MACTEC

CALCULATION COVER SHEET

Project Name: PSEG SITE ESP APPLICATION	**Project Number:** 6468-08-2251	**Calc Number:** 2251-ESP-GW-002	**Sheet #:** 1 of 114
Nuclear Safety Classification: SR NSR AO	**Subject: Groundwater Model**	**Discipline: Groundwater (GW)**	
Originator: Ronald Lewis	**Origination Date: September 17, 2009**	**Project Principal: Nelson Breton, CG (ME), LEP (CT)**	

Comments:

Rev #: A1	**Reason: Revised based on S&L comments**	By: RAL	**Date:** 12-4-09	**Approved:** STC
Rev #: A2	**Reason: Revised based on S&L comments**	By: RAL	**Date:** 12/7/09	**Approved:** STC
Rev #: A3	**Reason: Revised based on S&L comments**	By: RAL	**Date:** 12/12/09	**Approved:** STC
Rev #: A4	**Reason: Revised based on PSEG comments**	By: RAL	**Date:** 1/11/10	**Approved:** STC
Rev #: 0	**Reason: Issue record copy**	By: RAL	**Date:** 3/9/10	**Approved:** STC

DCN ESP726

MACTEC DESIGN VERIFICATION CONTROL SHEET

Design Verification Checklist
(excerpted from ANSI N.45.11 [1974 Edition] and ASME NQA-1-1994 Edition

Yes	No	N/A	Design Verification Element Note: Any items checked "No" automatically imply the design is not verified.
✓			Is the person performing the design verification qualified to originate the document?
✓			Is the design verification being performed by someone other than the supervisor of the originator?
✓			Were the design inputs correctly selected and incorporated into design?
✓			Are assumptions necessary to perform the design activity adequately described and reasonable? Where necessary, are assumptions identified for subsequent re-verifications when the detailed design activities are completed?
✓			Are the appropriate quality and quality assurance requirements specified?
		✓	Are the applicable codes, standards and regulatory requirements including issue and addenda properly identified, and their requirements for design met?
		✓	Have applicable construction and operating experiences been considered?
		✓	Have the design interface requirements been satisfied?
✓			Were appropriate design methods and computer programs used?
✓			Is the design output reasonable compared to design inputs?
		✓	Are the specified parts, equipment, and processes suitable for the required application?
		✓	Are the specified materials compatible with each other and the design environmental conditions to which the material will be exposed?
		✓	Have adequate maintenance features and requirements been specified?
		✓	Are accessibility and other design provisions adequate for performance of needed maintenance and repair?
		✓	Have adequate accessibility been provided to perform the in-service inspection expected to be required during the plant life?
		✓	Has the design properly considered radiation exposure to the public and plant personnel?
✓			Are the acceptance criteria incorporated in the design documents sufficient to allow verification that design requirements have been satisfactorily accomplished?
		✓	Have adequate pre-operational and subsequent periodic test requirements been appropriately specified?
		✓	Have adequate handling, storage, cleaning, and shipping requirements been specified?
		✓	Are adequate identification requirements specified?
✓			Are requirements for record preparation review, acceptance, retention, etc., adequately specified?

Verified by: [signature] Nadia Glucksberg Date: 2/16/10

Approved by: [signature] S Criscenzo Date: 3/4/10

List of Tables

List of Figures

List of Attachments

0.0 EXECUTIVE SUMMARY

MACTEC has prepared a numerical groundwater flow model to provide estimates of groundwater flow in support of the Early Site Permit (ESP) for the proposed new PSEG plant. A main objective of the modeling is to provide estimates of groundwater response to the dewatering activities that will be needed to support the new plant construction. By modeling the dewatering scenarios, the data may be used to estimate the drawdowns in aquifers across the site and specifically to identify where dewatering could influence the existing safety-related structures. The model outputs may also be used to estimate post-construction groundwater flow conditions and to estimate potential hydrostatic loadings on proposed and existing safety-related structures.

MACTEC constructed a groundwater flow model covering the major portion of the PSEG Site and extending about 3000 feet north of the Hope Creek cooling tower. The modeled area covers about 1200 acres. The model includes the shallow aquifer system, with seven layers each representing the identified hydrogeologic units (i.e., the fill materials, the alluvial aquifer, the Kirkwood aquitard, the Vincentown aquifer, the Hornerstown, the Navesink aquitard, and the Mount Laurel-Wenonah aquifer). The top of the next lower formation, the Marshalltown aquitard is considered impermeable and serves the base of the model domain.

Calibration of the steady-state numerical groundwater flow model consisted of adjusting hydrogeologic parameters, including boundary conditions, to approximate observed piezometric heads over the site, and to be consistent with observed hydraulic gradients and interpreted groundwater flow directions. Monthly groundwater level data were collected from January 2009 through December 2009 as part of the ESP from observations wells installed in the alluvial deposits and the Vincentown Formation. Other hydrogeologic parameters were adjusted during calibration. The values utilized in the model are consistent with either site-specific tests and observations, or literature reported ranges of the parameters, e.g., hydraulic conductivity or transmissivity.

A sensitivity analysis was performed on the calibrated model, indicating the most sensitive parameters in the model included the net recharge rate, the horizontal hydraulic conductivity of the alluvium, the vertical hydraulic conductivity of the Kirkwood aquitard, and hydraulic conductivity of the Mount Laurel-Wenonah Formation. The calibration was also sensitive to the reference elevations of the simulated Delaware River and the general head boundaries for the Vincentown and Mount Laurel-Wenonah aquifers.

The model was then used, with modifications to the layering as needed to adequately depict the dewatering scheme, to provide estimates of dewatering rates for a specified generalized dewatering scenario. Since a plant technology has not been selected, the construction dewatering model is based on an excavation size selected to bound the anticipated excavation dimensions and location for any of the four technologies being considered. The proposed conceptual dewatering scenario includes the dewatering of the power block area (bounding dimensions of 1950 feet by 1650 feet) down to the Kirkwood aquitard to allow excavation of the hydraulic fill. A smaller, deeper excavation will be advanced in the central area beneath the power block to accommodate the nuclear island and associated safety-related structures. This deeper excavation will extend through the Kirkwood Formation and into the founding layer in the Vincentown Formation. The majority of the dewatering is to be accomplished by dewatering wells installed inside the perimeters of the shallow and deeper excavation limits. Both the shallow and deeper excavations will also include the installation of a soil retention barrier, which will also have low permeability characteristics and could affect groundwater flow.

Conclusions based on the numerical groundwater model can be grouped into several categories. These include estimates calculated by the model to support evaluation of the following:

- Dewatering rates required to achieve the lowered groundwater conditions required for the foundation excavation;
- Potential aquifer drawdown due to dewatering for new plant construction on existing wetland areas and structures;
- Changes in shallow groundwater flow patterns and elevations as a result of the proposed construction and the resulting hydrostatic loads on future structures;
- Assessment of the suitability of the model to supply these estimates;
- Identification of sensitive parameter values in the model and their suitability; and
- Observations of general groundwater behavior in the aquifers of interest.

The conclusions for each of these categories are summarized below.

Dewatering Rates and Long-Term Rate Sensitivity. The modeling of the dewatering scheme considered for the proposed expansion construction indicated an estimate of about 5600 gpm to dewater the larger (plan view), shallower excavation to the top of the Kirkwood Formation. The transition into dewatering the smaller (plan view), deeper excavation, into the Vincentown Formation, is estimated to require dewatering rates of about 5230 gpm. These are initial rates for each phase of the excavation, and taper off with time, eventually requiring a total long-term rate of about 3600 gpm. Sensitivity analyses suggest a range of long-term flow rates from 3400 to 5400 gpm (See Table 8). This does not include influx of water from storm events, which must be dealt with separately.

Drawdown of Aquifer at Existing Structures and Adjacent Wetlands. Dewatering results in considerable drawdowns of the piezometric heads in order to maintain these levels below the target excavation depths. In the case of the shallow aquifers these are decreased at recharge boundary conditions, and the dewatering would appear to pose little threat to the wetland east of the proposed expansion since it is tidally affected and renewed daily.

The areal impact of dewatering may also affect the stability of existing structures. The following existing structures are within the projected zone of dewatering influence.

- HC Cooling Tower
- Salem and Hope Creek Independent Spent Fuel Storage Installation (ISFSI)
- Waste Treatment Plant
- HC Switchyard
- Learning and Development Center

- HC Nuclear Island
- Fuel Oil Tank
- Material Center
- Low Level Radioactive Waste Building
- Salem Nuclear Island
- Nuclear Operations Support Facility

Anticipated Changes in Shallow Groundwater Flow Patterns. Modeling of post-construction conditions suggests that groundwater flow patterns and water levels would return to the pre-construction conditions over most of the model domain. Only slight increases of about 0.5 feet were noted in some portions of the model. Changes to the site, following construction would also include:

- The presence of the soil retention barriers (likely permanent elements);
- A localized gap (window) in the Kirkwood aquitard that is now replaced with structural fill;
- Placement of fill to establish a plant grade approximately 27 ft higher than the existing grade;
- The existing shallow perched ponds within the excavation footprint will be removed; and
- Replacement of the existing vegetation with developed hard surface.

These physical changes will cause some variation in flow patterns; however the projected piezometric heads in the fill and alluvial materials are not expected to be much greater than the current static conditions.

Simulations for post-development suggest a potential average hydrostatic level of about 5 to 6 feet NAVD 88 within the soil retention barrier walls planned for the new unit. Considering the potential tidal effects in the Vincentown Formation, a design groundwater level of 6 feet NAVD 88 is appropriate within the soil retention barrier walls. Since the base elevations of some of the new structures may be deeper than the groundwater table, they will be subjected to hydrostatic loads. These loads will be less than loads which would result from the maximum groundwater levels of the DCDs. Thus, a permanent dewatering system is not required to protect the new structures.

Under normal conditions, pre- and post-construction water levels in shallow units across the PSEG site (outside the groundwater barrier walls) would appear to be similar, with post-construction shallow water levels only about a half-foot higher in some areas of existing structures (e.g., the cooling tower or Hope Creek unit). Thus, a permanent dewatering system is not required to protect the existing structures from groundwater changes following construction of the new unit. Therefore, the proposed expansion would appear to alter groundwater flow patterns only slightly from current conditions in the areas of present facilities, and the need for a permanent dewatering system is not envisioned.

Sensitive Parameters in the Model. During calibration of the model, the most sensitive input parameters were determined to be recharge applied over the model (including seepage losses from ponds in the new plant location), horizontal hydraulic conductivity of the alluvial and Mount Laurel-Wenonah aquifer units, vertical conductivity of the Kirkwood aquitard, reference head for the Delaware River, and GHB reference heads in the Vincentown and Mount Laurel-Wenonah Formations. During the dewatering simulations, the most sensitive parameters included the hydraulic conductivity of the Vincentown and Hornerstown Formations.

Sensitivity Analyses. Sensitivity analyses were performed on the dewatering model run, varying key parameters of the hydraulic conductivity of the Vincentown Formation, the vertical hydraulic conductivity of the leaky Navesink aquitard, and the vertical hydraulic conductivity of the Kirkwood aquitard. Averaging short-term initial rates, the model provided best estimates from about 5,200 to 5,600 gallons per minute over a year's simulation. The sensitivity analysis indicated that an expected range might vary from about 3,000 to 7,600 gallons per minute (averaging short-term initial rates). Given the larger proposed area for dewatering than that conducted for the Hope Creek unit, the estimated dewatering rates are generally consistent with those documented during the construction of the Hope Creek Generating Station. The estimated dewatering rates do not include storm water which may fall within the excavation limits. Collection sumps and high rate pumps will likely be needed to evacuate storm water from the excavation.

In summary, this groundwater model has been completed in support of the ESP for the PSEG Site. The model provides estimates of the expected groundwater response to dewatering and post-construction scenarios. However, the dewatering scenario and dewatering estimates are intended to be preliminary and are based on the assumed excavation boundaries. Groundwater modeling will be refined after the reactor vendor is selected, and the final excavation geometry is determined. Preparation of the COLA will likely warrant additional data, which could be obtained from pumping tests or other methods to further refine hydrogeologic parameters and model estimates of dewatering rates and drawdowns beneath existing safety-related structures.

Evaluation of the data gathered in support of the ESP combined with the location and size of the proposed plant excavation area has indicated that additional data is needed to refine estimates of dewatering rates and the potential for excessive drawdown at existing structures during the dewatering period. Once the technology and site layout has been determined, pumping tests are recommended at the PSEG site to further refine the groundwater model. The benefits of performing the pumping tests include determining pertinent aquifer characteristics of the Vincentown Formation in the proposed construction area, determine the effectiveness of the Kirkwood aquitard to limit vertical groundwater migration between the Riverbed deposits and the Vincentown Formation (since it is absent in some locations), to assess potentials for upwelling from the underlying Mount Laurel-Wenonah Formation during dewatering, and assess the potential for encountering recharge boundaries in the Vincentown Formation in the northern portion of the proposed construction area.

1.0 PURPOSE

MACTEC is performing groundwater modeling in support of the Early Site Permit (ESP) Application for proposed expansion of power generating capacity at the PSEG Site at Lower Alloways Creek Township, New Jersey.

The purpose of this calculation is to construct, calibrate and evaluate a numeric groundwater model to aid in assessing future groundwater conditions, and will be used to assist in evaluating:

- Dewatering rates required to achieve the lowered groundwater conditions required for the foundation excavation;
- Potential aquifer drawdown, due to dewatering for new plant construction, on existing wetland areas and structures; and
- Changes in shallow groundwater flow patterns and elevations as a result of the proposed construction and the resulting hydrostatic loads on future structures.

The following sections of this calculation package present a description of the physical setting, locate the excavation boundaries, and present a summary of available geologic and hydrogeologic information pertinent to model development, as well as current and estimated future water use and simulation of dewatering for conceptual construction details. The following sections also present the model domain, boundary conditions, and initial site conditions, such as interpreted flow directions, hydraulic gradients that are adjusted through calibration to approach the observed site conditions, and point-wise matches to observed piezometric levels in site monitoring wells and piezometers. This calculation package also describes simulations conducted in support of assessments of dewatering schemes, including potential effects on nearby safety-related structures (e.g., settlement due to water table lowering) and wetlands (e.g., potential draining).

2.0 Facility Description

The Salem and Hope Creek Generating Stations occupy the southern portion of the approximately 1,500-acre Artificial Island, located near the southwestern tip of New Jersey (see Figure 1), in Lower Alloways Creek Township, Salem County. The developed portions of the site occupy 373 acres of the 740-acre parcel owned by PSEG with the remainder of the site comprised of a variety of wetland types, desilting basins, and storm-water management facilities.

Artificial Island was constructed when dredge spoils removed from the Delaware River were deposited behind a naturally occurring sandbar, constructed dikes, and a bulkhead. Prior to PSEG development, Artificial Island could be characterized as tidal marsh and grasslands. Salem Generating Plant Units 1 and 2 were constructed at the southern end of Artificial Island and started commercial generation in 1977 and 1981, respectively (PSEG, 2008b). The Hope Creek unit is north of the Salem facility and came on line in 1986 (PSEG, 2008b). The Salem units are cooled by once-through cooling water drawn from the Delaware River; the Hope Creek unit employs a cooling tower with multiple cycles of the water obtained from the River.

Groundwater currently is used to supply potable water, for generating demineralized water, and for emergency fire fighting at the existing Salem and Hope Creek Generating Stations, and the uses and demands would become proportionately greater with the construction of the new plant. In addition, prior to the increased long term uses, groundwater may also be used during construction to support concrete batching and dust suppression.

3.0 Groundwater and Aquifer Characterization

This section presents regional and local hydrogeology and as well as the chloride concentrations present in the aquifers.

3.1 Regional Hydrogeology

The aquifer systems beneath New Jersey have been extensively characterized providing a broad descriptive literature base as well as comprehensive monitoring data for groundwater and surface waters available from the State of New Jersey Department of Environmental Protections (NJDEP) and the United States Geological Survey (USGS). Although the site is located in New Jersey, the close proximity to Delaware makes geologic publications from Delaware based studies also applicable to the site (e.g., Dugan, 2008).

The extensive research of groundwater conditions is partially due to the extensive use of groundwater in New Jersey and Delaware as a water supply resource and the potential threats to these supplies due to natural and induced saline (saltwater) intrusion along the coastal plain and estuaries, as well as potential releases of contaminants from industrial and other potential point and non-point sources.

The New Jersey coastal plain aquifer system is comprised of an alternating sequence of aquifers and aquitards (confining layers) dipping downward from the northwest to the southeast. The overburden sequence thickens as the bedrock surface also dips toward the southeast and the Atlantic Ocean. In some instances, aquifers may thin out entirely toward the northwest. Several of the aquifers serve as primary potable water sources for many communities in New Jersey, including those in Salem County, and water levels within the heavily utilized aquifers at some locations have declined over the years with increased use of these resources. The State of New Jersey (State) has attempted to control water use and has encouraged water conservation in order to limit aquifer use and stabilize water levels within the aquifers. The State oversees and grants permits with regard to accessing these groundwater resources.

As shown on Figure 2, the aquifer sequence generally consists of a shallow system (may include the Cape May, Piney Point, local alluvial deposits, or Kirkwood-Cohansey units), underlain by the Vincentown, Mt. Laurel-Wenonah, Englishtown (somewhat limited in extent), and Potomac-Raritan-Magothy (PRM) units. The PRM is generally further separated into the Upper, Middle and Lower PRM. Intervening aquitard units may include the Kirkwood Formation, the Navesink-Hornerstown Formation, the Mattawan Formation, and the generally thick clayey aquitards separating the PRM aquifers.

Regionally, the aquifers are recharged at areas where overlying aquitards are not present or from adjacent aquifers through leaky aquitards, and/or through surface water interactions with groundwater. In some areas, aquifers may receive induced recharge from the Delaware River. During times of drought there may be increased salinity due to the recharge from the Delaware River. Aquifers and aquitards will have spatially variable characteristics, especially with respect to thickness, transmissivity, vertical hydraulic conductivity, specific capacity, and leakance. A summary of typical aquifer and aquitard characteristics based on literature survey of the regional aquifer system is presented on Table 1.

3.2 Local Hydrogeology

Discussion of the local hydrogeology includes the shallow system of aquitards and aquifers (hydraulic fill, alluvium, Kirkwood, and Vincentown Formations) and the deeper systems (Hornerstown-Navesink, Mount Laurel-Wenonah, Marshalltown and the even deeper Potomac-Raritan-Magothy (PRM) Formations). For the purpose of this modeling report, the following information was derived mainly from the ARCADIS Remedial Investigation report (2004), but also includes results from several earlier explorations conducted by Dames & Moore. ARCADIS focused mainly on the shallower systems, typically no deeper than into the Vincentown Formation (five wells to characterize the Vincentown and determine if tritium released in the shallow aquifer had migrated below the Kirkwood aquitard). However, the Dames & Moore explorations included probing for water supplies as deep as into the Middle PRM. Hence most of the site-specific hydrogeologic information below the Vincentown is derived from information included in several Dames & Moore reports (and summarized in their 1988 report) (Dames & Moore, 1988) and from various USGS, Delaware, and New Jersey Geologic Survey reports. The actual thickness of each layer or formation was determined and reported in the MACTEC (2009c) calculation package. A more detailed description, including the soil classification and geotechnical sample results for each hydrogeologic unit is also provided in the same calculation package.

