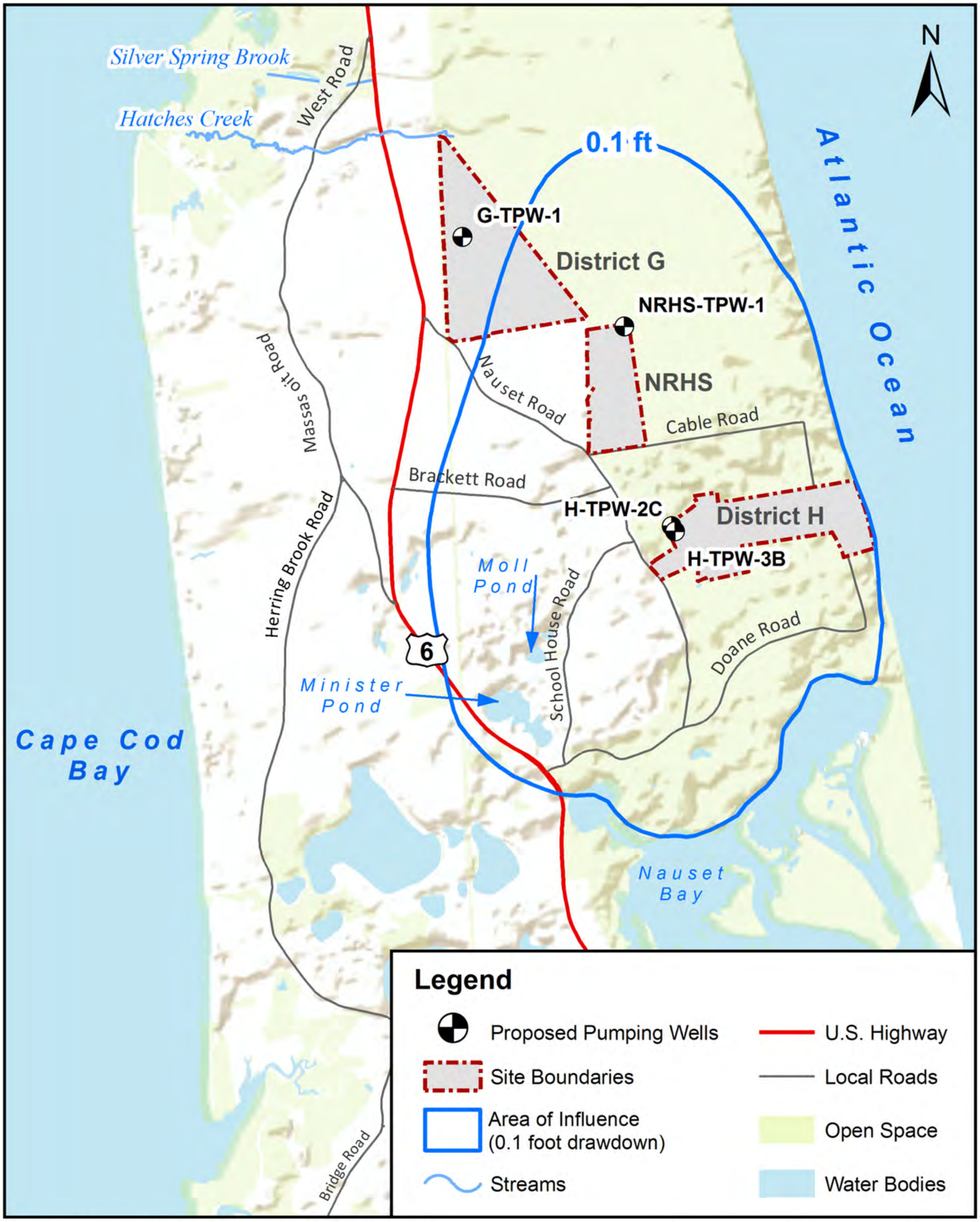
Legend

Well_ID
- Production Well
- Observation Well
- Piezometer
- Zone 2 TPW-2C (1.31 MGD)
- Zone 2 TPW-3B (1.31 MGD)

Figure 10-7
District H Zone II Area - Pumping H
TPW-3B or TPW-2C at 1.31 MGD on USGS Map
Eastham, MA