3.2.1 Hydraulic Fill

In the vicinity of the PSEG site, much of the shallow soil horizon is the result of filling operations. Prior to facility development, Artificial Island was built up through deposition of dredge materials (hydraulic fill) from various improvements to the shipping channels in the Delaware River. Prior construction activities for the existing plants have removed the fill from beneath safety related as well as select other structures. Where present, the hydraulic fill at the facility tends to average between 30 and 40 feet in thickness. Although minimal hydraulic conductivity data is available for the hydraulic fill, samples of the fill indicate a large percentage of fines (silts and clays) and would be expected to have a relatively low hydraulic conductivity. This is supported by the slug test conducted at observation well NOW-5U (screened in the hydraulic fill) and from published data from ARCADIS, although the values ranged from 0.1 ft./day to 6.5 ft./day. Some sand stringers have been noted in these deposits that may contribute to high estimated permeability locally; however, due to the deposition of the materials, it is unlikely that these stringers are continuous. In the area of the Hope Creek Cooling Tower, installation of pilings is believed to have disturbed the fill significantly and to have increases the effective hydraulic conductivity in this vicinity. As evidenced by the shallow surface water, and supported by groundwater levels (NOW-5U and EOW-4U are screened in the hydraulic fill and exhibit relatively stable groundwater elevations), the hydraulic fills appear to act as a confining unit for the underlying alluvial aquifer (MACTEC, 2009b).

3.2.2 Alluvial Deposits

Below the hydraulic fill is a naturally deposited alluvial material (commonly referred to as the alluvium or the riverbed sands and gravels). It is a relatively thin layer (ranging from 2 to 24 feet thick, but generally about 5 to 7 feet thick over much of the developed portion of the facility). These deposits average about 13 feet thick in the proposed plant area. Slug test hydraulic conductivity data for the new plant location in the alluvial deposits varied from about 0.3 to 8 feet per day, averaging 3.75 feet per day (these data are presented in Table 2 of this calculation). Horizontal groundwater flux through the alluvium is likely low given the low hydraulic conductivity, low hydraulic gradient, and limited thickness. This aquifer is not suitable for water supply given its low yield and somewhat elevated chloride content.

3.2.3 Kirkwood Aquitard

The Kirkwood aquitard, a confining layer, lies beneath the riverbed deposits, and is generally about 10 to 20 feet thick, but was determined to be absent in some locations. Specifically, this confining layer was not encountered in MACTEC borings NOW-2 and NOW-7 (locations depicted on Figures 3 and 4). Described as fat or lean clay in most borings, the Kirkwood can also be uncharacteristically sandy in others (e.g., in borings for new monitoring wells EOW-5, EOW-7, EOW-8, NOW-2, and NOW-8). The MACTEC borings indicate this aquitard is not horizontally continuous. Additionally, this aquitard was removed to facilitate construction of the existing units at the PSEG site.

3.2.4 Vincentown Aquifer

Beneath the Kirkwood confining layer lie the more permeable sands of the basal Kirkwood and the Vincentown Formation. Together, these more permeable sands, or silty or clayey sands, constitute the first major aquifer unit beneath the proposed facility. This unit varies from about 70 to 100 feet thick and is typically about 80 feet thick. However, the groundwater in the Vincentown Formation beneath the facility has high levels of chloride (believed due to recharge of the aquifer by the Delaware River estuary) and is not considered suitable for use as a water supply by PSEG. Transmissivity estimates for the Vincentown Formation vary from 530 to 2800 square feet per day, with specific capacities ranging from 0.3 to 8.3 gallons per minute per foot. Modeling conducted for the Hope Creek Generating Station dewatering project used a hydraulic conductivity of about 14 ft./d for the Vincentown (Dames & Moore, 1977). In more recent slug tests conducted by MACTEC in the proposed expansion area, estimates of hydraulic conductivity ranged from 0.3 to 10.7 ft/d (see Table 2) and averaged 3.8 ft/d.

3.2.5 Navesink-Hornerstown Confining Unit

The next deeper confining unit is referred to as the Navesink-Hornerstown Formation, generally considered to be a leaky aquitard about 30 to 40 feet thick that separates the Vincentown Formation from the Mt. Laurel-Wenonah aquifer. Recently, MACTEC performed borings at the PSEG site and characterized the Hornerstown as quite similar to the Vincentown Formation based on grain size distribution and visual logging. Hence in modeling, the Hornerstown is considered a separate formation from the Navesink Formation and assigned aquifer properties the same as those for the Vincentown Formation whereas the Navesink remains an aquitard. The average thickness of the Hornerstown Formation from the MACTEC-performed borings was reported to be approximately 18 feet, while the Navesink Formation average thickness was about 22 feet. Regional estimates for vertical hydraulic conductivity for the Navesink-Hornerstown aquitard have ranged from 0.003 to 9 ft/d.

Based on the studies conducted by Dames & Moore (1970, 1988), the increasing chloride concentrations observed shortly after the installation of PW-4 (well location shown on Figure 5) into the Mt. Laurel-Wenonah Formation were likely due to a window in the Navesink-Hornerstown Formation north of PW-4 that allowed the higher chloride concentrations in the Vincentown to migrate through the aquitard at a rate sufficient to raise chloride concentrations at

PW-4 above acceptable levels as defined by NJDEP drinking water standards. As such this is not considered a horizontally continuous aquitard.

3.2.6 Mount Laurel-Wenonah Aquifer

The next deeper aquifer, the Mount Laurel-Wenonah aquifer is about 100 to 125 feet thick at the facility (Dames & Moore, 1988). Reported hydraulic conductivities for the Mount Laurel-Wenonah have ranged from 10 to 19 ft/d, and reported transmissivities of the formation have ranged from 360 to 1870 square feet per day (Dames & Moore, 1988). This aquifer was investigated and selected as the original groundwater supply aquifer for the facility, having both good yield and satisfactory low chloride levels. However, leakage through the Navesink from the saline Vincentown increased chloride concentrations at supply wells, and eventually forced the development of other supplies.

The Marshalltown-Wenonah confining unit underlies the Mt. Laurel-Wenonah aquifer, and is up to 45 feet thick based on the deeper MACTEC borings. The thickness of the Marshalltown itself varied from 25 to 26 feet in the MACTEC borings with a high percentage of fines (clays and silts). For the purposes of the modeling, the top of the Marshalltown confining unit is taken as the (impermeable) base of the model developed for this calculation.

During dewatering scenarios, the Mount Laurel-Wenonah Formation may contribute to the simulated pumping due to the leaky nature of the Navesink aquitard and the anticipated drawdowns in the Vincentown. However, the deeper aquifers below the Marshalltown aquitard are not expected to be significant for purposes of this modeling (i.e., to contribute less than one percent of the upwelling of groundwater into the excavation).

3.2.7 Deeper Aquifers and Aquitards

The next deeper aquifer is the Englishtown Formation. This aquifer is of limited width in Salem County; it was encountered in some deep borings for some observation wells (e.g., OW-H, but not indicated as present in OW-A) and at PW-5 (see Figure 5).

The Merchantville-Woodbury confining unit separates the Englishtown from the Upper PRM aquifer (USGS, 2004) and may reach a thickness of about 40 feet (USGS/State of New Jersey, 1969). The Upper PRM aquifer contains the Magothy Sands as well as the Upper Raritan Sands, but it is into the Upper Raritan Sands that the facility production wells HC-1, HC-2, and PW-5 are screened.

There is some divergence in the USGS naming sequence of aquitards and aquifers in this depth range from that employed by Dames & Moore. Dames & Moore (1988) groups the Marshalltown-Wenonah aquitard, the Englishtown Formation and the Merchantville-Woodbury confining unit as one single aquitard, the Mattawan. Dames & Moore singled out the Magothy Sands as an aquifer separated from the Upper Raritan Sands by the Upper Raritan Clay. The USGS consolidates the Magothy Sands with the Upper Raritan Sands (with intervening aquitard) as the Magothy Formation/Upper PRM aquifer while considering the Englishtown Formation as a single aquifer (USGS, 2004). Dames & Moore (1974b) did not list the Englishtown as a principle aquifer underlying the site, and was also unclear as to the potential of the Magothy Sand as a sustainable groundwater supply.

The Upper Raritan aquifer provides good quality groundwater and is the source of water for three of PSEG's production wells (Hope Creek's HC-1 and HC-2, and Salem's PW-5). The aquifer varied from 70 to 100 feet thick in the Dames & Moore explorations (Dames & Moore, 1988). The Mattawan aquitard, the Magothy aquifer, the Upper Raritan Clay, and the Upper Raritan aquifer are often grouped together as the Upper PRM.

The Middle Raritan Clay, about 260 to 270 feet thick, separates the Upper PRM from the Middle PRM. The Middle PRM is thinner (45 to 55 feet) and generally has a lower transmissivity than the Upper PRM, although the transmissivity in the Upper PRM varies more widely than in the Middle PRM. The Middle PRM supplies only a relatively low percentage of the groundwater used at the Salem station due to higher chloride levels and concern for increasing chloride concentrations over time. Dames & Moore (1988) reported a relatively lower specific capacity and transmissivity of the Middle PRM than for the Upper PRM (see Table 1).

3.3 Chloride Concentrations in Groundwater Aquifers

The drinking water standard, which applies to the potable water supply, limits chlorides to less than 250 mg/l. In addition to complying with the chloride levels, supply wells must provide a suitable sustainable yield. The riverbed deposits and fill material aquifers do not satisfy the yield requirements or the chloride standard. The Vincentown aquifer could supply a sustainable flow rate; however it is affected by high chloride concentrations (reported in the approximate 2,000 to 4,000 mg/L range (Dames & Moore, 1988)).

In 1968, Dames & Moore began investigations to determine a groundwater supply for the facility. A test well, which was converted into production well PW-1, installed into the Mount Laurel-Wenonah Formation appeared to satisfy the requirements for low chloride (32 mg/L) and sustainable supply rate (200 to 250 gpm). Based on these determinations, three additional production wells, PW-2, -3 and -4, were also installed into the Mount Laurel-Wenonah aquifer. Shortly after PW-4 was started up, chloride concentrations increased sharply, reaching chloride concentrations greater than 500 mg/L, and the well was shut down. The cause was believed to have been a gap in, or a significant thinning of, the overlying Navesink-Hornerstown aquitard, which allowed influx of water from the Vincentown Formation that caused the increased chloride concentrations (Dames & Moore, 1970, 1988). Chloride concentrations in the Mt. Laurel-Wenonah aquifer increased to over 400 mg/L at PW-2 as well (Dames & Moore, 1988); the two remaining production wells in the Mt. Laurel-Wenonah aquifer (PW-2 and PW-3) are maintained for emergency back-up use only.

Chloride concentrations in the Upper PRM Aquifer were determined generally to be in the 10 to 20 mg/L range. This aquifer has become the principal source of groundwater at the facility, with production wells PW-5, HC-1, and HC-2 all drawing from this aquifer. No significant increases in chloride concentration in these Upper Raritan production wells have been observed over the period of their service.

Production well PW-6 is screened in the Middle PMR Aquifer. Initial samples taken in 1981 indicated a chloride concentration of 170 mg/L, less than the secondary drinking water standard of 250 mg/L (Page, 1981). Dames & Moore reported later sample results of as high as 334 mg/L in PW-6 (Dames & Moore, 1988). Currently, the Middle PRM Aquifer is used sparingly, with an average rate of only about 6.5 gpm over the period from 2002 to 2007 (PSEG, 2008c).

3.4 PSEG Groundwater Usage

Groundwater is primarily used for sanitary, potable and firewater demands at the existing PSEG facilities. The site has four active groundwater supply wells and two on emergency standby (e.g., for fire fighting). Groundwater supplies at the facility were initially developed following water supply resource investigations by Dames & Moore in the late 1960s and early 1970s. The first supply wells developed were PW-1 through PW-4 in the Mount Laurel-Wenonah Formation. These four wells were anticipated to provide an adequate supply, but as noted above, shortly after it went on line, PW-4 experienced increasing chloride levels above those expected and in excess of desired water supply quality characteristics. As a result, PW-4 was taken off-line and eventually abandoned in accordance with state regulations. Subsequently PSEG reduced its dependency on this formation for its groundwater supply. Currently, PW-1 has also been sealed and abandoned, and PW-2 and PW-3 are reserved for emergency uses only, e.g., for fire fighting, and are tested only quarterly to assure their readiness. In order to replace supply wells PW-1 through PW-4 for the Salem plant and provide groundwater for the Hope Creek plant, PSEG subsequently developed supplies in the deeper aquifers. The groundwater supply wells for the Hope Creek Generating Station are designated HC-1 and HC-2; both wells extend approximately 816 feet below ground surface (bgs) and are screened in the Upper PRM aquifer. The deep water supply wells for the Salem units, PW-5 and PW-6, extend approximately 840 and 1,138 feet bgs, respectively, and are screened in the Upper PRM and Middle PRM, respectively. Water supply records for the four deep wells for the period 2002 to 2007 indicated a range of flow rate of between 137 and 197 gallons per minute (gpm) for the Hope Creek wells, averaging 162 gpm, approximately equally distributed between HC-1 and HC-2 (PSEG, 2008c). For the Salem deep supply wells, PW-5 and PW-6, the combined flow rate varied from 169 to 262 gpm, averaging 209 gpm, over the 2002 to 2007 period (PSEG, 2008c). PW-5 typically provides about 97 percent of the Salem generating station groundwater supply. The combined Salem and Hope Creek average annual flow rate over the 2002 to 2007 period was 371 gpm, and ranged from 306 to 417 gpm (PSEG, 2008c). Reported pumping rates for 2008 altered the average rates slightly to 217 gpm for the Salem units and to 161 gpm for the Hope Creek unit over the 2002 through 2008 period (TetraTech, 2009).

PSEG has authorization from the New Jersey Department of Environmental Protection (NJDEP) and the Delaware River Basin Commission (DRBC) for consumptive use of up to 43.2 million gallons of groundwater per month at the Salem and Hope Creek generating station sites. The current license was issued in 2000, modified slightly in 2004, and is in effect until January 31, 2010 (NJDEP, 2000; NJDEP, 2004). The water allocation permit also has restrictions on maximum monthly withdrawal rates (2,900 gpm) and annual withdrawals (300 million gallons) (NJDEP, 2004). Based on the average rates over 2002 to 2007 (PSEG, 2008b), and assuming a 31-day month, average actual monthly usage has been about 38.3 percent of that authorized, whereas on an annual basis, the current (2002 to 2007 average) rates constitute about 65 percent of that permitted. Annual average rates vary by year.

The projected increased use of groundwater for the proposed expansion during and post-construction has been estimated as consisting of the following components and flow rates. During construction, 118,500 gallons per day for potable and sanitary use; 8,400 gallons per day for concrete mixing and curing; and 40,000 gallons per day for dust control, for a total of 166,900 gallons per day or 116 gpm. During operation, the components of required flow include the potable and sanitary systems (93 gpm average, 216 gpm maximum), demineralized water distribution system (107 gpm), fire protection system (5 gpm average, 625 gpm maximum), and miscellaneous makeup (5 gpm), for a total of 210 gpm normal average, with a projected 953 gpm maximum (Sargent & Lundy, 2009). The projected total average groundwater diversion for the three generating stations under normal operating conditions would be 588 gpm (Hope Creek at 161 gpm, Salem at 217 gpm, and the expansion at 210 gpm). On an annual basis, this rate (309 million gallons per 365-day year) would slightly exceed the permit annual allocation limit.

3.5 Site Groundwater Level Data

In both the locations considered for expansion (northern and eastern) (see Figure 1), MACTEC installed eight pairs of observation wells. Each pair of wells consisted of an upper and lower well. Most of the shallow wells are screened within the alluvial aquifer (riverbed sands and gravels), and all of the deeper wells are screened in the Vincentown Formation. In addition, several piezometers were installed at wetland ponded areas to determine surface water levels and vertical gradients with respect to underlying sediments at these locations (these locations are depicted on Figure 5).Monthly water level measurements have been obtained spanning January through December 2009. In addition, the September 2009 water level measurement event also included water level measurements at 12 alluvial aquifer monitoring wells and three Vincentown aquifer monitoring wells located within the Hope Creek protected area to provide added coverage over the developed portion of the site. While the data from the supplemental alluvial wells were consistent with previous measurements in these wells, the elevations in the three supplemental Vincentown wells did not appear consistent with measurements in the monthly measured wells and were not utilized in the modeling. These data indicate very small hydraulic gradients across the alluvial deposits as well as the Vincentown Formation at the site, and typically neutral or only slightly downward vertical hydraulic gradients across the Kirkwood aquitard separating the alluvial from the Vincentown aquifer (MACTEC 2010). Piezometers showed small gradients from surface water to groundwater in underlying sediments or in the hydraulic fills overlying the alluvial aquifer across the entire site and, as some surface waters are subject to tidal fluctuations, gradients could be tidally dependent. At some locations, especially at EOW-4U and NOW-5U, measurements in the hydraulic fill suggested that there may be locally perched groundwater within this layer (PSEG, 2008c). This is consistent with the water level data collected from the shallow piezometers.

3.6 Tidal Effects in the Shallow Aquifers

The partially confined Vincentown aquifer, and, to a lesser degree, the shallow alluvial aquifer, display tidal effects of the Delaware River estuary. Dames & Moore (1988) had noted the tidal effects, and ARCADIS (2004) further examined the tidal effects with continuous recording pressure transducers in select wells in the shallow aquifer and in the five wells installed Vincentown (Wells K, L, P, Q, and V). The amplitude of the tidal effects was seen to be roughly proportional to the distance from the river, with Well L, about 140 feet away, responding the most. Only Well Q, about 370 feet from the river, did not conform to this pattern. No significant tidal effects were noted in the shallow wells monitored for tidal effects within the cofferdam at Salem Units 1 and 2 (Well N) and just outside it (Well W, about 240 feet from the river). ARCADIS concluded that the Kirkwood aquitard was of sufficiently low permeability and of adequate thickness to restrict tidal effects in the Vincentown from affecting shallow groundwater flow in the area of the tritium release at Salem Unit No. 1. While the shallow aquifer system is in contact with the river, it is likely that sediments in the river may moderate the tidal effects (MACTEC 2009a). Moreover, the bulkhead constructed to retain the hydraulic fill along the western edge of Artificial Island may also provide some isolation of the alluvial aquifer from the tidal fluctuation. Some intertidal mixing zone within the shallow aquifer likely exists, but may be of a relatively narrow width especially within the low permeability hydraulic fills.

MACTEC (2009a, 2009b) further characterized the tidal effects at the PSEG Site. Pressure transducers were installed in two well pairs (NOW-1 and NOW-3) in the alluvium and the Vincentown Formation, and a reference transducer in the Delaware River. The objective was to determine if the tidal impacts in the alluvial deposits and Vincentown Aquifer were similar to those observed at the Salem and Hope Creek Stations. Transducer monitoring of water levels in the Vincentown Formation varied approximately 1 foot about the average in NOW-3L, and approximately 0.3 ft about the average in NOW-1L, which are located approximately 205 ft and 765 ft from the river, respectively. The tidal study of the upper wells, NOW-3U and NOW-1U indicated tidal fluctuations of approximately 0.3 ft and 0.1 ft about the average, respectively. The measured effects at these locations were relative to a change of plus/minus three feet in the Delaware River (MACTEC, 2009a). NOW-3U is close to the river and also near NOW-2U, where the Kirkwood aquitard was found to be absent (MACTEC, 2009c); some tidal influence is not unexpected under these circumstances. Analysis of 2009 water level data (MACTEC, 2010) suggested that except for these two alluvial wells, tidal effects were small to negligible in the alluvium. These findings are consistent with previous tidal studies conducted by ARCADIS (2004).

3.7 Surface Waters

The Delaware River estuary bounds the west and south sides of the PSEG site. The proposed new plant location is bounded on the west by the Delaware River. The bathymetry of the Delaware River indicates a river depth of 12 to 20 feet along the facility riverbank. This suggests that the alluvial aquifer, encountered about 30 to 40 feet below ground surface, may not directly contact the river at the river's edge but may discharge through river sediments or directly at some greater distance into the river channel.

The proposed location of the new unit contains several small ponds. Based on water level measurements, these ponds appear to be perched above the normal water table and to contribute very little recharge to the underlying water table. A tidally influenced wetland area is located to the east of the new plant location. Several fingers of unnamed streams penetrate into this area providing a means for groundwater discharge to leave this area. Some small portion of the new plant location may exhibit groundwater flow toward this wetland area. Storm water runoff from the developed portions of the PSEG site is directed off site through several storm water diversion structures and drainage channels.

The next nearest stream to the facility is Alloway Creek, which is situated about 2 miles north of the site and is unlikely to be affected by any operations at the site itself.

3.8 Precipitation and Net Recharge

On a regional basis, ARCADIS provides the following description of the climate and precipitation (ARCADIS, 2004):

"Salem County is located in southwestern New Jersey. The county's climate is considered to be humid and temperate, as the climate in this county is readily influenced by its proximity to the Delaware Bay. Coastal storms are not uncommon in this region and can produce high winds and heavy rainfall, which can cause wind damage and flooding in low-lying areas (USDA, 1969).

Wind direction in this region is dependent upon the season; during the summer, winds are typically from the southwest while during the winter, winds are commonly from the northwest. Temperatures vary by season and the maximum expected high temperature for a given year is 96 degrees Fahrenheit, while the minimum expected yearly low temperature is minus 2 degrees Fahrenheit. The average annual precipitation total is 39.9 inches."

Net recharge is that portion of total precipitation that percolates into the subsurface and actually reaches the water table. It is the total precipitation less runoff, less evaporation and less transpiration (water lost through vegetation uptake). Runoff includes that portion of precipitation not able to penetrate the ground surface through natural soil characteristics, slope, and diversion by trees, buildings, and/or pavement.

ARCADIS (2004) arrived at a net recharge rate of 8.5 inches per year for their modeling of the shallow aquifer in the vicinity of Salem Unit No. 1. However, this rate was applied to areas where supposedly hydraulic fill was replaced by much more permeable structural fill, and the thickness of this unit was able to transport the recharge laterally out of the model through the constant head nodes representing the Delaware River. Over much of the facility area, conditions for permitting recharge are reduced, especially in wetland areas where low permeable surface soils such as the hydraulic fills are present, wetlands represent ponded or groundwater discharge areas, and potential evapotranspiration is high. The relatively thin alluvial aquifer with its relatively low hydraulic conductivity and gradient also suggests limited lateral groundwater movement and limited recharge. Another controlling feature of the net recharge is the vertical hydraulic conductivity and presence of the Kirkwood aquitard, which controls vertical seepage through the alluvium into the lower Vincentown Formation. For the groundwater model, lower initial recharge rates were applied over much of the model, and final rates were determined in model calibration.

3.9 Hydraulic Conductivity

The hydraulic conductivity of the various aquifers has been determined regionally in several studies. A summary table of published regional and site-specific data for various aquifers is presented in Table 1. The closest regional study is reported by the Delaware Geologic Survey on the Delaware coast directly opposite the PSEG site. The reported transmissivity for the Mount Laurel-Wenonah aquifer at this location was 815 square feet per day (Dugan, 2008). Mapping in that report indicated the thickness of the Mount Laurel-Wenonah is from 51 to 75 feet at that location, suggesting a hydraulic conductivity ranging from about 11 to 16 ft/d. At the PSEG site, several major pumping tests have been conducted, but mainly in the Mount Laurel – Wenonah aquifer or deeper. These have little relevance to the shallower aquifers under consideration here (mainly the alluvial and Vincentown aquifers). Some short-term pumping tests and slug tests have been performed in the shallower aquifers including work completed for SGS and HCGS, and these are described in the following subsections.

3.9.1 Pumping Tests

ARCADIS (2004) described the results of several short-term pumping tests to characterize the alluvial aquifer in the vicinity of Salem Units 1 and 2. Results ranged from 0.03 to 2.27 ft/d.

Dames & Moore conducted pumping tests in the Mount Laurel – Wenonah aquifer in a preliminary search for a groundwater supply for the facility. Results summarized in their 1988 report indicated the following ranges for the shallow formations: alluvium (0.12 to 1.75 ft/d); Vincentown (0.95 to 2.5 ft/d); and Mount Laurel – Wenonah (0.67 to 4.5 ft/d). Reported values for other tests suggested comparable or somewhat higher hydraulic conductivities: alluvium (13.2 to 440 gallons per day per foot [gpd/ft], or 1.8 to 59 feet per day [ft/d]). Reported transmissivities of the Vincentown were 5,000 to 11,000 gpd/ft, or 668 to 1470 square ft per day; and of the Mount Laurel – Wenonah 4,900 to 8,700 gpd/ft or 655 to 1163 square feet per day. Dames & Moore (1977) also conducted a pumping test on one of the dewatering wells installed for the excavation for the Hope Creek unit. The result was an estimate of 14 ft/d; however, specific capacities varied for many of the Hope Creek dewatering wells, suggesting variable hydraulic conductivity for the Vincentown.

3.9.2 Slug Tests

ARCADIS (2004) performed slug testing in a few monitoring well locations. For two wells into the structural fill, the estimated range was 0.09 to 4.3 ft/d, which may reflect different levels of compaction. The estimated hydraulic conductivity for Well U screened in the alluvium was 2.95 ft/d.

In 2009, MACTEC performed slug tests and slug test analyses on the eight pairs of wells in the new plant location (MACTEC, 2009c). Test results are presented on Table 2. In summary, estimates for hydraulic conductivity were: hydraulic fill at 0.1 ft/d (one sample); alluvium ranging from 0.3 to 8.0 ft/d; and Vincentown ranging from 0.3 to 10.7 ft/d. Average hydraulic conductivity for the alluvium is 3.75 ft/d and for the Vincentown is 3.85 ft/d.

3.10 Water Wells

A detailed presentation of the chronology of the development of groundwater supplies for the facility has been presented in Sections 3.3 and 3.4. It should be noted that these supplies are in much deeper aquifers and have no relevance to groundwater flow in the shallow aquifers, including the deeper Vincentown; in the Mount Laurel – Wenonah Formation, former supply wells PW-2 and PW-3 are maintained for emergency use only and tested only quarterly.

A small (approximately 20 gpm) extraction well system is in operation within the structural fill south of Salem Unit No. 1. This system produces only slight localized drawdown of the water table and is not significant to site-wide groundwater flow in either the alluvium or the Vincentown (ARCADIS, 2003; PSEG, 2008a).

4.0 Numerical Groundwater Model Development

The following subsections describe the development of a numerical finite-difference groundwater model for the facility.

4.1 Conceptual Hydrogeologic Model

This section presents a more focused summary of the hydrogeologic and site-specific information presented in previous sections. It also provides the basis for the initial construction of the groundwater flow model described in later sections of this calculation package.

The PSEG Salem and Hope Creek Generating Stations have been constructed primarily on filled land consisting of a large proportion of dredge spoils (hydraulic fill) from the Delaware River. However, the hydraulic fills were replaced in areas with compacted structural fills in order to provide sufficient bearing for safety-related structures. These fill materials directly overlie the Vincentown Formation. Together, the fills (hydraulic and structural), and the alluvium constitute the shallow groundwater flow system over most of the site. The base of the shallow flow system is the top of the Kirkwood confining unit at approximately -25 ft NAVD88 (MACTEC 2009c). The shallow aquifer is recharged by infiltration of precipitation where not impeded by buildings, pavement, or other storm water diversion structures. Wetland areas and ponded water may also interact with the water table. Shallow groundwater flow is generally toward the Delaware River, i.e., west and south, or toward low-lying wetland areas to the east and north. The Delaware River, west and south of the PSEG Site, is the primary surface water body and likely interacts with shallow site groundwater. The river is tidal adjacent to the facility with a bottom elevation of approximately -45 feet NAVD88 near mid-channel (United States Coast and Geodetic Survey). Adjacent to the facility, the river has broadened to about 2.5 miles wide as it merges into Delaware Bay. Freshwater flows in the Delaware typically range between about 6,000 to 22,000 cubic feet per second (cfs) at Trenton, New Jersey (USGS, 2009). At the PSEG facility, the ebb and flow of the tidal waters greatly increases flow in the estuary. Three other smaller streams, Alloway Creek, Hope Creek, and the Salem River, flow into the Delaware and are situated approximately 2 miles northeast, 2.5 miles east, and 7 miles north of the facility, respectively. Several wetlands and small ponded areas occupy parts of the undeveloped portion of the property. Development of the proposed plant will require removal of these ponds. Based on the groundwater contours generated from the monthly groundwater readings, the tidal wetlands east of the facility appear to be groundwater discharge areas (MACTEC, 2010). Precipitation falling within the developed portion of the property is largely collected as run-off from impervious surfaces and flows through swales, storm water piping, and ditches toward the Delaware River west and south of the facility, or east toward marsh lands which in turn eventually discharge to the Delaware River.

The Vincentown Formation (including the basal Kirkwood sands) is present beneath the Kirkwood confining unit and ranges in thickness from about 35 to 93 feet thick in new plant and Eastern Location areas. The average thickness is about 52 feet in the new plant area and about 55 feet in the eastern area. Both the Vincentown, and to a much lesser degree, the alluvial aquifer, display tidal effects of the estuarine Delaware River. The Kirkwood aquitard appears to isolate the shallow system from the Vincentown Formations in places, but is thin or absent in others.

The Navesink-Hornerstown confining unit is leaky and some communication is apparent between the overlying Vincentown and the underlying Mount Laurel-Wenonah aquifers. In the area of the facility, the Hornerstown exhibits characteristics very similar to the Vincentown aquifer, and in modeling will be treated as a separate aquifer layer. The Upper PRM is the next lower aquifer, and this unit is tapped by three facility production wells, HC-1, HC-2, and PW-5, which produced average flow rates of 364 gpm from 2002 to 2007. The remaining facility deep production well, PW-6, is in the next deeper aquifer, the Middle PRM, but supplies only a small portion of the Salem plant's groundwater supply needs (approximately 6.5 gpm average 2002 to 2007). The PRM is a much used groundwater resource in southern New Jersey, but the nearest supply wells of any significance are located about 8.5 miles across the Delaware River in Delaware, and about 15 miles to the northeast in Salem (City) (PSEG, 2008c). There are no off-site public water supply wells or private wells within 1.6 kilometers (km) (1 mile) of the Salem and Hope Creek Generating Station sites. The nearest off-site potable water supply well is located more than 5.6 km (3.5 miles) west of the site, across the Delaware River, in Delaware (PSEG, 2008b).

4.2 Numerical Modeling

Due to the complexity of the shallow aquifer system at the PSEG facility, numerical modeling offers the best framework to assess potential effects of construction/dewatering and post-construction conditions on groundwater flow and water levels throughout the site that might affect safety-related structures.

4.2.1 Model Code Selection

MACTEC has utilized the USGS finite-difference three-dimensional groundwater flow model code, MODFLOW (USGS 1988, 1996, and 2000). MODFLOW is a standard of the groundwater modeling community and offers a wide range of boundary condition and solver options that satisfy the anticipated demands posed by the facility hydrogeologic setting and constructed conditions. MODFLOW was used by ARCADIS (2004) in modeling the shallow system at the PSEG Salem generating station, and has been used by the USGS in modeling both shallow and deep aquifer systems throughout New Jersey (e.g., USGS, 1997, 1998, 2003, and 2006).

4.2.2 Numerical Solver and Closure Criterion

MODFLOW offers a variety of packages for iteratively solving the array of algebraic equations representing the partial differential equations governing fluid flow in a porous medium. Among the solvers is a direct matrix solver for relatively small problems, and solvers such as successive over-relaxation (SOR), strongly implicit procedure (SIP), and preconditioned conjugate gradient (PCG) methods which employ various iterative algorithms to achieve convergence to observed conditions (see section 5.1). Of these, the SIP and PCG solvers are most often invoked, with the PCG solver typically more stable under a wider variety of equation classes. In the modeling performed here, the PCG method is the selected solver. Relatively conservative convergence criteria are specified for the PCG solver, 0.001 feet for a head closure criterion and 1 for a residual criterion for convergence.

4.2.3 Model Grid and Domain

The model domain covers nearly the entire PSEG facility property boundaries as shown on Figure B-1. [Figures generated using the model through the Groundwater Vistas modeling platform are identified as B-xx and are presented in Attachment B.] The model grid is uniformly-spaced with 20-foot square blocks covering the model domain. While the grid spacing is too dense relative to the entire model domain to show on Figure B-1, Figure B-2 shows the grid over the proposed new plant location.

The purpose in including such a major portion of the facility is to reduce the number of artificially specified head boundaries taking advantage of the river and perimeter extents to include natural boundaries and reduce potentials for model domain boundary effects under applied stresses toward the interior of the model. Lastly, the model also includes the eastern area and utilizes the water level data available in this portion of the model.

4.2.4 Model Vertical and Horizontal Datums

The datums used for the modeling include coordinates in New Jersey State Planar coordinates (North American Datum of 1983 [NAD83]) and elevations relative to the North American Vertical Datum of 1988 (NAVD88). The coordinates of the origin (lower left hand corner) of the model are E197800, N229200. The grid is rotated 3.5 degrees to line up the model grid with some of the boundary conditions and make them easier to assign. The plant datum, used in several of the early facility investigations, may be converted to the NAVD88 datum by subtracting 89.92 feet (ARCADIS, 2004).

4.2.5 Model Layers

The base model (which may be modified to enable more accurate placement of proposed structures, especially vertically) is set up to include one hydrogeological unit per layer for calibration. Model bottom layer elevations include interpretations of strata from previous investigations supplemented by the data from MACTEC-installed borings in the PSEG Site as well as in the eastern area. Geologic interpretations from the MACTEC Geotechnical Data Report were used to estimate layer thicknesses (MACTEC, 2009c). Layer surface elevations at the perimeter of the model have been based on extrapolating elevations in known areas to the model extents via the specification of dummy points for the particular surface. The layers in the model include:

Layer 1 – Hydraulic or structural fill. The top of this layer is taken as 10 feet NAVD as the general average elevation of most of the site. This is not an important input parameter as the top layer is taken as water table (unconfined) and the digital model does not consider soils above the groundwater level. The base of this layer is at a variable elevation and is taken from the digitizing of this surface from ARCADIS plans supplemented by the MACTEC boring data and points extrapolated to the model perimeter. This xyz file (easting, northing, and NAVD 88 elevation) was then kriged (an interpolation methodology) using the contouring software SURFER (Golden Software, 1998-2002) using default settings and imported into the modeling software platform Groundwater Vistas (Environmental Simulations, Inc., 2005). Figure B-3 shows contours of the bottom of the fill layer in the model. For layer 1, the hydraulic or structural fill layer is established in the model as an unconfined condition.

Layer 2 – Alluvium (riverbed sands and gravels) aquifer. This is generally a fairly thin layer over much of the model but does reach average thickness of about 13 to 15 feet in the new plant location. The bottom of this layer conforms to the top of the Kirkwood aquitard. This surface was generated similarly to the bottom of Layer 1, with ARCADIS interpretation of this surface supplemented with MACTEC data and extrapolated dummy points. Figure B-4 shows contours of the bottom of the alluvium layer in the model. This layer, as well as the deeper layers, are specified as convertible (variable transmissivity) in MODFLOW, that is, they behave as confined if the piezometric head is greater than the top elevation of the layer, and unconfined otherwise.

Layer 3 – Kirkwood aquitard. This is also a relatively thin layer over much of the model domain and actually pinches out in some areas. Figure B-5 shows contours of the bottom of the Kirkwood aquitard model layer.

Layer 4 – Vincentown aquifer. The Vincentown aquifer is present across the site, and varies in thickness from about 35 to 93 feet in the new plant and eastern areas. In the new plant area, the average thickness was about 52 feet, and in the eastern area averaged about 55 feet. Site-specific data have been used to create surfaces representing the top and bottom of the Vincentown, partly based on the ARCADIS determination of the thickness of the Kirkwood aquitard over the developed portions of the facility. Figure B-6 depicts interpreted contours of the bottom of the Vincentown Formation.

Layer 5 – Hornerstown unit. A limited number of locations were available to determine the thickness of the Hornerstown, which, where encountered, has exhibited characteristics similar to the Vincentown Formation. The data suggested a relatively consistent thickness averaging 18.5 feet. The top of the Hornerstown was taken as the bottom of the Vincentown, and the bottom generated by subtracting 18.5 feet from this surface elevation. Figure B-7 shows contours of the bottom of the Hornerstown Formation in the model.

Layer 6 – Navesink aquitard. The top of the Navesink was taken as the bottom of the Hornerstown. Again, the available but limited data suggested a relatively uniform thickness averaging about 22 feet thick. The bottom of the Navesink was then taken as the top elevation minus 21.9 feet. The combined thickness of the Hornerstown and Navesink is about 40 feet as is typically reported in literature and indicated in site-specific data. Figure B-8 shows contours of the bottom of the Navesink aquitard layer in the model.

Layer 7 – Mount Laurel-Wenonah aquifer. Available limited data were used to estimate the distribution of the thickness of the Mount Laurel-Wenonah Formation. This ranged from 112 to 121 feet in the northern portion of the model domain, and about 122 feet thick along the southern boundary of the model. The overall average thickness of this unit in the model is about 119 feet. Figure B-9 shows contours of the bottom of the Mount Laurel-Wenonah aquifer in the model.

Figure B-10 shows a vertical section across the model in an east-west direction and through the new plant location selected for plant expansion.

4.2.6 Boundary Conditions

Boundary conditions applied in the base model include use of the river, general head boundary, no-flow, and well package modules in MODFLOW. The MODFLOW drain and horizontal flow barrier boundary condition packages were also used in the dewatering simulations and are described in Section 6.1.

4.2.6.1 The River Package

The MODFLOW river package, a head-dependent flux boundary condition, allows the interaction of groundwater and surface water to be moderated by the assumption of a sediment layer in the stream, which is expressed as a conductance term. The conductance term incorporates the vertical hydraulic conductivity of the sediment layer, the area of the stream within the model block, and its thickness. When the conductance term is high, the resistance to inter-flow is small, as might be the case for a sandy or gravel-bottom stream. The conductance term is generally adjusted through the model calibration process as typically no or very little data are available to directly quantify fluxes, particularly over large areas such as included in this model. The river package boundary condition is specified in model layer 1 for the Delaware River, small ponds on the new plant location, and for drainage ways in the tidally affected wetland area east of the new plant location. Surface water elevations (river stage, for example) are specified as essentially at sea level for the Delaware River and the tidal drainage ways in the wetland to the east, and range from 4 to 5 feet for the small ponds on the new plant location based on piezometer readings at several ponds. Use of the river package boundary condition package in the model is depicted on Figure B-1.

4.2.6.2 General Head Boundaries

General head boundaries (GHBs) are used to create artificial specified head boundaries; but unlike constant head boundaries, the amount of flow in or out of the model is moderated depending on a specified reference elevation at some distance from the boundary, the head difference between the computed head in the model at the boundary and the reference elevation, the cross sectional areas through which flow can occur, and the hydraulic conductivity of the formation. The model head at a GHB can then flex, leading to a generally more realistic depiction of the head at the boundary and limiting the flow rate through the boundary unlike the infinite capacity of a constant head boundary. GHBs have been specified for most of the conductive aquifer layers at the model boundaries in accordance with interpreted heads and flow direction within the model area and modified during the model calibration process. The location of general head boundaries for the aquifer layers are shown on Figures B-11 through B-13.

4.2.6.3 No-Flow Boundaries

No-flow boundaries are areas or boundaries through or across which no groundwater flow occurs. The model grid presumes no flow outside its boundaries, which is why other types of boundaries may need to be specified. If the model grid extended beyond an interpreted watershed area, no-flow boundaries might be assigned to define this in the model. In this particular model, no-flow boundaries are considered to exist where streamlines to flow occur, or where subsurface structures extend below the groundwater table (see Figure B-3 for examples in the Salem and Hope Creek power block vicinities). Since the only significant flow through aquitards is presumed to be vertical, no-flow boundaries surround the model in model layers 3 (Kirkwood aquitard) and 6 (Navesink aquitard).

4.3 Assumptions

Several of the assumptions made in the design and construction of the model have been presented in the site hydrogeologic conceptual model. Added detail on assumptions made in the model is presented in the following subsections.