Basemap Sources: USGS, ESRI, TANA, AND, and MassGIS

0 0.5 1 Miles

District H Area of Influence –
Pumping H-TPW-3B at 1.31 MGD

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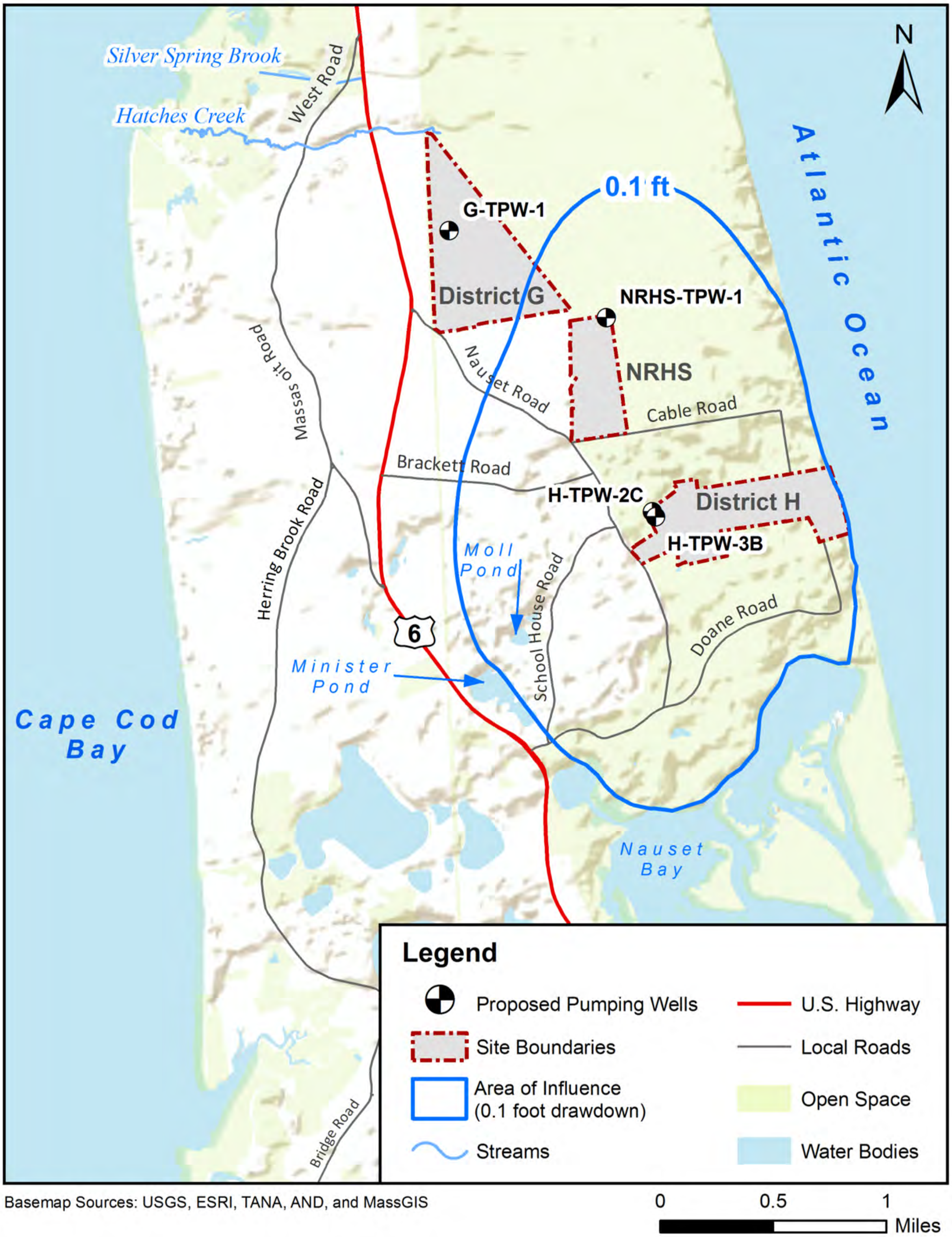
Figure 10-8



Basemap Sources: USGS, ESRI, TANA, AND, and MassGIS

District H Area of Influence – Pumping H-TPW-2C at 1.31 MGD

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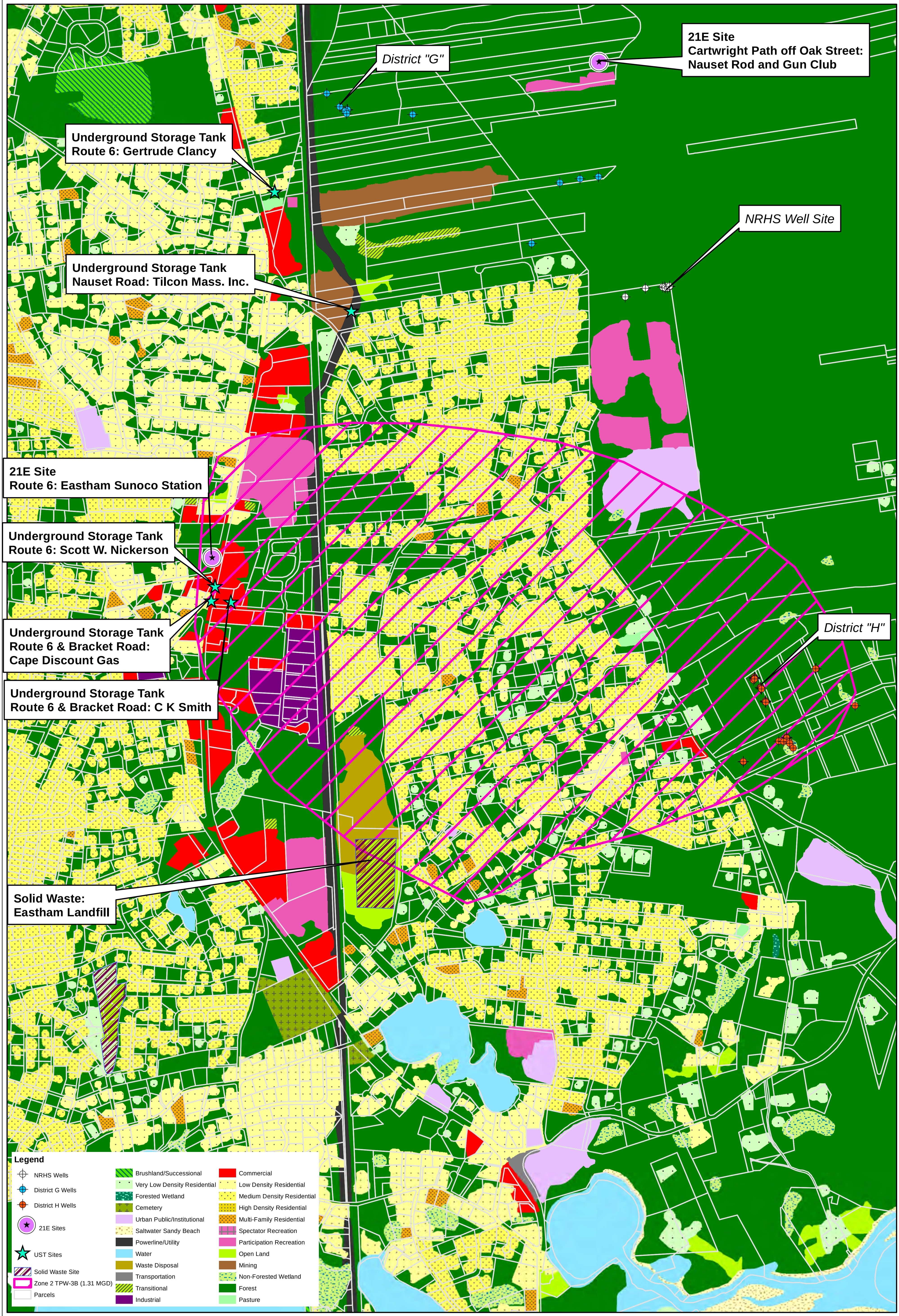
Figure 10-9