4.3.1 Aquifer and Aquitard Units

Each of the layers in the base model represents a separate aquifer or aquitard unit except for a few areas where the Kirkwood aquitard is absent. These gaps in the Kirkwood occur naturally as was determined at two boring locations in the northern portion of the site (NOW-2 and NOW-7), at places where the unit was breached to seat the nuclear islands of the Salem and Hope Creek units on the firm Vincentown Formation, and where sand drains were installed for construction dewatering at the Hope Creek unit. The breaches associated with construction of the existing structures have not been included in the model and it is considered that these have relatively slight overall effects on the potentiometric heads in the alluvium or Vincentown Formation. Although the dimensions of the natural absences are not known in the new plant area, an extent has been assumed to at least depict the locations.

4.3.2 Boundary Conditions

General head boundaries (GHBs) have been prescribed at one or more lateral boundaries of each of the aquifer units with the exception of the hydraulic or structural fill unit. Here, the river package is the western or southern boundary. Little lateral groundwater flow is likely to occur in the hydraulic fill given its low apparent hydraulic conductivity and hydraulic gradient, and the river package accepts what little lateral flow there is. In the vicinity of Salem Units 1 and 2, the extent of the structural fill is greater, and may connect with the river in some locations. However, here, the presence of a groundwater extraction system prevents discharge of tritium-contaminated groundwater. For aquitard units, the model perimeter boundaries are all no-flow under the assumption of no significant horizontal groundwater flow in these units, only vertical. This flux across aquitards may be upwards or downwards depending on the direction of the hydraulic gradient, and the magnitude of the flux is dependent on the thickness of the aquitard, its vertical hydraulic conductivity, and the hydraulic gradient across the unit.

4.3.3 Steady-State Condition

The model is calibrated to a steady-state condition, which is to say to average flow conditions. The water level data for both the alluvium and the Vincentown Formation have been shown to be slightly and moderately, respectively, affected by tides in the Delaware River estuary. As such, and also in response to precipitation events, the condition of groundwater and potentiometric heads in aquifers at the site is actually in a constant state of flux. In order to represent an average flow condition in the model, the available data sets have been averaged since it is apparent that some correspond to different phases of the tidal cycle. The data sets, then, have some underlying variability, which makes the model calibration less exact to matching these observed values. This is discussed more in Sections 5.1 and 5.2, and also in MACTEC 2010.

4.3.4 Hydraulic Conductivities

While a number of pumping tests have been conducted in the Mount Laurel-Wenonah and deeper aquifers, very few and only short-term pumping tests have been performed at the PSEG site in the shallower alluvial aquifer. ARCADIS performed these pumping tests and additional slug tests in shallow wells in support of the 2003-04 investigation and report of conditions in the vicinity of the Salem Unit No. 1.

MACTEC installed 16 pairs (each pair consists of one shallow well and one deeper well) of groundwater monitoring wells and performed slug tests in eight pairs of wells in 2009. Additionally, MACTEC advanced geotechnical borings to obtain data with which to support the ESP in the geology, hydrogeology, and other groundwater issues, including development of this numerical groundwater model.

Results of these tests have been discussed in Section 3.7. The results of these slug and pumping tests, i.e., estimated hydraulic conductivity values, are considered representative of the actual hydraulic conductivity values and suitable as guidance for the assignment of hydraulic conductivity values in the groundwater model. The horizontal hydraulic conductivity is assumed to be isotropic, i.e., independent of direction, and will be referred to as Kh. The vertical hydraulic conductivity will be referred to as Kv.

4.3.5 Groundwater Recharge

Recharge is the net amount of water or precipitation penetrating the ground surface that reaches and actually is incorporated into the aquifer. Net recharge is anticipated to be greater over the developed areas of the site (excluding buildings and paved areas) as coarser grained material has been placed over the site for development, whereas in the undeveloped portions of the site, low permeable hydraulic fill is present, and greater presence of vegetation which increases the evapotranspiration loss back to the atmosphere and results in less recharge to the shallow aquifer. In some places, data suggests that groundwater within the fills may be perched. Assumptions for initial recharge rates in some areas will be made based on previous modeling inputs (e.g., ARCADIS), but final recharge rates will be varied and assigned during model calibration.

Zero recharge has been assigned over surface water bodies. However, the river package is a head-dependent boundary condition and provides for interchange with the groundwater based on the head differential in the river package node. Thus, the Delaware River is predominantly a discharge area, while ponds in the north area allow seepage into the underlying fill materials. While the ponds influence the base model calibration, they will be removed during plant expansion construction.

4.3.6 Water Wells

No municipal, industrial/commercial, or private water supply wells are present within several miles of the site. The facility has four primary groundwater supply wells that withdraw water from the Upper PRM (wells HC-1, HC-2 and Salem PW-5) and the Middle PRM (Salem PW-6 at typically low rates). In addition, two of four wells originally planned for facility groundwater supply from the Mount Laurel-Wenonah have been abandoned (PW-1 and PW-4), while the remaining two wells in this aquifer (PW-2 and PW-3) are for a stand-by emergency use only. It is estimated in the development of the numerical model that withdrawals by the supply wells have no effect in the aquifers represented by the model. The rationale for this is that the Marshalltown aquitard overlying the Upper PRM is very thick and of low vertical hydraulic conductivity allowing no significant effect to be manifest in the Mount Laurel-Wenonah. Also that PW-2 and PW-3, being tested for readiness only quarterly have insufficient volume and removal rates to affect piezometric heads in the Mount Laurel-Wenonah for any significant time.

4.3.7 Plant Area Excavations

Excavations have been performed at both Salem Unit 1 and 2 and the Hope Creek nuclear islands through the shallow units to bear these structures on the Vincentown Formation. Estimates have been included in the model. These areas of higher hydraulic conductivity are still small relative to the overall extent of the aquifer system being modeled and may have only slight localized groundwater level effects.

The current plans for excavation for the new plant location are based on bounding conditions as the technology for the reactor has not yet been determined and areas required for layout of nuclear islands and associated facilities vary considerably. The bounding conditions provide for conservative assumptions of the effects of the construction on the site groundwater regime. The excavation for the nuclear island is planned to extend down into the upper reaches of the basal Kirkwood and Vincentown Formations and then to backfill the excavation with compacted structural fill.

5.0 Model Calibration

Model calibration is an iterative process whereby initial assumptions regarding the values of significant input parameters are varied in an attempt to provide a reasonable representation of the observed hydrogeologic system. The modeler, in adjusting parameter values, attempts to stay within reasonable ranges based on site-specific or literature values. In the process of adjusting these parameter values, the modeler develops a sense of which parameters the model results are more sensitive to, and this allows the modeler to limit the number of parameters that require adjustment. If the model cannot be made to provide a reasonable facsimile of the real system with realistic input parameter values, it may be an indication that the site conceptual model is incorrect, or that there are areas of the model domain which have been insufficiently characterized. The following subsections present detail on the calibration process and the guiding values shaping the calibration.

5.1 Calibration Targets

Calibration objectives, in addition to attaining calibration with reasonable input parameter values, can involve different measures depending on the available data for the site. Water level data are available which can be used as calibration guides in three different ways. First, the model and the interpreted groundwater flow directions from contoured data, should agree. Second, the hydraulic gradients, both horizontal and vertical, should be similar between model computed and observed values. Third, the differences between observed water levels (or piezometric heads) and ones computed by the model for the same location should agree in general.

The difference between the observed value and the computed value is termed a residual. It is unlikely that any set of water levels is sufficiently representative of true steady-state conditions, or that the model can be so detailed as to represent any but the most simple level of aquifer system heterogeneity, such that there would be a perfect fit between all observed and computed heads within the model. Statistical analysis of residuals can help determine a satisfactory degree of fit. Typical statistical measures of the residuals include average residual, absolute mean residual, standard deviation, sum of the squares of the residuals, and a measure of the relative error determined by the ratio of the standard deviation to the range of head values encountered.

The water level data used to guide the calibration were based on monthly water level data sets spanning January through December, 2009, for the northern and eastern sets of wells installed in 2008 to support the ESP. These data sets provided measurements in 14 wells in the alluvium and 16 in the Vincentown Formation. The water levels obtained from two wells screened within hydraulic fills appeared to be indicative of perched conditions, and were not included in the target calibration set. Evaluation of the data resulted in rejection of obvious measurement error and deletion of statistical outliers (see MACTEC, 2010), see Table 3. Further, the minimum and maximum values were also deleted to provide a trimmed mean water level for each location for purposes of model calibration. In addition, a round of water levels was taken in September 2009 for select "B-series" wells installed by ARCADIS in 2006 and principally monitoring the alluvial aquifer. These B-series well data were considered to be minimally affected by tidal influence, and appear to be consistent with previous water levels reported in these wells. Review of the accumulating water level data suggest that most of it appears to be minimally affected by the tidal effects. (MACTEC, 2009a). The target water levels are presented on Table 5.

5.2 Calibration Criteria

Model calibration consists of comparing model output with interpreted gradients and flow directions derived from observational data. These calibration criteria are discussed more in the following subsections.

5.2.1 Groundwater Head Residuals Criteria

Given the nature of the averaging of the water levels and the degree of tidal influence noted for these wells, a target of 0.5 feet was set as the average of the absolute value of the residuals. While, the industry standard generally uses a target of less than 10 percent for the ratio of the standard deviation of the residuals to the range in the observed water levels, the variability in the data due to tidal influence and the relatively small range of observed water levels (piezometric heads) make this difficult to attain. The model fit with observed conditions is described in Sections 5.3.2 and 5.3.3. Variability of the water level data is apparent in the averages and standard deviations of the data for each monitoring location (see Table 3).

5.2.2 Groundwater Flow Criteria

More realistically, a match of observed hydraulic gradients and agreement of flow direction in the model compared to the interpreted flow directions from contouring of observed measurements is more important. Calibrated model output head contours may be compared to interpreted water level data as presented in Attachment A.

5.3 Final Model Calibration

Model calibration was approached by varying key parameter inputs to approach the calibration criteria cited in subsections 5.2.1 and 5.2.2. These parameters included horizontal and vertical hydraulic conductivity for aquifers, vertical hydraulic conductivity for aquitards, reference heads and conductances for river and GHB boundary conditions, and areal distribution and amount of recharge. Manual adjustment of these parameters was performed in order to approach calibration criteria, and then reverse modeling using the parameter estimating program PEST (Doherty, 2004) was employed to further refine the degree of calibration. Final calibrated model input parameter values and measures of calibrated model fit are discussed in the following subsections.

5.3.1 Final Calibrated Model Parameter Values

Final calibrated model input parameter values are presented in Table 4. Each of these is within ranges provided by site-specific data or literature values. Vertical and horizontal hydraulic conductivity values are specified as one value per layer except where native materials have been replaced with structural fill (see Figures B-14 through B-16). In the new plant location, only native materials are present and single values are used for each aquifer or aquitard. In two locations in the new plant location, the Kirkwood aquitard appears to be absent, but the extent of the absence is not known. For purposes of this modeling exercise a limited area has been considered as depicted on Figure B-16. Only recharge has been aerially distributed; Figure B-17 shows the areas and rates of net recharge applied in the calibrated model.

Final model parameters of hydraulic conductivity are in agreement with ranges of these values available from site-specific information or literature provided values. The one parameter of most concern is the vertical hydraulic conductivity of the Kirkwood aquitard. Based on preliminary model runs and simulations, a mid-range value of 0.003 ft/d was selected for the vertical hydraulic conductivity of the Kirkwood aquitard and fixed at that value for subsequent calibration. The value of 0.003 ft/d limits net recharge to low values over much of the model domain if hydraulic conductivities within the fill and alluvium are to be consistent with available data. This uncertainty is evaluated through the sensitivity analyses in Section 6.2. While it is shown that the vertical hydraulic conductivity of the Kirkwood aquitard has little effect on estimates of dewatering flow rates, it does have an effect on the estimated drawdown in the shallow alluvium. A sensitivity run with a vertical hydraulic conductivity of the Kirkwood of 0.001 feet per day showed only very slight drawdowns in the alluvium at existing structure locations, while at a value of 0.01 ft/d the drawdowns were much greater.

5.3.2 Model Agreement with Hydraulic Gradients and Groundwater Flow Directions

Figures B-18 through B-22 depict model-computed generated heads contoured in Groundwater Vistas for model aquifer layers 1 (fills), 2 (alluvium), 4 (Vincentown), 5 (Hornerstown), and 7 (Mount Laurel-Wenonah). Data is most plentiful for the alluvium, and, while data is available for the Vincentown, these data are likely affected by tidal influence, hence the interpreted flow direction is less certain, but generally suggests groundwater flow toward the river through the new plant location. Little head data is available for the Mount Laurel-Wenonah and insufficient for contouring heads across the model domain. General head boundaries have been inserted in the model based on USGS regional modeling which suggests a predominantly southerly to southeasterly flow direction across the model domain.

The model-generated head contours in the alluvium are consistent with data obtained across the site for the B-series wells and for water level data sets collected in wells installed in the northern and eastern area (see Attachment A). In general, the model duplicates the conceptual site model in that a radial flow pattern develops with a groundwater high or highs situated approximately mid-site and groundwater moving towards the Delaware River in the eastern and southern portions, and northerly and easterly toward the wetlands or westerly toward the Delaware in the more northerly portions of the facility (see Figure B-19). Some local depressions in the alluvium piezometric surface appear due to large areas of no or limited recharge and/or thinness of the Kirkwood aquitard. The maximum aquifer head in the model is 3.5 feet NAVD 88 in the alluvium, which corresponds well with observed maximum levels in the B-series wells.

5.3.3 Model Point-wise Calibration and Analysis of Residuals

Comparison of the observed versus model computed heads gives rise to a residual value at each target location. The analysis of the residuals affords a means of quantifying the fit of the model to the observed data. The analysis of the residuals includes calculating their mean, the mean of the absolute value of the residual, standard deviation, sum of squares of the residuals, ratio of the standard deviation of the residuals to the range of observed water levels. Table 5 presents the residuals and the computed statistical measures. These statistics suggest a reasonable fit to the data considering that some are tidally affected and likely display transient effects due to this cycling. The mean residual is minus 0.04 ft, with a standard deviation of 0.36 ft, and a mean absolute residual of 0.27 ft. The ratio of the standard deviation to the range of observed values is 0.138. While this is higher than a usual target of 0.1, the nature of the variability in the data observations and the small range of observed heads (2.60 ft) make this difficult to attain.

Figure B-23 presents a plot of the computed heads versus the observed heads at the target locations. While showing some spread, the points lie about a 1:1 slope line that would indicate zero residuals. This spread is likely due to the tidal influences within the data, the averaging of water level measurements that span the period of measurement, and to the spatial variability arising from aquifer and aquitard heterogeneity across the model domain.

5.3.4 Model Water Balance

Details of the water balance for the model are summarized on Table 6. Water into the model is derived from recharge (24 percent), GHBs (71 percent), and the remainder from river seepage (5 percent). Principal losses out of the model are through GHBs (79 percent) and rivers (21 percent). The overall internal water balance for inputs versus outputs as computed by MODFLOW is minus 0.146 percent, indicating a good closure of the model solver and no anomalous behavior.

Downward seepage through the Kirkwood and Navesink aquitards is evident in the layer by layer water balances, although the GHBs contribute significant inflow to the Vincentown and Hornerstown units. Seepage across these units is variable as the Vincentown, being tidally affected, would establish counter-gradients to reverse flow potentials through aquitards during portions of the tidal cycle.

5.4 Model Sensitivity

During the course of the manual adjustments of model input parameters, it became apparent that the most sensitive parameters would be the recharge, vertical conductance of the Kirkwood and Navesink aquitards, specified conductances and reference heads for some GHB boundary condition nodes, and horizontal hydraulic conductivities of the aquifer units.

A more formal sensitivity analysis of the response of the model to ranges of selected parameter values (varied one at a time) was investigated by comparison of the model residual statistics for the range of parameter values to those of the calibrated base model. This analysis is summarized in Table 7, which also shows the range of values over which the parameter was varied. For hydraulic conductivities, the sensitivity analysis considered the calibrated value multiplied by 0.25, 0.5, 2 and 4 (e.g., considering the horizontal hydraulic conductivity of the Vincentown Formation as 10.7 ft/d, the sensitivity of the model was evaluated using values of 2.67, 5.35, 21.4 and 42.8 ft/d). For recharge, sensitivity analyses considered the calibrated value multiplied by 0.5, 0.75, 1.25 and 1.5. For the Delaware River, river nodes and GHB packages, the reference heads were varied by minus 2 to plus 2 feet, and the conductance terms were varied by factors of from 0.1 to 10. It should be noted that the effects of varying a single variable at a time focuses only on that variable. Effects of changes in the value of a variable may be offset by adjustments in other parameter values to maintain a reasonable calibrated model (the set of parameter values producing a reasonably calibrated model is not unique). The main purpose of the sensitivity analysis is to identify those variables which appear to have the greatest effect in the model. Identifying these parameters or areas within a model where sensitive parameters have a greater effect can identify areas where the model may benefit from added data and the nature of that data.

As Table 7 indicates, the model is most sensitive to recharge over the main portion of the facility, vertical hydraulic conductivity of the Kirkwood, the reference heads for GHBs for the Vincentown and Mount Laurel-Wenonah, the reference head for the Delaware River, and the horizontal hydraulic conductivity of the alluvium and Mount Laurel-Wenonah. While some effects were noted for some of the other input parameter values, the responses in the model to these were not nearly as pronounced as the aforementioned sensitive parameters.

6.0 SIMULATIONS

The principal use of the model in supporting the ESP is to provide estimates of required dewatering rates for the proposed construction of the new unit, and estimates of the potential distances, where resulting drawdowns would extend and their magnitude at potentially safety-related structures and wetland areas. Secondarily, the model is being used to provide a rationale for specifying a conservative estimated expected hydrostatic loading at the proposed expansion nuclear island site. These simulations, including modifications of the base model, are described in the following subsections. This section also presents a sensitivity analysis for the dewatering simulation and estimated dewatering rates.

6.1 Dewatering Simulation

Since the reactor vendor has not been selected, the simulation of dewatering in support of the ESP is based on the bounding envelope of the excavations required to construct any of the four plant designs under consideration. Thus, the resulting estimates below should be considered preliminary and will be reconsidered in the COLA Phase following selection of a plant vendor.

Proposed bounding excavation conditions for the construction of the expansion are depicted on figures in Attachment C. The construction excavation in the power block area will extend down to the Kirkwood to allow replacement of the hydraulic fill and alluvial deposits with structural fill. Under the safety-related components of the power block, the excavation will extend deeper to the competent layer. These bounding dimensions of the deeper excavation are 1095 feet in a north-south direction and 900 feet in an east-west direction. The deeper excavation layout would be approximately centered within the power block area whose western extent is approximately 300 feet east of the Delaware River.

The proposed dewatering and excavation sequence would include establishing an outer soil retention barrier system (considered in this bounding dewatering scenario to extend down to about elevation -90 ft NAVD88) as depicted on Figure B-24. Dewatering wells are considered on the interior of the barrier and extend down into the Vincentown Formation, dewatering down to below the Kirkwood aquitard within the expanse of the outer barrier contained area. An average target elevation for the top of the Kirkwood is approximately -45 ft NAVD88, but this surface is variable across the area and depth of excavation will vary across the proposed power block area. Once this larger area has been excavated, a second, inner soil retention barrier (also considered as down to a minus 90-foot elevation) would enclose the smaller area where the nuclear island and safety related structures would be constructed. This inner barrier wall is depicted on Figure B-25. Additional dewatering wells would be placed within this inner barrier extending down into the Vincentown and likely Hornerstown units. The dewatering objective in the smaller, inner excavation is to lower the hydrostatic elevation below the intended target excavation depth of approximately -67 feet NAVD88 (this may vary locally by a few feet). The excavations would eventually be backfilled and the plant area built up to an estimated final elevation of 36.9 feet NAVD88 to provide protection from probable maximum flooding due to PMH (Probable Maximum Hurricane).