1 inch = 1,000 feet

0 500 1,000 2,000 Feet

N W E S

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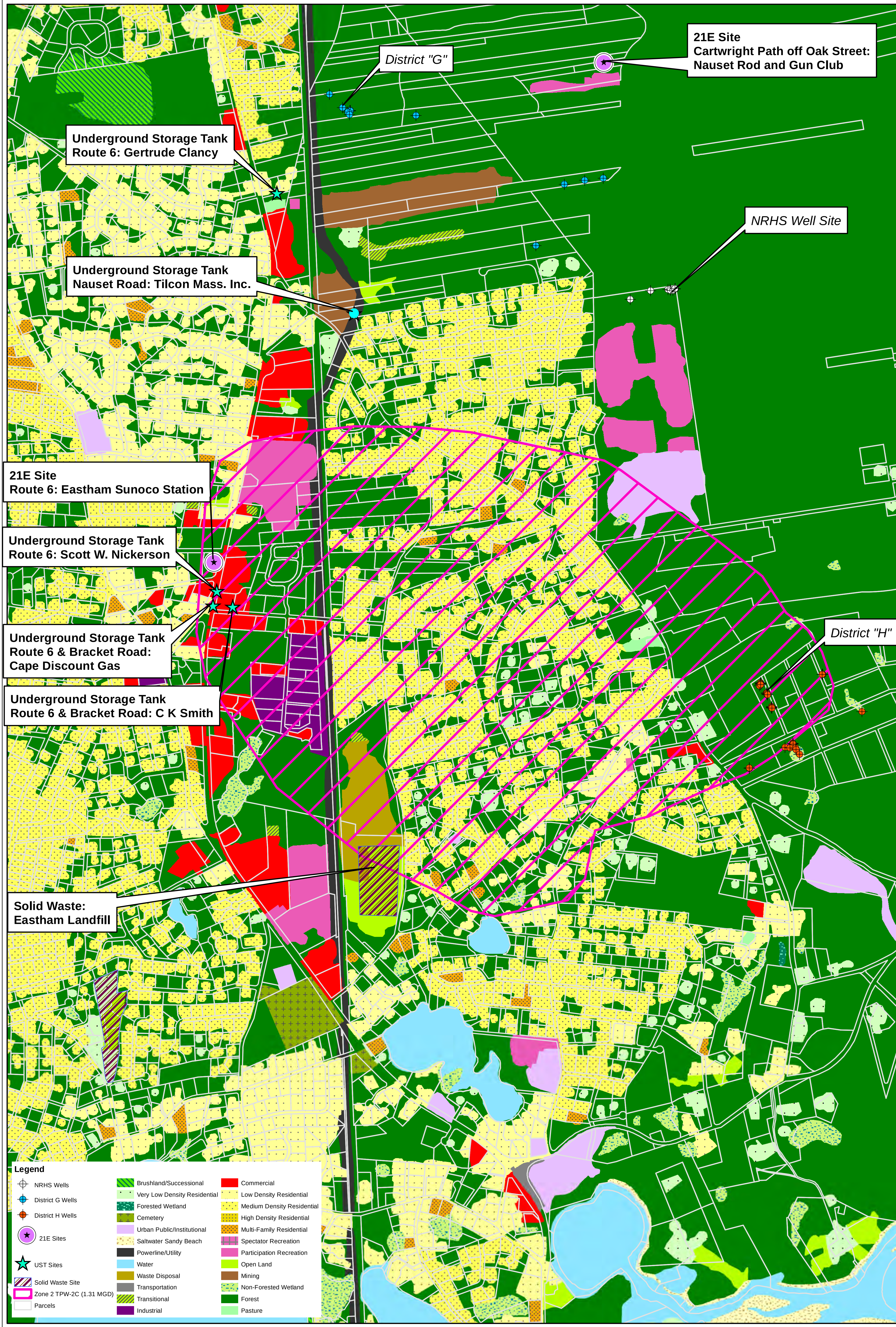
Figure 11-1
District H Zone II Area with Land Use - Pumping H TPW-3B at 1.31 MGD Eastham, MA



1 inch = 1,000 feet

0 500 1,000 2,000 Feet

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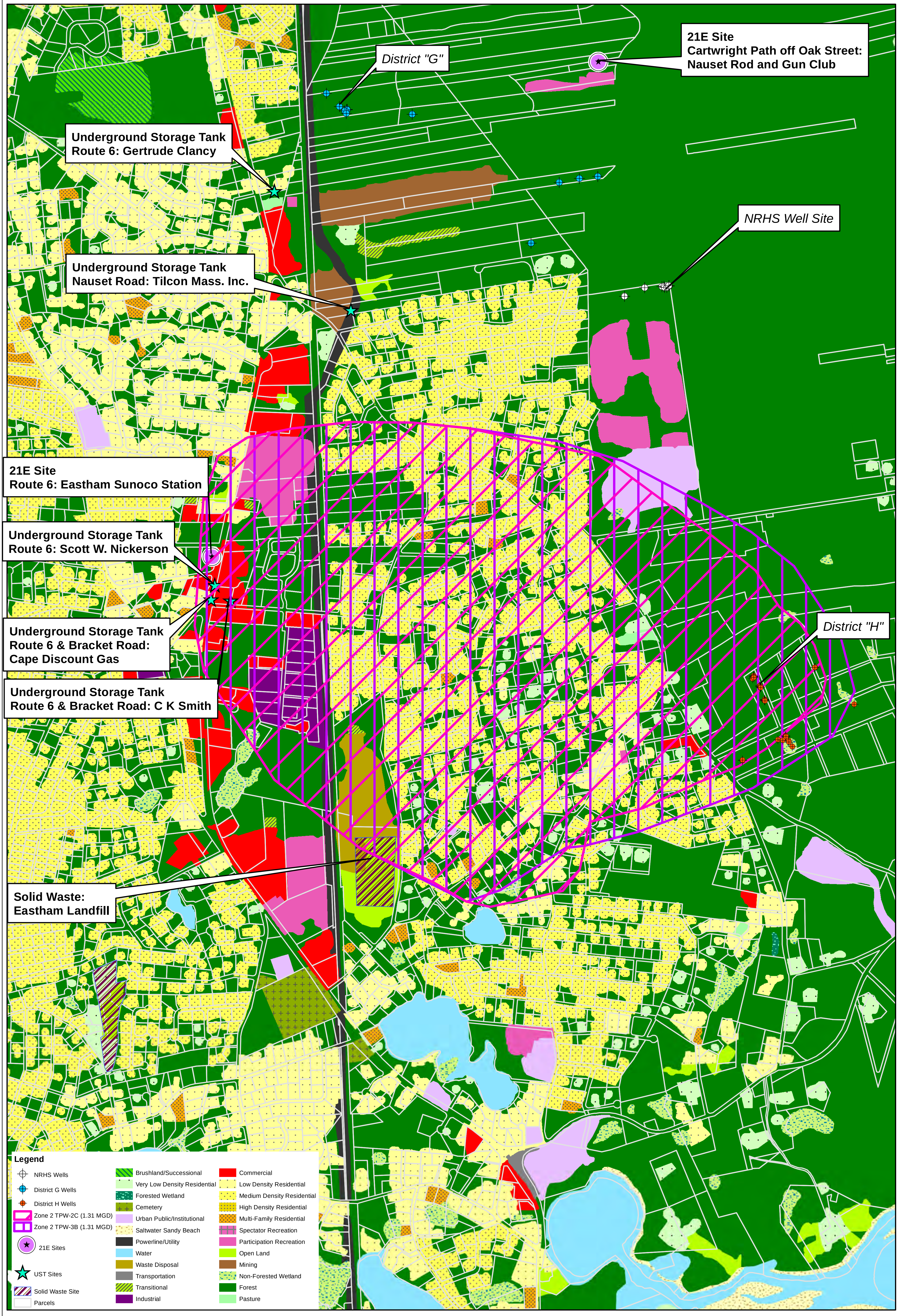
Figure 11-2
District H Zone II Area with Land Use - Pumping TPW-2C at 1.31 MGD
Eastham, MA



1 inch = 1,000 feet

0 500 1,000 2,000 Feet

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N W E S

Figure 11-3
District H Zone II Area with Land Use - Pumping TPW-3B or TPW-2C at 1.31 MGD
Eastham, MA