In order to properly represent the barrier walls constructed down to approximately -90 feet NAVD88, the model layer representing the Vincentown was separated into two model layers. The parameter values and GHB boundary conditions were re-established for the newly added layer, and the bottom of the new layer (the upper Vincentown) set at an elevation of -90 feet NAVD88. The model was further modified by using the horizontal flow barrier (HFB) package in MODFLOW to represent the soil retention system which will also retard groundwater flow where it is present. The effectiveness of the barrier system was conservatively set as equivalent to a one-foot thickness of a 0.0283 ft./day material. A specific yield of 0.2 was assigned to aquifers, and 0.1 to the aquitards. The confined aquifer storage coefficient was 0.0001 and the total porosity was 0.35 for aquifers and 0.40 for aquitards. (Kresic, 1997)

A second model layer split was performed, this one for the hydraulic fill, similarly as was done for the Vincentown. Here the intent or purpose was to allow the top of the soil retention barrier to be represented at a below ground surface elevation since it will likely be left in place. This barrier may serve to restrict groundwater flow, possibly permit buildup of heads within the barrier, and allow groundwater to flow over the top of the barrier; the top of the barrier was assumed to be at elevation 5 feet NAVD88. This model variant was run in steady-state to generate a set of initial heads that would be used in the transient model for the dewatering simulation.

The modified model then has nine layers: layer 1 – upper fill; layer 2 – lower fill; layer 3 – alluvium; layer 4 – Kirkwood aquitard; layer 5 – upper Vincentown; layer 6 – lower Vincentown; layer 7 – Hornerstown; layer 8 – Navesink aquitard; and layer 9 – Mount Laurel-Wenonah. It should be noted that the calibration for the initial 7 layers is applicable to the modified model for purposes of simulations. The calibration was reviewed for the split-layering and was shown to have no significant effect on the calibration as measured by the point wise statistics.

The larger, power block excavation area was enclosed using the HFB through model layers 2 through 5 (lower fills down through the upper portion of the Vincentown), see Figures B-24 and B-25. The smaller nuclear island and associated safety-related structure area was also enclosed, but this time just through model layers 4 (Kirkwood) and 5 (upper Vincentown), see Figure B-25.

Dewatering wells were represented by drain nodes. The conductance of the drain node is set purposefully high to minimize resistance to flow into the drain node. Drain nodes were placed about 100 feet apart in model layer 3 (alluvium) (see Figure B-24), and at 200-foot intervals in layers 5 and 6 (upper and lower Vincentown, see Figures B-25 and B-26). Drains/wells were not placed in model layer 4 (Kirkwood) since no significant lateral flow would be expected to occur in this aquitard unit. While actual dewatering wells may be screened across all units, the simulation adequately captures the expected flows. (The placement of simulated wells in the alluvium is not intended to signify actual pumping wells and pumps in the alluvium, but that the screened intervals of the deep wells may be open across the alluvium as they were in the dewatering at Hope Creek.) The depth of placement is consistent to that of wells installed for the Hope Creek dewatering and construction. This simulation of dewatering wells is not meant to present a proposed design, just to provide adequate sinks to estimate potential dewatering rates and drawdowns.

The dewatering simulation was run in two stages. In the first stage, only the outer wells at the perimeter of the power block were active. In a simulated time of about 90 days, the piezometric heads within the upper Vincentown had dropped below the Kirkwood aquitard. This happens reasonably quickly because of the confined nature of the aquifer (heads drop rapidly due to the low confined storage coefficient). Although a lengthy period would then follow in which excavation, the placement of the second, inner barrier system and installation of the second ring of dewatering wells, the simulation skipped this period of time and the second phase assumed excavation of the power block area and these inner ring wells were all in place immediately following the first phase. The second phase ran to a total simulated period of 365 days to achieve some measure of long-term expected dewatering rates. Heads drop more slowly during this period as the upper Vincentown becomes partially saturated (unconfined), and the larger specific yield determines this rate of dewatering. By this time, a near steady-state dewatering rate has been established. The simulation estimates that the initial dewatering rate will be approximately 5,600 gallons per minute (gpm), decreasing to about 3,450 gpm at 90 days. As the second phase begins, 90 days after the start of the first phase, the rate increases to about 5,250 gpm, decreasing to a near steady-state rate of about 3,600 gpm at 365 days. The alluvium initially contributed about 800 gpm, but this rate declined very rapidly within a day to about 120 gpm and declined to about 30 gpm by the end of the simulation. Table 8 summarizes the time-dependent extraction rate schedule for the simulation.

The model-generated drawdowns at one year for the fills, the alluvium, and the upper Vincentown are shown on Figures B-27 through B-29, respectively. The resultant drawdowns are elongated in the direction of the interior of the facility due to boundary conditions to the north and west. This elongation is due to recharge boundaries and presence of higher hydraulic conductivity materials in portions of the developed portions of the facility, the model allows sufficient space for the drawdowns to extend toward the existing structures under consideration. Table 9 also summarizes drawdowns in the Alluvium and Vincentown Formation at one year of simulated time beneath the centers of the: Hope Creek cooling tower, Hope Creek unit, Salem Units 1 and 2 and other structures. Drawdown at the center of the excavation area for the base simulation in the Vincentown is presented on Table 10. Hydrographs of drawdown versus time at hypothetical monitoring wells in the alluvium and upper Vincentown are shown on Figures B-30 through B-35. The drawdowns portrayed on the figures are at a simulated dewatering duration of one year, and may continue to increase over longer time until contributions to the total flow rate from storage become minimal. For the best estimate scenario, contributions from storage were about 14 percent at 90 days, about 6.5 percent at one year, and about 3.7 percent at two years. Conditions experienced during actual dewatering will depend on the actual final design layout, how the system is brought on line, rates of excavation, depths of wells and depth of pump placement, local variations in hydraulic conductivity, and control exercised over individual pumping rates. These conditions should be monitored during the dewatering and construction phase as they were during the Hope Creek dewatering and excavation. Details of the actual dewatering system design and further refinement of dewatering rate estimates will be developed and presented during the preparation of the COLA.

The results of the simulation suggested that a ring of perimeter wells around the full extent of the power block excavation may be inefficient for dewatering the fill and alluvium within a reasonable time frame. The distance is too great to efficiently dewater a thin aquifer, the Kirkwood is effective as an aquitard over much of the area, and precipitation falling over the area would also retard the rate at which the piezometric levels would decline. While the target level is -45.2 feet NAVD as shown on the conceptual section, the surface of the Kirkwood does vary across the power block extent and is absent in places. Where the surface of the Kirkwood is higher in the model, the target elevation is not attained there. Sand drains may be a possible addition to augment draining from the fill and alluvium down into the Vincentown where it is more effectively extracted. Sand drains were a component of the dewatering scheme employed during the pre-excavation activities at the Hope Creek unit.

Some drawdown is apparent in the fills extending under the wetlands to the east of the area proposed for development (see Figure B-27). However, these effects are limited, and this area also receives influx of tidal waters, further lessening the potential for establishing conditions that might detrimentally affect these areas. Drawdowns within the Vincentown extend further than in shallower layers as this unit is confined and is providing the bulk of the dewatering rate; however, much of this effect is contained under the Kirkwood aquitard and does not affect structures where the Kirkwood is present and effective.

A comparison with the dewatering conducted for the construction of the Hope Creek unit is informative. While the area being dewatered was smaller, the excavation methods did not include a flow barrier to reduce horizontal pumping requirements. The total dewatering rates for Hope Creek were about 3000 gpm. Measured drawdowns as great as about 40 feet were recorded about 1000 feet west of the center of the dewatering area and near the Delaware River. The monitoring network for the Hope Creek dewatering was limited to the east and south (Dames & Moore, 1978). Given the differences in pumping rate, excavation size and absence of a flow barrier, the rates observed during dewatering during the construction of the Hope Creek Plant generally validate the pump rates and drawdowns estimated by this modeling activity .

The simulation of the dewatering scenario includes only contributions from groundwater and average recharge conditions over the excavation influenced area. Direct precipitation into the excavation during storm events also needs to be accounted for. A one-day one-inch storm event over the entire excavation area could result in the accumulation of about two million gallons of water in the excavation. Sumps and sump pumps would need to be assigned to remove this water in an expeditious manner, and would require adequate limits be defined in the dewatering permit. To remove this much water in the course of a day would require a rate of about 1,393 gpm per inch of rainfall over the average dewatering rate to maintain the desired drawdowns, and proportionately higher rates for more intense storms. This simulation is based on the best estimates of hydrogeologic parameters currently in the model. As these parameters have some level of uncertainty, a sensitivity analysis for the dewatering simulation was conducted and is presented in the following section.

6.2 Dewatering Simulation Sensitivity Analysis

The dewatering rates estimated for the simulation presented in Section 6.1 are primarily a function of the excavation area(s), depth of excavation, and hydrogeologic parameters, primarily the specific yield, the horizontal hydraulic conductivity of the Vincentown and Hornerstown aquifers, and the vertical hydraulic conductivity of the Navesink aquitard. While the alluvium and fills contain a significant volume of water, the rates at which they are released or seep into the deeper Vincentown are relatively small compared to the total longer term dewatering rates. However, the vertical hydraulic conductivity of the Kirkwood aquitard greatly influences the estimated extent and degree of the drawdown projected in the shallow alluvial aquifer.

The specific yield is a measure of the amount of groundwater that is released from the matrix as the soil is dewatered. For the aquitards (hydraulic fill, Kirkwood, and Navesink), this is taken as a relatively conservative 10 percent. The storage coefficients come into play during early portions of transient simulations, when water is released from storage, but as the dewatering proceeds, the amount released from storage becomes less and less, and the long-term rates are drawn from boundary conditions or vertically from neighboring layers.

Since the dimensions of the proposed excavation are fixed for this simulation, the selected specific yields are reasonable, and long-term rates are not dependent on the storage coefficients, the sensitivity of dewatering rates was conducted by:

- increasing and decreasing the horizontal hydraulic conductivity of the Vincentown and the Hornerstown Formations;
- increasing and decreasing the vertical hydraulic conductivity of the Navesink;
- by increasing and decreasing the vertical hydraulic conductivity of the Kirkwood aquitard;
- increasing the Kh of the Mount Laurel-Wenonah; and
- increasing the Kv of the Vincentown and Hornerstown aquifers.

The results of these sensitivity simulations, including estimated rates and drawdowns at select main plant existing structures are summarized on Tables 8, 9 and 10, and discussed briefly below.

<u>Decrease Vincentown/Hornerstown horizontal hydraulic conductivity to 5.35 ft/d.</u> This model run produced the lowest estimates of dewatering rates, but also showed that the drawdowns propagate more slowly and do not quite attain the target elevation within the deeper excavation by the end of the simulated year (-54 versus the target -67). The simulation suggested that attempts to increase flow rates could be countered by increases in drawdown that may result in increased upwelling. The wells would need to create greater drawdowns at the perimeter in order to achieve the targets, or if drawdown is limited by the depth of installation, additional wells may be needed.

<u>Increase Vincentown/Hornerstown horizontal hydraulic conductivity to 21.4 ft/d.</u> This sensitivity run produced the greatest dewatering flow rates. Drawdowns also propagated more rapidly, reaching the first stage (elevation -45.2) in the Vincentown in about a day; however, the upper fills still require longer times to drain. At one year the final elevation within the upper Vincentown was comparable to the base simulation, but required the higher pumping rate.

<u>Decrease vertical hydraulic conductivity of the Navesink to 0.0272 ft/d.</u> Halving the vertical conductivity of the Navesink aquitard between the lower Mount Laurel Wenonah and the upper Vincentown aquifers resulted in a modest decrease of about 200 gpm in the total 365-day pumping rate compared to the base simulation. Decreasing the seepage upward slightly improved the rate at which the target elevations were achieved.

<u>Increase vertical hydraulic conductivity of the Navesink to 0.109 ft/d</u>. Doubling the vertical hydraulic conductivity of the Navesink aquitard resulted in a slight increase of about 5 percent in the estimated total pumping rate necessary to achieve the target piezometric head in the Vincentown for the deeper excavation. Elevations achieved in the Vincentown Formation at 90 and 365 days were very comparable with those in the base dewatering simulation.

Decrease vertical hydraulic conductivity of the Kirkwood aquitard. Decreasing the vertical conductivity of the Kirkwood aquitard to 0.001 ft/d in the base model simulation run had little effect on the estimated dewatering extraction rate. However, this parameter had a significant effect on the extent and the amount of drawdown projected in the alluvium at existing structures and in the wetland east of the proposed site of the new unit (see Figure B-36 and Table 10).

Increase vertical hydraulic conductivity of the Kirkwood aquitard. Increasing the vertical hydraulic conductivity of the Kirkwood aquitard to 0.01 ft/d had little effect on the estimated dewatering extraction rate. However, this parameter had a significant effect on the extent and amount of drawdown projected in the alluvium at existing structures and in the wetland east of the proposed site of the new unit. This resulted from the increased seepage and connection between the alluvium and Vincentown Formation with the less effective aquitard (see Table 10).

Increase the horizontal hydraulic conductivity of the Mount Laurel-Wenonah aquifer. Increasing the horizontal hydraulic conductivity of the Mount Laurel-Wenonah aquifer to 15 ft/d increased the estimated long-term pumping rate by about 230 gpm over the base simulation run (see Table 10), about 6 percent.

Increase the vertical hydraulic conductivity of the Vincentown and Hornerstown units. Increasing the vertical hydraulic conductivity of the Vincentown and Hornerstown units to 1 ft/d (a factor of 5) increased the estimated long-term pumping rate by about 320 gpm over the base simulation run (see Table 10) about 9 percent.

6.3 Simulations for Estimating Future Hydrostatic Loading at the New Unit

Post-construction conditions were conservatively considered to include increased recharge local to the new unit due to the replacement of the low hydraulic conductivity hydraulic fills with the more permeable structural fills. Recharge rates over the development area were increased to 8 in/yr from the base calibrated model. Consideration was also given to the breach in the Kirkwood that accompanies the excavation for the nuclear island. In one run, the Kirkwood was considered to have been breached over the full deeper excavation area for support of safety-related structures. In a second run, a space of 40 feet within the assumed 440-by-440-foot bounding area for the nuclear island was left open to the lower aquifer (see Figure B-37). In both of these scenarios, the gap allows flow from the alluvium into the Vincentown thereby relieving potential head build up from recharge. The results of this second run, the more conservative for the alluvium, are shown for the alluvial or structural fill layer on Figure B-38 and Figure B-39 for the upper Vincentown. Heads (water level elevations) within the simulated soil retention barrier were as great as 5.3 feet. Part of this buildup is due to the presence of the simulated soil retention barrier. However, engineered features in the barrier design could be implemented to dissipate some of the resultant hydrostatic pressure in the shallow aquifer.

Since the simulations are based on estimated average aquifer conditions, tidal effects are not evident in the model outputs. However, since the nuclear island will be in direct contact with the Vincentown, it will experience hydrostatic loadings from tidal activity in the Vincentown. In consideration of the uncertainties in conditions that may arise, including potential effects of the soil retention barriers that may be left in place, a conservative hydrostatic loading of +6 feet NAVD88 is recommended. This is also consistent with the hydrostatic loading prescribed for the Hope Creek development.

Under normal conditions, pre- and post-construction water levels in shallow units across the PSEG facility would appear to be similar, with post-construction shallow water levels only about a half-foot higher in some areas of existing structures (e.g., the cooling tower or Hope Creek unit) requiring no permanent long-term dewatering at the new unit.

7.0 LIMITATIONS OF THE MODELING

Groundwater models represent an approximation or simplification of the actual hydrogeologic system. While a well-constructed groundwater model will be based on as much of the existing data as possible, these data typically represent only a small fraction of the system being modeled. In addition, groundwater systems are typically complex with heterogeneities in the system producing perturbations which deviate from the ideal. In addition, groundwater systems may be constantly in flux, and obtaining an average flow condition on which to base the model may be made more difficult. The groundwater modeler seeks to capture the essence of the system or its dominant features and produce a close representation of the interpreted groundwater flow using values of input parameters and choices of boundary conditions that mirror reality. If this can be done, the model can be used within limits to provide estimates of the effects of future events. In all cases, the modeler must bear in mind that the set of input conditions used to calibrate the model are not unique, and that simulations conducted with the model under extreme conditions may cause the model to provide inaccurate results. These circumstances require the modeler to conduct sensitivity analyses in order to provide reasonable ranges of estimates and to assure that the model has not been overly stresses during simulations.

While the model uses site-specific information, there are still areas of the model where data are not available or may only be an approximation of the spatial distribution of parameters. Here averages taken from other similar conditions are extrapolated, resulting in simplifications and assumptions of homogeneous conditions. While there may be local variations, this approach may produce acceptable results over larger areas which average out these variations.

In developing the model, realistic input parameter values have been incorporated to provide a reasonable representation of the actual hydrogeologic system. This provides the current understanding of the site hydrogeology and the best basis for deriving estimates of dewatering and future conditions. The model has been suitably constructed and calibrated for its intended purposes of providing these estimates for the ESP. To the extent possible, previous information and features in the modeling performed by ARCADIS for the Salem Unit 1 area have been retained in this model. However, the small scope of that model relative to the much larger domain of the current model, and the distance of the Salem Unit 1 from the proposed area for expansion limit the usefulness of that information as applied to the larger domain.

The proximity of the proposed excavation for the power block area relative to the Delaware River and the model perimeter boundary conditions must also be considered. The use of river and GHB type boundary conditions rather than constant head boundaries was chosen to alleviate this potential concern. Further, in evaluating the results of the base dewatering simulation, relative contributions to wells along the perimeters of the proposed excavations nearer these boundaries were compared with those farther away. These comparisons indicated that the combined pumping for the northern wells (both inner and outer rings of wells) at the end of the simulated period compared to the southern wells were in the ratio of 53 to 47 percent (see Attachment D). Similarly comparing the western wells nearer the river to the eastern wells further away resulted in a ratio of 55 to 45 percent. This appears to be realistic considering the setting. The resultant head and drawdown contours projected by the model, while compressed where near the boundaries are considered realistic for areas interior to the model and in the vicinities of the safety-related structures.

The model has been used to provide estimates of conditions based on preliminary layouts for the new unit. Until the final technology is selected for the COLA, and space requirements for the new unit and its associated structures are determined, the estimates provided in this modeling are to be considered only approximate for general planning purposes, and will be refined as details for the actual dewatering and construction are developed. The current model may be used to help evaluate and optimize alternative dewatering schemes.

8.0 CONCLUSIONS

Conclusions based on the numerical groundwater model can be grouped into several categories. These include estimates calculated by the model to support evaluation of the following:

- Dewatering rates required to achieve the lowered groundwater conditions required for the foundation excavation;
- Potential aquifer drawdown due to dewatering for new plant construction on existing wetland areas and structures;
- Changes in shallow groundwater flow patterns and elevations as a result of the proposed construction and the resulting hydrostatic loads on future structures;
- Assessment of the suitability of the model to supply these estimates;
- Identification of sensitive parameter values in the model and their suitability; and
- Observations of general groundwater behavior in the aquifers of interest.

The conclusions for each of these categories are summarized below.

8.1 Dewatering Rates and Long-Term Rate Sensitivity

The modeling of the dewatering scheme considered for the proposed expansion construction indicated an estimate of about 5600 gpm to dewater the larger (plan view), shallower excavation to the top of the Kirkwood Formation. The transition into dewatering the smaller (plan view), deeper excavation, into the Vincentown Formation, is estimated to require dewatering rates of about 5230 gpm. These are initial rates for each phase of the excavation, and taper off with time, eventually requiring a total long-term rate of about 3600 gpm. Sensitivity analyses suggest a range of long-term flow rates from 3400 to 5400 gpm (See Table 8). This does not include influx of water from storm events which must be dealt with separately.

8.2 Drawdown of Aquifer at Existing Structures and Adjacent Wetlands

Dewatering results in considerable drawdowns of the piezometric heads in order to maintain these levels below the target excavation depths. In the case of the shallow aquifers these are decreased at recharge boundary conditions, and the dewatering would appear to pose little threat to the wetland east of the proposed expansion since it is tidally affected and renewed daily.

The areal impact of dewatering may also affect the stability of existing structures. The following existing structures are within the projected zone of dewatering influence.

- HC Cooling Tower
- Salem and HC ISFSI
- Waste Treatment Plant
- HC Switchyard
- Learning and Development Center
- HC Nuclear Island
- Fuel Oil Tank
- Material Center
- Low Level Radioactive Waste Building
- Salem Nuclear Island
- Nuclear Operations Support Facility

The degree to which drawdowns occur in the alluvial or structural fill about these units is largely a function of the competence of the Kirkwood aquitard. Additional data gathered in concert with pumping tests in the proposed expansion areas will be needed to more accurately evaluate the potential drawdowns once the final selection for the expansion technology is determined.

8.3 Anticipated Changes in Shallow Groundwater Flow Patterns

Modeling of post-construction conditions suggests that groundwater flow patterns and water levels would return to the pre-construction conditions over most of the model domain. Only slight increases of about 0.5 feet were noted in some portions of the model. Changes to the site, following construction would also include:

- The presence of the soil retention barriers (likely permanent elements extending from elevation -5 ft NAVD88 to -90 ft NAVD88);
- A localized gap (window) in the Kirkwood aquitard that would be replaced with structural fill;
- Placement of fill to establish a plant grade approximately 27 ft higher than the existing grade;
- The existing shallow perched ponds within the excavation footprint will be removed; and
- Replacement of the existing vegetation with developed hard surface.

These physical changes will cause some variation in flow patterns; however the projected piezometric heads in the fill and alluvial materials are not expected to be much greater than the current static conditions.

Simulations for post-development suggest a potential average hydrostatic loading of about 3 to 4.5 feet NAVD 88 on the new unit, but based on considerations of potential tidal effects in the Vincentown, a design loading of 6 feet NAVD 88 is recommended and is consistent with that proposed for the Hope Creek Station. The elevations of the bottom of the new structures may be deeper than the groundwater table; however, under normal conditions, pre- and post-construction water levels in shallow units would appear to be similar across the PSEG facility, with post-construction shallow water levels about a half-foot higher in some areas of existing structures (e.g., the cooling tower or Hope Creek unit) requiring no permanent long-term dewatering at the new unit. The characteristics of the soil retention barriers, which likely will be left in place, may also locally affect the hydrostatic loading.

Generally, because the ground surface for the new plant will be raised to approximately 36.9 feet NAVD88 and the groundwater barrier walls will remain in place, the maximum anticipated groundwater elevations within the groundwater barrier walls is 6 ft NAVD88. Thus the groundwater will be approximately 30 ft below the final plant grade. Thus, the anticipated hydrostatic loading on the future structures is less than the conservative hydrostatic water level on which the Design Control Documents (DCDs) are based.

Therefore, the proposed expansion would appear to alter groundwater flow patterns only slightly from current conditions in the areas of present facilities, and the need for a permanent dewatering system is not envisioned.

8.4 Sensitive Parameters in the Model

During calibration of the model, the most sensitive input parameters were determined to be recharge applied over the model (including seepage losses from ponds in the new plant location), horizontal hydraulic conductivity of the alluvial and Mount Laurel-Wenonah aquifer units, vertical conductivity of the Kirkwood, reference elevation for the Delaware River, and GHB reference heads in the Vincentown and Mount Laurel-Wenonah Formations. During the dewatering simulations, the most sensitive parameters included the hydraulic conductivity of the Vincentown and Hornerstown Formations.

8.5 Sensitivity Analyses

Sensitivity analyses were performed on the dewatering model run, varying key parameters of the hydraulic conductivity of the Vincentown Formation, the vertical hydraulic conductivity of the leaky Navesink aquitard, and the vertical hydraulic conductivity of the Kirkwood aquitard. Averaging short-term initial rates, the model provided best estimates for the construction dewatering from about 5,200 to 5,600 gallons per minute over a year's simulation. The sensitivity analysis indicated that an expected range might vary from about 3,000 to 7,600 gallons per minute (averaging short-term initial rates). Given the larger proposed area for dewatering than that conducted for the Hope Creek unit, the estimated dewatering rates are generally consistent with those documented during the construction of the Hope Creek Generating Station. The estimated dewatering rates do not include storm water which may fall within the excavation limits. Collection sumps and high rate pumps will likely be needed to evacuate storm water from the excavation.

8.6 Summary

This groundwater model has been completed in support of the ESP application for the PSEG Site. The model provides estimates of the expected groundwater response to dewatering and post-construction scenarios. However, the dewatering scenario and dewatering estimates are intended to be preliminary and are based on the assumed excavation boundaries. Groundwater modeling will be refined after the reactor vendor is selected, and the final excavation geometry is determined. Preparation of the COLA will likely require additional data, which could be obtained from pumping tests or other methods to further refine hydrogeologic parameters and model estimates of dewatering rates and drawdowns beneath existing site structures. Data gathered in support of the ESP combined with the location and size of the proposed plant excavation area has indicated that additional data is needed to refine estimates of dewatering rates and the potential for excessive drawdown at existing structures during the dewatering period. Once the technology and site layout has been determined, pumping tests are recommended at the PSEG site to further refine the groundwater model. The purposes for the pumping tests will be to determine aquifer characteristics of the Vincentown Formation in the proposed area of construction (the increased area of the power block extends beyond the explorations conducted in that area), determine the effectiveness of the Kirkwood aquitard to limit drawdown in the alluvial aquifer and fill (since it is absent in some locations and estimated dewatering drawdown effects in the alluvium are very sensitive to the vertical hydraulic conductivity of the Kirkwood aquitard), to assess potentials for upwelling from the underlying Mount Laurel-Wenonah Formation during dewatering, and assess the potential for encountering recharge boundaries in the Vincentown Formation in the northern portion of the proposed power block area.

9.0 REFERENCES

ARCADIS, 2003. The full document citation was not included. The document is titled "Development of a Groundwater Flow and Solute Transport Model. Salem Generating Station" and is included as Appendix B – Groundwater Modeling Results to an unspecified document.

ARCADIS, 2004. Remedial Investigation Report. PSEG Nuclear, LLC, Salem Generating Station, Hancock's Bridge, New Jersey. March, 2004.

Benson, R.N. 2004, "Characterization of the Potomac Aquifer, an Extremely Heterogeneous Fluvial System in the Atlantic Coastal Plain of Delaware," in the Atlantic Coastal Plain of Delaware: Delaware Geological Survey Open File Report 45, 2004.

Dames & Moore, 1968b. "Groundwater Supply Investigation, Proposed Nuclear Power Plant Near Salem NJ".

Dames & Moore, 1970. Investigation of Saline production Well No. 4.

Dames & Moore, 1974a. Groundwater Supply Investigation, Hope Creek.

Dames & Moore, 1974b. Groundwater Supply Well #5"

Dames & Moore, 1977. Report, October 1977, Stages 3 to 10, Excavation/Dewatering, Hope Creek Generating Station, Lower Alloways Creek Township, New Jersey, Public Service Electric and Gas Company.

Dames & Moore, 1978. Report, June 1978, Stage 11 Monitoring Program for Excavation/Dewatering, Hope Creek Generating Station, Lower Alloways Creek Township, New Jersey. Public Service Electric and Gas Company.

Dames & Moore, 1988. Final Report Study of Groundwater Conditions and Future Water-Supply Alternatives Salem/Hope Creek Generating Station, Artificial Island, Salem County, New Jersey PSE&G. July 15, 1988.

Doherty, J., 2004. PEST, Model-Independent Parameter Estimation, User Manual: 5th Edition. Watermark Numerical Computing.

Dugan, B., et al., 2008. Hydrogeologic Framework of Southern New Castle County. Open File Report No. 49. Delaware Geological Survey. Newark, Delaware.

Environmental Simulations, Inc., 2005. Guide to Using Groundwater Vistas.

Golden Software, Inc., 1993-2002. SURFER 8, User's Guide.

Kresic, N., 1997. Quantitative Solutions in Hydrogeology and Groundwater Modeling. Lewis Publishers, New York, NY

MACTEC, 2009a. Tidal study. Calculation Number: 2251-ESP-GW-001. Rev. A2, December 2009.

MACTEC, 2010. Groundwater Elevations and Hydraulic Gradients. Calculation Number 2251-ESP-GW-004. Rev. B1 January 11, 2010.

MACTEC, 2009b. Hydraulic Conductivity & Tidal Study Data Report, Rev. A. November 25, 2009.

MACTEC, 2009c. Geologic Stratification. Calculation Package 2251-ESP-GE-001. Rev. 1. September 4, 2009.

NJDEP, 2000. Water Allocation Permit No. 2216P. Letter to PSEG dated June 30, 2000 with permit and conditions attached.

NJDEP, 2004. Water Allocation Permit – Minor Modification Program Interest ID: 2216P. Letter with permit modifications and conditions attached.

NJOIT, 2007, State of New Jersey Office of Information Technology, Aerial Survey of Salem New Jersey.

Page, Leo, 1981. No. 6 Test and Production Well.

PSEG, 2008a. Quarterly Remedial Action Progress Report, Fourth Quarter 2007, PSEG Nuclear, LLC, Salem Generating Station.

PSEG, 2008b. Applicant's Environmental Report – Operating License Renewal Stage Salem Generating Station. Revision 2a. December 2008.

PSEG, 2008c. Applicant's Environmental Report – Operating License Renewal Stage, Hope Creek Generating Station. Revision 2a. December 2008.

Sargent & Lundy, 2009. Water Balance Calculation. Calculation No. 12310-014-M-001 Rev. 0.

USGS/State of New Jersey, 1969. Geology and Ground-Water Resources of Salem County, New Jersey. State of New Jersey Department of Conservation and Economic Development, Division of Water Policy and Supply, Special Report No. 33. J. Rosenau, S. Lang, G. Hilton, and J. Rooney.

USGS, 1988. A Modular Three-Dimensional Finite-Difference Ground-Water Flow Model. M. McDonald and A. Harbaugh. USGS, TWI – Book 6, Chapter A1.

USGS, 1996. User's Documentation for MODFLOW-96, an update to the U.S. Geological Survey Modular Finite-Difference Ground-Water Flow Model. USGS Open-File Report 96-485.

USGS, 1997. Hydrology of the Unconfined Aquifer System, Salem River Area: Salem River and Raccoon, Oldmans, Alloway, and Stow Creek Basins, New Jersey, 1993-94. M. Johnson and E. Charles. Water-Resources Investigations Report 96-4195.

USGS, 1998. Ground-Water Flow in the New Jersey Coastal Plain. Mary Martin. Professional Paper 1404-H.

USGS, 1999a. Hydrogeology of, Water Withdrawal from, and Water levels and Chloride Concentrations in the Major Coastal Plain Aquifers of Gloucester and Salem Counties, New Jersey. Cauller, S., G. Carleton and M. Storck. Water-Resources Investigations Report 98-4136.

USGS, 1999b. Simulation of Ground-Water Flow and Movement of the Freshwater-Saltwater Interface in the New Jersey Coastal Plain. Pope, D. and A. Gordon. Water-Resources Investigations Report 98-4216.

USGS, 2000. MODFLOW-2000, the U.S. Geological Survey Modular Ground-Water Flow Model – User Guide to Modularization Concepts and the Ground-Water Flow Process. Open-File Report 00-92.

USGS, 2003. Documentation of Revisions to the Regional Aquifer System Analysis Model of the New Jersey Coastal Plan. Lois M. Veronin, Water-Resources Investigations Report 03-4268.

USGS, 2004. Vulnerability of Production Wells in the PRM Aquifer System to Saltwater Intrusion from the Delaware River in Camden, Gloucester and Salem Counties, New Jersey. A. Navoy, L. Voronin and E. Modica. Scientific Investigations Report 2004-5096.

USGS, 2006. Hydrogeology and Simulated Effects of Ground-Water Withdrawals, Kirkwood-Cohansey Aquifer System, Upper Maurice River Basin Area, New Jersey. Scientific Investigations Report 2005-5258. S. Cauller and G. Carleton.

USGS, 2009. SUGS Stream Gauge 1463500 Delaware River near Trenton, NJ Daily Stream Flow Statistics, Website http://waterdata.usgs.gov/nj/nwis/dvstat/?referred_module=sw&site_no01463500&or_01463500_5=147753,00060,5,1912-10-01,2009-01-31&format=html_table&stat_cds=mean_va&date=format=YYYY-MM-DD&rdb_compression=files&submitted_form=parameter+selection_list, accessed May 20, 2009.

FIGURES


New Plant Location
East Area Location
Source: NJOIT, 2007
LEGEND
Site Boundary
New Plant Location
East Area Location
N
W
E
S
0
500
1,000
Feet
PSEG Power, LLC
PSEG Site ESPA
Groundwater Model Calc. Package
Site Location and Proposed Expansion Locations
FIGURE 1
Rev 0

Era	Period	Epoch	Formation/Unit	Primary Lithologies	Geologic Conditions	Unit Thickness	Occurrence in Site Area
CENOZOIC	Quaternary	Holocene	Quaternary Marsh deposits	muck and peat; silt, sand and clay	aggradation of Delaware Bay estuary	variable thickness	present over most of the site area in low lying areas
			~~ unconformity ~~~~~~~~~~				
		Pleistocene	DELAWARE: Delaware Bay Group — Scotts Corners Formation; ~~ unconformity ~~; Lynch Heights Formation / NEW JERSEY: Cape May Formation	estuarine terrace deposits with coarse to fine sand and pebbles with concentrations of heavy minerals; peat; isolated fluvial deposits?	transgressive and regressive cycles	variable thickness	outcrops in eastern and western portions of the site area
			~~ unconformity ~~~~~~~~		regression and erosion		
	Tertiary	Upper Tertiary (Miocene)	Kirkwood Formation	clay silt and sand deposited in two or three marine cycles	polycyclic transgression and regression phases	90 feet at southern portions of site area; pinches out northward	subcrop only
			~~ unconformity ~~~~~~~~		regression and erosion		
		Lower Tertiary	Shark River Formation	glauconitic sand and mudstone	low sediment input	70 feet (Benson, 2004)	subcrop only
			~~ unconformity ~~~~~~~~		regression and erosion		
			Manasquan Formation	lower glauconitic member; upper clayey sand to silt member	low sediment input and bioturbation	40 feet (Benson, 2004)	subcrop only
			~~ unconformity ~~~~~~~~		regression and erosion		
			Vincentown Formation	quartz sand to quartz-rich calcareous sand with bryozoians and foraminifera	low sediment input and extreme bioturbation	90 feet (Benson, 2004)	outcrops in NW site area
			Hornerstown Formation	highly glauconitic sand with distinctive green color		30 feet (Benson, 2004)	
MESOZOIC	Cretaceous	Upper Cretaceous	Navesink	fossiliferous, clayey glauconitic sand	transgression to midshelf conditions	20 feet (Benson, 2004)	subcrop only
			Mount Laurel Formation	thinly bedded clays and sands with cross-bedding; thin pebbly sands	regressive pulse; low sediment input	100 feet (Benson, 2004)	subsurface only
			Wenonah Formation	clayey, silty, slightly glauconitic fine sand			
			Marshalltown Formation	intensely burrowed, very silty fine sand with glauconite	transgression, low sediment input	20 feet (Benson, 2004)	
			Englishtown Formation	micaceous silt to very fine sand	regressive pulse	25 feet (Benson, 2004)	
			Woodbury Formation	micaceous, chloritic, silty clay			
			Merchantville Formation	glauconitic sand to micaceous silty clay	transgression and establishment of widespread marine conditions; low sediment rates	120 feet (Benson, 2004)	
			Magothy Formation	beach and estuarine deposits of cross-bedded sand, with clay and silt layers; some lignite	transition to marine conditions	50 feet, pinches out north of site location (Benson, 2004)	
			~~ unconformity ~~~~~~~~		regression and erosion		
		Lower Cretaceous	Potomac Group (Formation)	white, gray and red interbedded silts, clays, and quartose sand	aggrefating alluvial plain; thermal subsidence	800 to 1650 feet (Benson, 2004)	
			~~ pre-Cretaceous unconformity ~~~~~~~~		uplift and erosion		
			Basement Complex				
	Triassic	Upper Triassic	Triassic Basin?	Fanglomerates and lacustrine sediments; diabase volcanics	Amalgamation of Pangea followed by rifting to form North America	undetermined	
PRECAMBRIAN? PALEOZOIC?	Proterozoic? Paleozoic?	NeoProterozoic to Silurian?	Carolina Superterrane?	meta mafic to felsic plutons and volcanics with sediments, and ultramafic components			
			Philadelphia Terrane?	aluminous to quartz-rich schist with interbedded amphibolites (Wissahickon Formation) with ultramafic components; Wilmington Complex felsic to mafic arc complex			