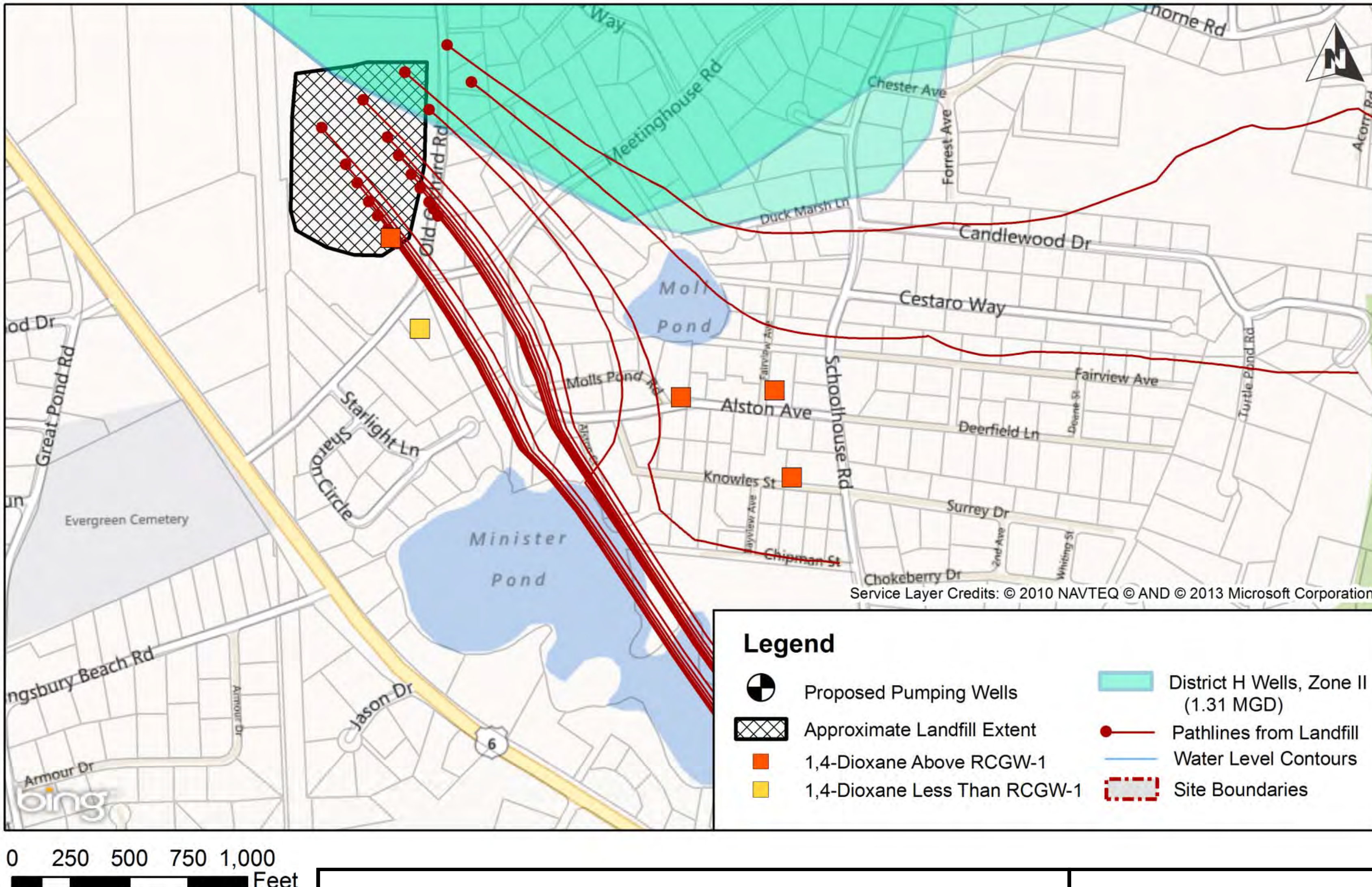

Figure 11-4: Relationship of District H Zone II to Landfill

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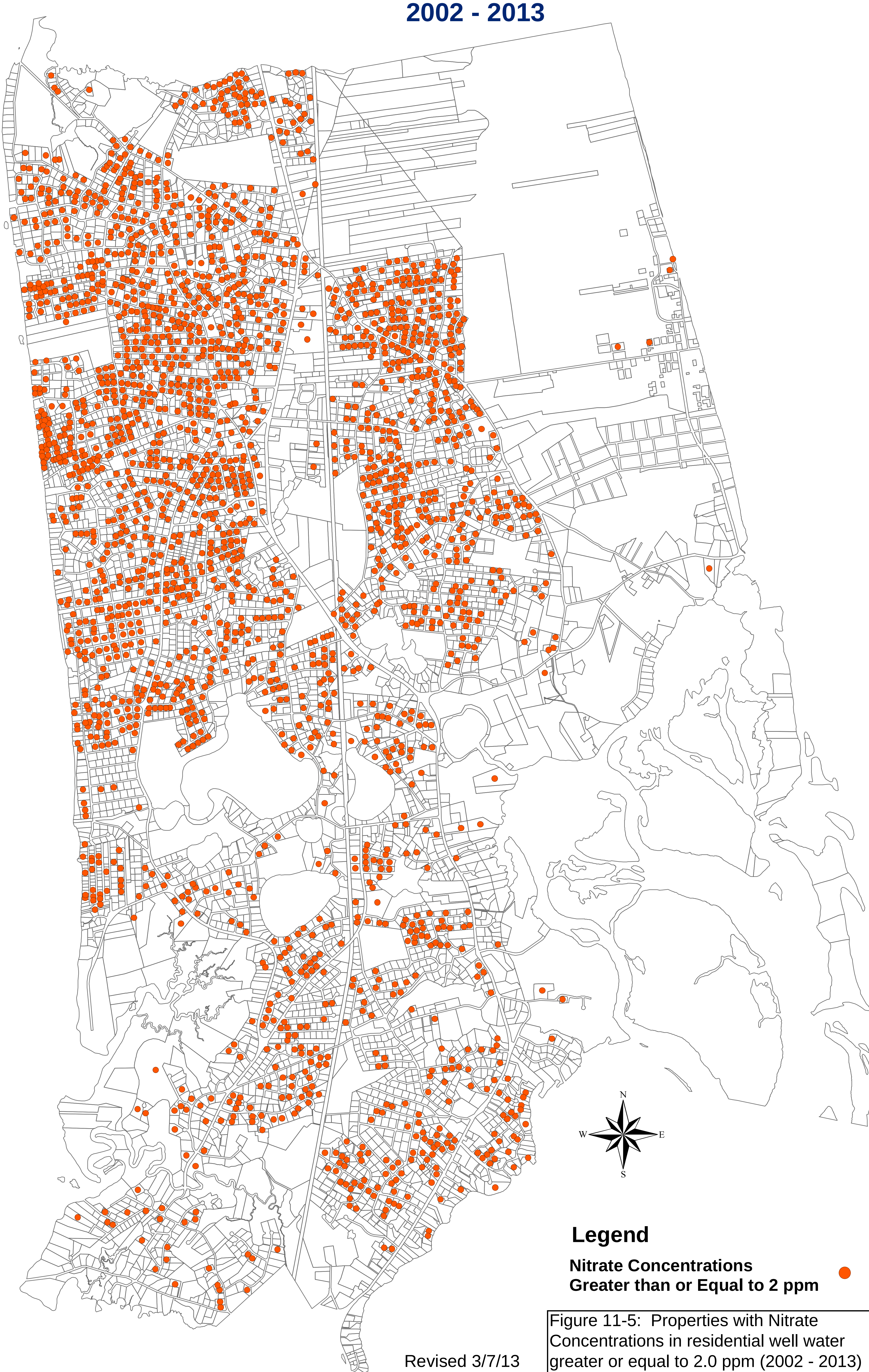
Eastham Water Survey Program - Nitrate Analysis
2002 - 2013



Legend

Nitrate Concentrations Greater than or Equal to 2 ppm

Revised 3/7/13

Figure 11-5: Properties with Nitrate Concentrations in residential well water greater or equal to 2.0 ppm (2002 - 2013)