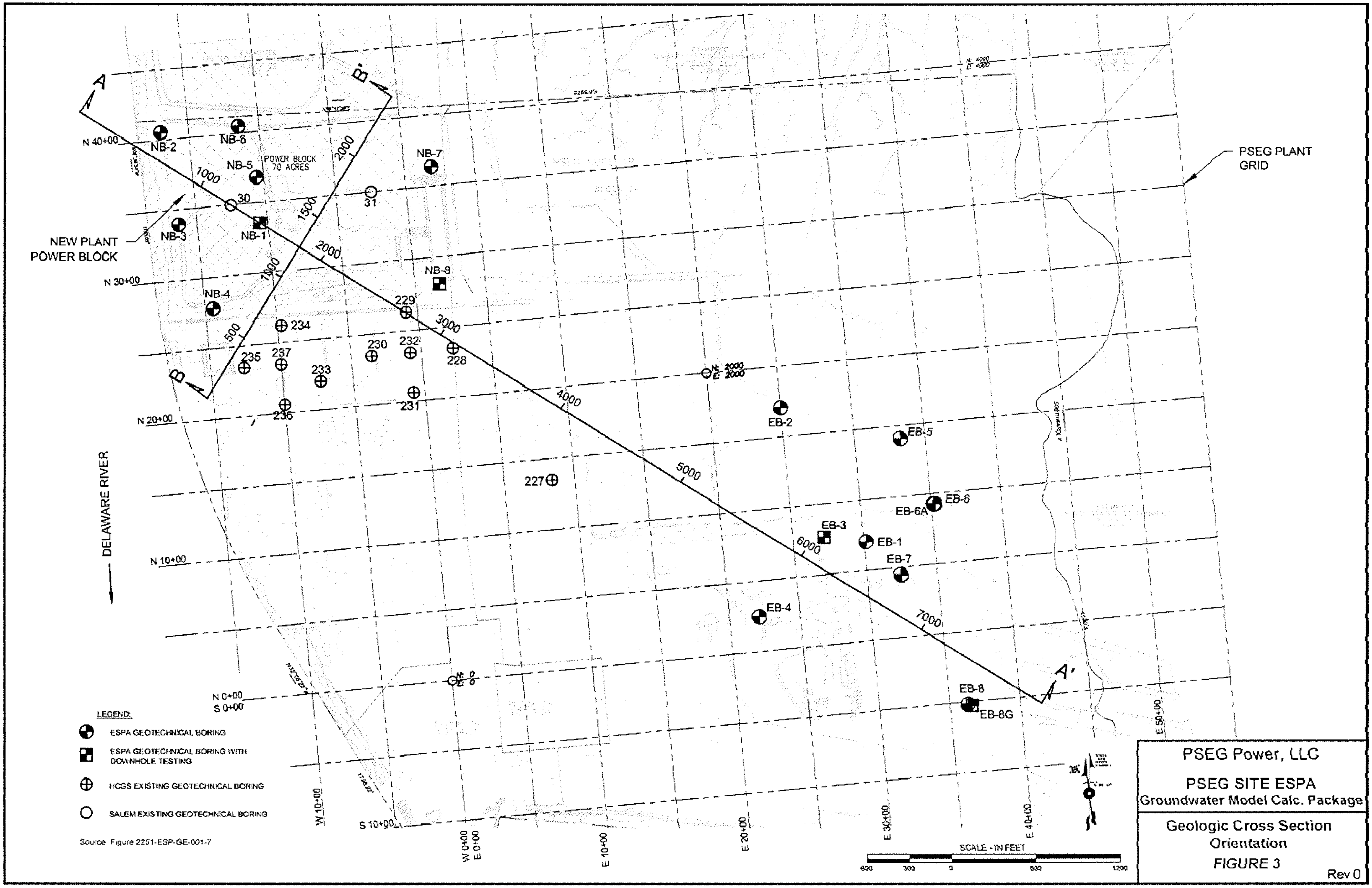
PSEG Power, LLC

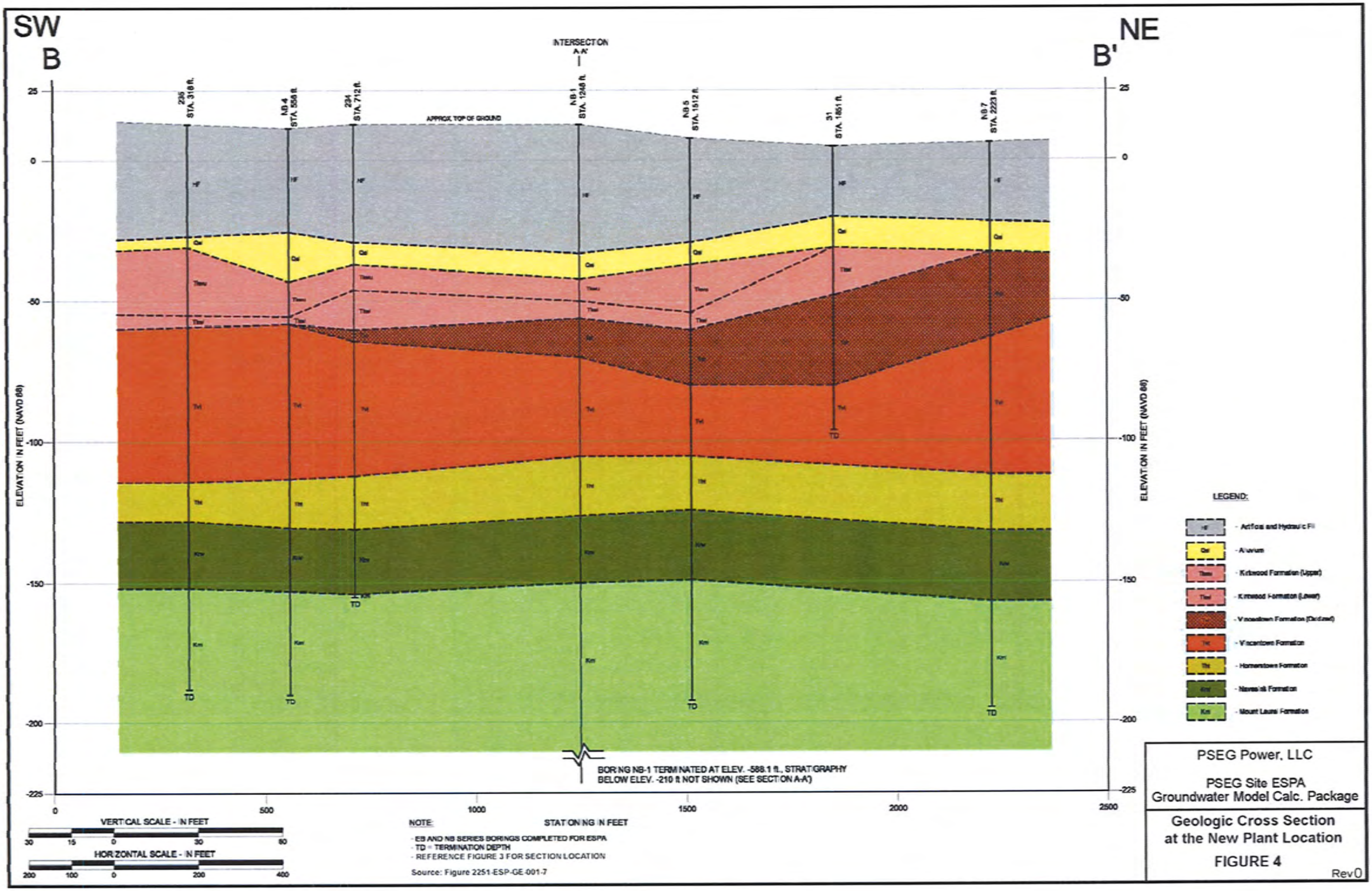
PSEG Site ESPA
Groundwater Model Calc. Package

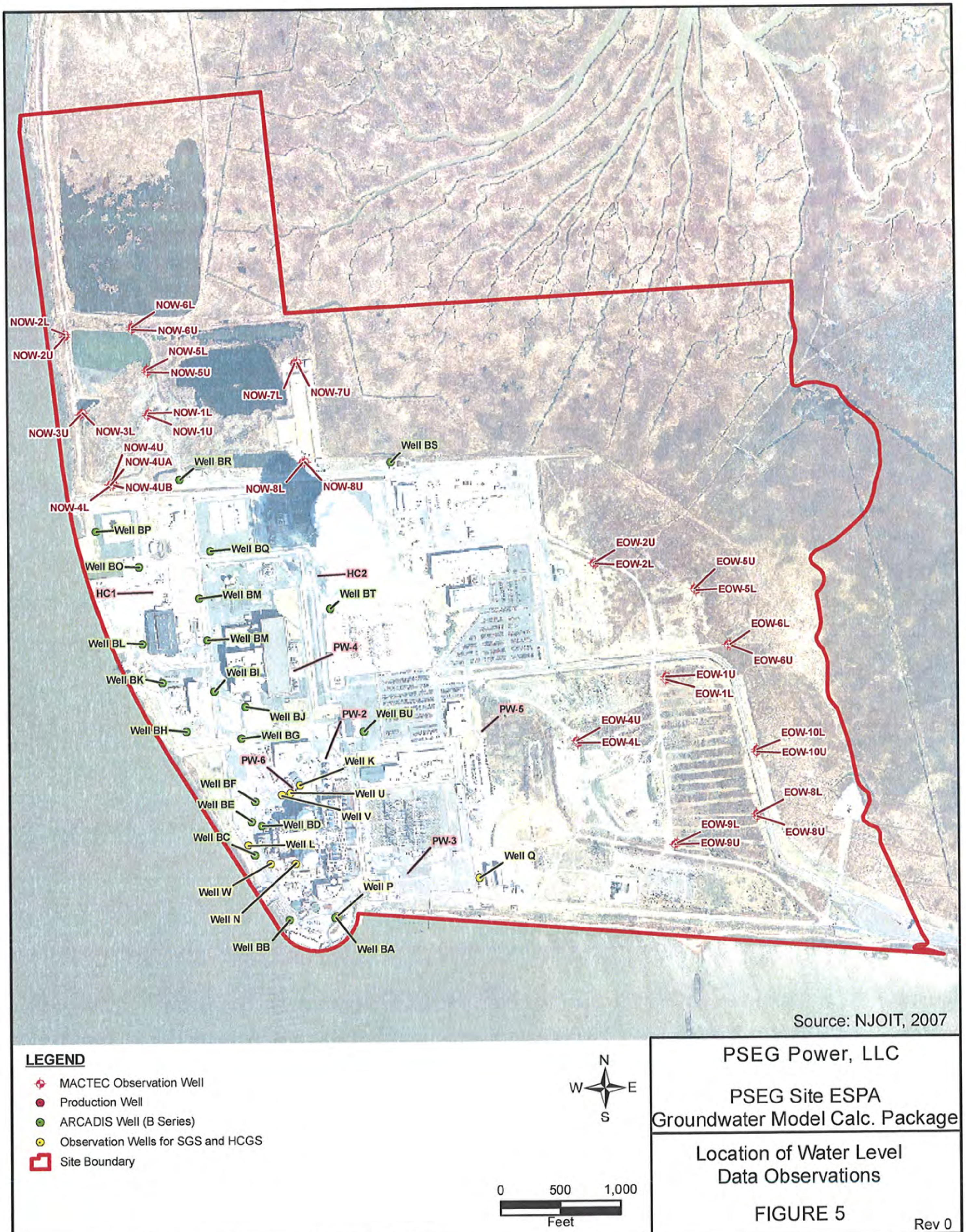
Hydrogeologic Unit Sequence

FIGURE 2

Rev 0


A
B'
A'
B
NB-2
NB-6
NB-5
NB-7
NB-3
NB-1
NB-4
NB-8
POWER BLOCK
70 ACRES
30
31
229
234
230
232
228
235
237
233
236
231
227
EB-2
EB-5
EB-6
EB-6A
EB-3
EB-1
EB-7
EB-4
EB-8
EB-8G
N 40+00
N 30+00
N 20+00
N 10+00
N 0+00
S 0+00
S 10+00
W 10+00
W 0+00
E 0+00
E 10+00
E 20+00
E 30+00
E 40+00
E 50+00
NEW PLANT
POWER BLOCK
PSEG PLANT
GRID
DELAWARE RIVER
LEGEND:
ESPA GEOTECHNICAL BORING
ESPA GEOTECHNICAL BORING WITH DOWNHOLE TESTING
HCGS EXISTING GEOTECHNICAL BORING
SALEM EXISTING GEOTECHNICAL BORING
Source: Figure 2251-ESP-GE-001-7
SCALE - IN FEET
PSEG Power, LLC
PSEG SITE ESPA
Groundwater Model Calc. Package
Geologic Cross Section
Orientation
FIGURE 3
Rev 0


SW
B
NE
B'
INTERSECTION
A-A'
235
STA. 318 ft.
NB-4
STA. 558 ft.
234
STA. 712 ft.
NB-1
STA. 1248 ft.
NB-5
STA. 1512 ft.
31
STA. 1851 ft.
NB-7
STA. 2223 ft.
APPROX. TOP OF GROUND
ELEVATION IN FEET (NAVD 88)
25
0
-50
-100
-150
-200
-225
TD
BORING NB-1 TERMINATED AT ELEV. -588.1 ft., STRATIGRAPHY
BELOW ELEV. -210 ft NOT SHOWN (SEE SECTION A-A')
0
500
1000
1500
2000
2500
STATIONING IN FEET
VERTICAL SCALE - IN FEET
HORIZONTAL SCALE - IN FEET
LEGEND:
- Artificial and Hydraulic Fill
- Alluvium
- Kirkwood Formation (Upper)
- Kirkwood Formation (Lower)
- Vincentown Formation (Oxidized)
- Vincentown Formation
- Hornerstown Formation
- Navesink Formation
- Mount Laurel Formation
NOTE:
- EB AND NB SERIES BORINGS COMPLETED FOR ESPA
- TD = TERMINATION DEPTH
- REFERENCE FIGURE 3 FOR SECTION LOCATION
Source: Figure 2251-ESP-GE-001-7
PSEG Power, LLC
PSEG Site ESPA
Groundwater Model Calc. Package
Geologic Cross Section
at the New Plant Location
FIGURE 4
Rev0



PSEG Power, LLC

PSEG Site ESPA
Groundwater Model Calc. Package

Location of Water Level
Data Observations

FIGURE 5

Rev 0

TABLES

Table 1								
Regional and Site-Specific Aquifer Characteristics								
Formation	**Transmissivity**	**Hydraulic Conductivity**	**Porosity**	**Storage Coefficient**	**Specific Yield**	**Specific Capacity**	**Leakance**	**Reference**
Structural Fill		0.09 to 4.3 ft/d; 6.5 ft/d						12
Riverbed Sands and Gravel	13.2 to 440 gpd/ft	0.9 to 13.1 gpd/ft^2						8
		0.12 to 1.75 ft/d; 1.8 to 59 ft/d						7
		0.03 to 2.27 ft/d						12
Kirkwood Aquitard		Kv = 0.00002 to 0.00005 ft/d						8
							1e-5/d	10
Basal Kirkwood-Vincentown Aquifer						0.5 to 8.3 gpm/ft		2
	5,000 to 11,000 gpd/ft	0.95 to 2.5 ft/d				0.3 to 1.9 gpm/ft		7
	530 ft^2/d							8
	2,000 to 2,500 ft^2/d							10
		14 ft/d						14
		2.95 ft/d						12
	1,987 to 2,791 ft^2/d							11
Hornerstown - Navesink Aquitard		4 to 8.7 ft/d	0.522 to 0.543					2
		Kv = 0.42 gpd/ft^2						8
		Kv = 0.003 to 9 ft/d						8
							5e-5/d	10
							3.35e-5 to 6.87e-5/d	11
Mt. Laurel - Wenonah Aquifer	7,000 gpd/ft	18.7 ft/d						1
		10 ft/d	0.444			0.7 to 9 gpm/ft		2
	7,500 to 14,000 gpd/ft							3
	4,900 to 8,700 gpd/ft	0.67 to 4.5 ft/d				0.2 to 3.8 gpm/ft		7
	360 to 1.430 ft^2/d	13 to 19 ft/d						8
	1,000 ft^2/d							10
	815 ft^2/d							13
	726 to 922 ft^2/d							11
Marshalltown-Wenonah Aquitard		0.001 to 0.01 gpd/ft^2						2
		Kv = 0.00006 to 0.13 ft/d						8
							6e-6/d	10
							5.91e-6 to 7.13e-6/d	11
Englishtown Aquifer						up to 10 gpm/ft		2
	1,100 to 2,100 ft^2/d	12 to 67 ft/d						8
	500 ft^2/d							10
	415 to 552 ft^2/d							11
Merchantville-Woodbury Confining Unt		Kv = 0.000004 to 0.0004 ft/d						8
							3e-6/d	10
							2.15e-6 to 3.85e-6/d	11
Upper PRM Aquifer	10,000 to 25,000 gpd/ft							4
	15,000 to 25,000 gpd/ft							5
	9,000 to 27,000 gpd/ft					10.6 to 26.7 gpm/ft		7
	870 to 24,210 gpd/ft	240 ft/d						8
	2,000 ft^2/d							10
	1,086 to 2,419 ft^2/d							11
Confining Unit, Upper to Middle PRM		Kv = 0.084 ft/d						8
							2e-6/d	10
							1.797e-7 to 2.69e-7/d	11
Middle PRM Aquifer	4,700 to 11,500 gpd/ft							4
	8,590 gpd/ft	129.5 ft/d		0.0025				6
	670 to 4,000 gpd/ft							7
	4,000 ft^2/d							10
	3,024 to 3,813 ft^2/d							11
Confining Unit, Middle to Lower PRM							5e-6/d	10
							7.19e-7 to 1.67e-5/d	11
Lower PRM Aquifer	2,300 to 16,600 ft^2/d							8
	4,000 to 5,000 ft^2/d							10
	4,844 to 5,299 ft^2/d							11

Notes:
D&M = Dames & Moore
USGS = United States Geological Survey
NJDEP = New Jersey Department of Environmental Protection
NJ = State of New Jesey
T = transmissivity
K = horizontal hydraulic conductivity
Kv = vertical hydraulic conductivity
L = leakance
n = porosity
s = storage coefficient (confined)
Sy = specific yield

References:

(1) Dames & Moore, 1968. Groundwater Supply Investigation, Proposed Nuclear Power Plant Near Salem, NJ
(2) USGS/State of New Jersey, 1969. Geology and Ground-Water Resources of Salem County, New Jersey. Special Report No. 33
(3) Dames & Moore, 1970. Investigation of Saline Production Well No. 4
(4) Dames & Moore, 1974a. Groundwater Supply Well #5
(5) Dames & Moore, 1974b. Groundwater Supply Investigation, Hope Creek.
(6) Page, Leo, 1981. No. 6 Test and Production Well.
(7) Dames & Moore, 1988. Final Report Study of Groundwater Conditions and Future Water-Supply Alternatives Salem/HopeCreek Generating Station, Artificial Island, Salem County, New Jersey PSE&G, July 15, 1988.
(8) USGS, 1998. Ground-Water Flow in the New Jersey Coastal Plain. Professional Paper 1404-H.
(9) USGS, 1999a. Hydrogeology of, Water Withdrawal from, and Water Levels and Chloride Concentrations in the Major Coastal Plain Aquifers of Glouster and Salem Counties, New Jersey. Water-Resources Investigations Report 98-4136.
(10) USGS, 1999b. Simulation of Ground-Water Flow and Movement of the Freshwater-Saltwater Interface in the New Jersey Coastal Plain. Water-Resources Investigations Report 98-4216.
(11) USGS, 2003. Documentation of Revisions to the Regional Aquifer System Analysis Model of the New Jersey Coastal Plain. Water-Resources Investigations Report 03-4268.
(12) ARCADIS, 2004. Remedial Investgation Report. PSEG Nuclear, LLC, Salem Generating Station, Hancock's Bridge, New Jersey. March 2004.
(13) Dugan, B., et al., 2008. Hydrogeologic Framework of Southern New Castle County. Open File Report No. 49. Delaware Geological Survey. Newark, Delaware.
(14) Dames & Moore, 1977. Report, October 1977, Stages 3 to 10, Excavation/Dewatering, Hope Creek Generating Station Lower Alloways Creek Township, New Jersey. Public Service Electric and Gas Company.

Table 2
Slug Test Results
for Northern Area
Shallow Aquifers

Well	Formation	Result feet/day
Shallow		
NOW-1U	Alluvium	8.0
NOW-2U	Alluvium	8.0
NOW-3U	Alluvium	0.3
NOW-4U	Alluvium	0.7
NOW-5U	Hydraulic fill	0.1
NOW-6U	Alluvium	3.5
NOW-7U	Vincentown	1.4
NOW-8U	Alluvium	0.4
Deeper		
NOW-1L	Vincentown	4.5
NOW-2L	Vincentown	3.6
NOW-3L	Vincentown	1.4
NOW-4L	Vincentown	10.7
NOW-5L	Vincentown	1.7
NOW-6L	Vincentown	6.2
NOW-7L	Vincentown	2.4
NOW-8L	Vincentown	0.3

Notes: Individual results are rounded off to one decimal place.
See Hydraulic Conductivity & Tidal Study Data Report, Rev. A (MACTEC, November 25, 2009) for details on slug testing.

Table 3
Water Level Measurements
January to December 2009
North and East Sites
Alluvium and Vincentown

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ave	Std dev	Range
North Site Alluvium															
NOW-1U		0.36	0.61	0.59	0.66	1.32	1.14	0.94	1.13	1.22	1.18		0.92	0.33	0.96
NOW-2U	-0.10	-0.42	-0.48	-0.17	-0.08	2.04	-0.41	1.72	2.08	2.19	-0.20	0.88	0.59	1.11	2.67
NOW-3U	-0.21	-0.36	0.15	-0.19	0.18	1.20	0.56	0.66	1.13	1.18	0.60	1.23	0.51	0.59	1.59
NOW-4UB		0.03	0.46	0.36	0.40	1.18	1.00	0.75	0.95	1.09	0.95	1.34	0.77	0.41	1.31
NOW-6U	0.50	0.35	0.76	0.62	0.65	1.35	1.12	0.98	1.31	1.31	1.15	1.44	0.96	0.37	1.09
NOW-7U	0.40	0.18	0.74	0.77	0.79	1.40	1.14	1.07	1.41	1.46	1.01	1.64	1.00	0.44	1.46
NOW-8U	0.72	0.41	0.84	0.74	0.86	1.57	1.24	1.21	1.38	1.39	1.15	1.57	1.09	0.37	1.16
Vincentown															
NOW-1L		0.25	0.56	0.50	0.65	1.58	1.07	1.14	1.54	1.66	1.02	1.67	1.06	0.51	1.42
NOW-2L	-0.05	-0.31	-0.32	-0.20	0.74	2.16	-0.17	1.86	2.82	2.15	-0.01	1.10	0.81	1.16	3.14
NOW-3L	-0.14	-0.25	-0.40	0.10	-0.99	1.63	0.10	1.69	1.90	1.38	0.61	1.25	0.57	0.97	2.89
NOW-4L	-0.71	-0.30	-0.01	-0.16	0.37	1.70	0.43	1.20	1.80	1.56	0.43	1.45	0.65	0.86	2.51
NOW-5L	0.54	-0.19	0.31	0.35	0.52	1.54	0.93	0.73	1.54	1.59	0.65	1.57	0.84	0.60	1.78
NOW-6L	-0.11	-0.08	0.26	0.17	-0.58	1.56	0.88	0.80	1.54	1.63	1.04	0.21	0.61	0.74	2.21
NOW-7L	0.39		0.59	0.70	0.71	1.11	0.87	0.94	1.34	1.39	0.75	1.51	0.94	0.36	1.12
NOW-8L	0.50	0.36	0.70	0.79	0.90	1.54	1.15	1.14	1.44	1.43	1.08	1.51	1.05	0.40	1.18
East Site Alluvium															
EOW-1U	0.95	0.90	1.20	1.08	1.18	1.74	1.51		2.54	1.59	1.52	1.79	1.45	0.47	1.64
EOW-2U	2.92	2.80	2.83	2.49	2.70	3.02	2.96		2.74	3.09	2.87	3.40	2.89	0.24	0.91
EOW-5U	1.03	0.83	1.16	1.10	1.19	1.70	1.45	1.43	1.61	1.59	0.51	1.78	1.28	0.38	1.27
EOW-6U	1.00	0.79	1.20	1.12	1.16	1.71	1.45	1.43	1.59	1.60	1.49	1.78	1.36	0.30	0.99
EOW-8U	0.72	1.02	1.47	0.95	1.27		1.73	1.65	1.46	1.70	1.46	2.27	1.43	0.43	1.55
EOW-9U	-0.06	0.08	0.50	0.55	0.35	1.20	0.78	0.75	1.21	1.13	0.86		0.67	0.43	1.27
EOW-10U		1.43	1.37	1.32	1.39	2.07	1.58	1.52	1.71	1.85	1.86	2.30	1.67	0.32	0.98
Vincetown															
EOW-1L	0.79	0.62	0.92	0.98	0.95	1.59	1.29		1.59	1.59	1.27	1.59	1.20	0.36	0.97
EOW-2L	1.06	0.74	1.25	1.18	1.12	1.74	1.42	1.39	1.76	1.67	1.43	1.72	1.37	0.32	1.02
EOW-4L	0.62	0.51	1.09	0.90	1.00	1.75	1.33	1.19	1.85	1.91		1.59	1.25	0.48	1.40
EOW-5L	1.09	0.92	1.30	1.25	0.86	1.79	1.51	2.39	1.78	1.74	1.49	1.77	1.49	0.44	1.53
EOW-6L	0.98	0.70	1.30	1.14	1.06		1.45	0.47	1.80	0.74	1.45	1.74	1.17	0.43	1.33
EOW-8L	0.12	0.13	0.60	0.55	0.68	1.48	0.94	0.85	1.59	1.61	1.05	1.27	0.91	0.52	1.49
EOW-9L	0.45	0.41	0.68	0.77	0.97	1.68	1.28	1.05	1.86	1.86	1.18	1.49	1.14	0.51	1.45
EOW-10L	0.60	0.66	1.12	0.94	0.35	1.66	1.36	1.24	1.71	1.76	1.34	1.61	1.20	0.47	1.41

Notes:
- Initially considered inconsistent with data set
- Outlier value deleted
- Rejected as inconsistent with data set following outlier analysis

Elevations are in feet relative to NAVD88 datum

See MACTEC, 2010, Groundwater Elevations and Hydraulic Gradients, Calculation Package 2251-ESP-GW-004 for a detailed account of the water level data analysis.

Table 4
Calibrated Model - Input Parameter Values

Hydraulic conductivities, ft/d		Horizontal	Vertical	
Hydraulic fill		0.1	0.03	
Structural fill		6.5	0.65	
Alluvium		3.89	0.48	
Kirkwood aquitard		0.02	0.003	
Vincentown		10.7	0.2	
Hornerstown		10.7	0.2	
Navesink		0.4	0.0545	
Mount Laurel-Wenonah		10	10	
Recharge		ft/d	in/yr	
Zone 1	Wetlands north	0.00003521	0.15	
Zone 2	Buildings, pavement	0	0	
Zone 3	Developed facility	0.0002907	1.27	
Zone 4	Wetlands east	0.0001385	0.61	
Zone 5	Semi-impermeable	0.0004176	1.83	
Zone 6	Near Salem units 1&2	0.001826	8	
Storage coefficient		Confined	Specific yield	Porosity
Aquifers		0.0001	0.2	0.35
Aquitards		0.0001	0.1	0.4
River package		Ref Elev	Conductance	
Delaware River		-0.1	56.6	
Ponds		4 to 5.4	0.0282 to 0.0566	
Streams		0	5.66 to 11.3	
General Head Boundaries		Ref Elev	Conductance	
Alluvium		-0.5	25.1	
Vincentown		0.5 to 2.0	408 to 640	
Hornerstown		0.5 to 2.0	148	
Mount Laurel-Wenonah		-1 to 0.8	3590 to 3940	

Notes:
1. Reference elevations are in feet NAVD88
2. Units of conductance are square feet per day
3. GHB conductances are a function of thickness and generally vary along their lengths.

Table 5
Residuals Statistical Analysis
Final Calibrated Model

Name	Easting	Northing	Layer	Observed	Computed	Residual
NOW-1U	198443	234543	2	0.93	1.04	-0.11
NOW-1L	198450	234564	4	1.08	0.79	0.29
NOW-2U	197755	235207	2	0.53	0.50	0.03
NOW-2L	197753	235228	4	0.73	0.60	0.13
NOW-3U	197885	234553	2	0.53	0.39	0.14
NOW-3L	197898	234565	4	0.60	0.64	-0.04
NOW-4UB	198147	233963	2	0.79	0.90	-0.11
NOW-4L	198148	233973	4	0.67	0.70	-0.03
NOW-5L	198438	234927	4	0.87	0.81	0.06
NOW-6U	198314	235269	2	0.98	1.13	-0.15
NOW-6L	198313	235288	4	0.63	0.80	-0.17
NOW-7U	199694	234976	2	1.02	1.11	-0.09
NOW-7L	199676	234973	4	0.93	1.01	-0.08
NOW-8U	199756	234142	2	1.11	1.99	-0.88
NOW-8L	199736	234139	4	1.06	0.97	0.09
EOW-1U	202758	232322	2	1.40	2.04	-0.64
EOW-1L	202758	232298	4	1.22	0.89	0.33
EOW-2U	202158	233275	2	2.88	2.14	0.74
EOW-2L	202178	233271	4	1.40	0.98	0.42
EOW-4L	202021	231773	4	1.26	0.83	0.43
EOW-5U	203007	233057	2	1.31	1.75	-0.44
EOW-5L	203021	233040	4	1.46	0.96	0.50
EOW-6U	203281	232587	2	1.38	1.76	-0.38
EOW-6L	203301	232588	4	1.17	0.93	0.24
EOW-8U	203520	231144	2	1.41	1.51	-0.10
EOW-8L	203516	231163	4	0.91	0.80	0.11
EOW-9U	202826	230917	2	0.69	1.54	-0.85
EOW-9L	202845	230926	4	1.14	0.76	0.38
EOW-10U	203521	231687	2	1.64	1.55	0.09
EOW-10L	203522	231707	4	1.22	0.85	0.37
Well_BA	199984	230320	2	1.97	1.80	0.17
Well_BF	199322	231301	2	1.88	1.96	-0.08
Well_BG	199212	231829	2	2.30	2.36	-0.06
Well_BH	198752	231891	2	1.77	1.54	0.23
Well_BL	198390	232627	2	1.69	1.38	0.31
Well_BM	198936	232658	2	2.26	2.66	-0.40
Well_BP	198010	233572	2	1.09	0.85	0.24
Well_BQ	198966	233401	2	2.95	2.72	0.23
Well_BR	198711	234004	2	1.72	1.91	-0.19
Well_BS	200475	234137	2	2.71	1.77	0.94
Well_BT	199958	232909	2	3.13	3.08	0.05
Well_BU	200236	231883	2	2.95	3.00	-0.05
			Residual Mean			0.04
			Res. Std. Dev.			0.36
			Sum of Squares			5.48
			Abs. Res. Mean			0.27
			Min. Residual			-0.88
			Max. Residual			0.94
			Range in Target Values			2.60
			Std. Dev./Range			0.138

Note: Target water level data were selected as the average of the acceptable data (see Table 3) with the high and low value also deleted. See Calculation Package 2251-ESP-GW-004 for details on the treatment of water level data collected for this purpose.

Table 6
Calibrated Model - Water Balance

	Unit	Top	Bottom	GHB	River	Recharge	% error
Model	All						-0.146
In		*	*	18480	1355	6131	
Out		*	*	20468	5536	0	
Layer 1	Fills						0.0041
In		*	4135	*	1355	6119	
Out		*	6073	*	5536	0	
Layer 2	Alluvium						-0.000086
In		6073	3874	0	*	0.46	
Out		4135	3490	2322	*	0	
Layer 3	Kirkwood Aquitard						0.0013
In		3490	3859	*	*	11.7	
Out		3874	3487	*	*	0	
Layer 4	Vincentown						-0.0876
In		3487	428	11256	*	0.2	
Out		3859	10851	475	*	0	
Layer 5	Hornerstown						-0.0195
In		10851	428	7223	*	*	
Out		573	17762	460	*	*	
Layer 6	Navesink Aquitard						-0.0001
In		17763	564	*	*	*	
Out		573	17754	*	*	*	
Layer 7	Mt. Laurel-Wenonah						-0.12
In		17754	*	0	*	*	
Out		564	*	17211	*	*	

Notes: 1. * - indicates this feature not applicable
2. Rates given are in cubic feet per day

Table 7
Summary Sensitivity Statistical Analysis
Calibrated Base Model

Input Parameter	Range				
	lowest	lower	Calibrated	higher	highest
Hydraulic fill, Kh, ft/d	0.025	0.05	0.1	0.2	0.4
ave residual	-0.02	0.01	0.04	0.08	0.14
average absolute	0.29	0.28	0.27	0.29	0.31
standard deviation	0.38	0.36	0.36	0.37	0.38
sum of squares	5.94	5.52	5.48	5.93	6.84
Alluvium, Kh, ft/d	0.97	1.94	3.89	7.88	15.76
ave residual	-0.13	-0.06	0.04	0.18	0.35
average absolute	0.33	0.29	0.27	0.3	0.41
standard deviation	0.42	0.39	0.36	0.35	0.37
sum of squares	8.19	5.49	5.48	6.46	11.1
Kirkwood, Kh, ft/d	0.005	0.01	0.02	0.04	0.08
ave residual	0.04	0.04	0.04	0.04	0.04
average absolute	0.27	0.27	0.27	0.27	0.27
standard deviation	0.36	0.36	0.36	0.36	0.36
sum of squares	5.48	5.48	5.48	5.48	5.48
Vincentown, Kh, ft/d	2.67	5.35	10.7	21.4	42.8
ave residual	0.12	0.09	0.04	-0.02	-0.08
average absolute	0.3	0.28	0.27	0.26	0.26
standard deviation	0.37	0.36	0.36	0.36	0.37
sum of squares	6.41	5.91	5.48	5.48	6.01
Hornerstown, Kh, ft/d	2.67	5.35	10.7	21.4	42.8
ave residual	0.06	0.05	0.04	0.02	0
average absolute	0.27	0.27	0.27	0.27	0.26
standard deviation	0.36	0.36	0.36	0.36	0.36
sum of squares	5.58	5.54	5.48	5.42	5.42
Navesink, Kh, ft/d	0.1	0.2	0.4	0.8	1.6
ave residual	0.04	0.04	0.04	0.04	0.04
average absolute	0.27	0.27	0.27	0.27	0.27
standard deviation	0.36	0.36	0.36	0.36	0.36
sum of squares	5.48	5.48	5.48	5.48	5.48
Mt. Laurel-Wenonah, Kh, ft/d	2.5	5	10	20	40
ave residual	-0.18	-0.08	0.04	0.16	0.26
average absolute	0.3	0.27	0.27	0.31	0.36
standard deviation	0.38	0.36	0.36	0.37	0.39
sum of squares	7.41	5.77	5.48	6.86	9.14
Structural fill, Kh, ft/d	1.62	3.25	6.5	13	26
ave residual	0.01	0.03	0.04	0.05	0.06
average absolute	0.29	0.27	0.27	0.28	0.28
standard deviation	0.38	0.36	0.36	0.36	0.36
sum of squares	5.97	5.5	5.48	5.59	5.71
Recharge, zone 1, ft/d	1.761E-05	2.641E-05	3.521E-05	5.282E-05	7.042E-05
ave residual	0.05	0.05	0.04	0.03	0.01
average absolute	0.27	0.27	0.27	0.27	0.28
standard deviation	0.36	0.36	0.36	0.36	0.37
sum of squares	5.43	5.45	5.48	5.56	5.68
Recharge, zone 3, ft/d	0.0001453	0.0002179	0.0002907	0.0004361	0.0005814
ave residual	0.27	0.15	0.04	-0.19	-0.41
average absolute	0.4	0.32	0.27	0.39	0.56
standard deviation	0.45	0.38	0.36	0.48	0.72
sum of squares	11.5	7.02	5.48	11.3	28.9

Table 7
Summary Sensitivity Statistical Analysis
Calibrated Base Model

Recharge, zone 4, ft/d		0.0000693	0.0001039	0.0001385	0.0002078	0.000277
	ave residual	0.14	0.09	0.04	-0.06	-0.16
	average absolute	0.27	0.26	0.27	0.31	0.37
	standard deviation	0.35	0.34	0.36	0.44	0.57
	sum of squares	5.87	5.27	5.48	8.38	14.6
Recharge, zone 5, ft/d		0.0002088	0.0003132	0.0004176	0.0006264	0.0008352
	ave residual	0.06	0.05	0.04	0.02	0.01
	average absolute	0.28	0.27	0.27	0.28	0.29
	standard deviation	0.36	0.36	0.36	0.36	0.37
	sum of squares	5.6	5.51	5.48	5.58	5.9
Recharge, zone 6, ft/d		0.000913	0.001369	0.001826	0.002283	0.002739
	ave residual	0.08	0.06	0.04	0	-0.03
	average absolute	0.29	0.28	0.27	0.29	0.32
	standard deviation	0.38	0.37	0.36	0.38	0.43
	sum of squares	6.39	5.76	5.48	6.01	7.94
Hydraulic fill, Kv, ft/d		0.0075	0.015	0.03	0.06	0.12
	ave residual	0.01	0.02	0.04	0.06	0.07
	average absolute	0.26	0.27	0.27	0.27	0.28
	standard deviation	0.36	0.36	0.36	0.36	0.36
	sum of squares	5.46	5.44	5.48	5.59	5.72
Alluvium, Kv, ft/d		0.12	0.24	0.48	0.96	1.92
	ave residual	0.04	0.04	0.04	0.04	0.04
	average absolute	0.27	0.27	0.27	0.27	0.27
	standard deviation	0.36	0.36	0.36	0.36	0.36
	sum of squares	5.5	5.49	5.48	5.48	5.48
Kirkwood, Kv, ft/d		0.00075	0.0015	0.003	0.006	0.012
	ave residual	-0.73	-0.3	0.04	0.28	0.43
	average absolute	0.91	0.51	0.27	0.35	0.46
	standard deviation	1.11	0.63	0.36	0.39	0.49
	sum of squares	73.4	20.2	5.48	9.59	17.9
Vincentown, Kv, ft/d		0.05	0.1	0.2	0.4	0.8
	ave residual	-0.01	0.02	0.04	0.05	0.05
	average absolute	0.28	0.27	0.27	0.27	0.27
	standard deviation	0.37	0.36	0.36	0.36	0.36
	sum of squares	5.89	5.58	5.48	5.45	5.44
Hornerstown, Kv, ft/d		0.05	0.1	0.2	0.4	0.8
	ave residual	0.03	0.04	0.04	0.04	0.04
	average absolute	0.27	0.27	0.27	0.27	0.27
	standard deviation	0.36	0.36	0.36	0.36	0.36
	sum of squares	5.47	5.48	5.48	5.48	5.48
Navesink, Kv, ft/d		0.0136	0.0272	0.0545	0.109	0.218
	ave residual	-0.01	0.02	0.04	0.05	0.06
	average absolute	0.27	0.27	0.27	0.27	0.27
	standard deviation	0.36	0.36	0.36	0.36	0.36
	sum of squares	5.54	5.47	5.48	5.51	5.53
Mt. Laurel-Wenonah, Kv, ft/d		0.3	0.6	1.2	2.4	4.8
	ave residual	0.03	0.04	0.04	0.04	0.04
	average absolute	0.27	0.27	0.27	0.27	0.27
	standard deviation	0.36	0.36	0.36	0.36	0.36
	sum of squares	5.47	5.48	5.48	5.48	5.48
Structural fill, Kv, ft/d		0.16	0.32	0.65	1.3	2.6
	ave residual	0.04	0.04	0.04	0.04	0.04

Table 7
Summary Sensitivity Statistical Analysis
Calibrated Base Model

average absolute	0.27	0.27	0.27	0.27	0.27
standard deviation	0.36	0.36	0.36	0.36	0.36
sum of squares	5.47	5.47	5.48	5.49	5.49
Delaware River, ref head, ft	-2.1	-1.1	-0.1	0.9	1.9
ave residual	0.3	0.17	0.04	-0.09	-0.22
average absolute	0.42	0.34	0.27	0.31	0.42
standard deviation	0.48	0.39	0.36	0.4	0.49
sum of squares	13.4	7.66	5.48	6.95	12.2
Delaware River, conductance, 1/d	5.66	11.3	56.6	283	566
ave residual	0.01	0.03	0.04	0.04	0.04
average absolute	0.28	0.27	0.27	0.27	0.27
standard deviation	0.37	0.36	0.36	0.36	0.36
sum of squares	5.61	5.49	5.48	5.51	5.51
GHB, Alluvium, ref head, ft	-2.5	-1.5	-0.5	0.5	1.5
ave residual	0.09	0.07	0.04	0.01	-0.01
average absolute	0.29	0.28	0.27	0.27	0.29
standard deviation	0.37	0.36	0.36	0.36	0.37
sum of squares	6.12	5.68	5.48	5.53	5.83
GHB, Alluvium, conductance, 1/d	2.51	5.02	25.1	125.5	251
ave residual	0.03	0.03	0.04	0.05	0.05
average absolute	0.27	0.27	0.27	0.27	0.27
standard deviation	0.36	0.36	0.36	0.36	0.36
sum of squares	5.48	5.48	5.48	5.5	5.5
GHB, Vincentown, ref head, delta ft	-2	-1	0	1	2
average absolute	0.76	0.47	0.27	0.39	0.69
standard deviation	0.38	0.36	0.36	0.38	0.43
sum of squares	28.9	11.7	5.48	10.1	25.6
GHB, Vincentown, conductance, factor	x 0.1	x 0.2	x 1	x 5	x 10
average absolute	0.28	0.27	0.27	0.27	0.27
standard deviation	0.36	0.36	0.36	0.36	0.36
sum of squares	5.66	5.56	5.48	5.47	5.46
GHB, Hornerstown, ref head, delta ft	-2	-1	0	1	2
average absolute	0.4	0.31	0.27	0.29	0.35
standard deviation	0.36	0.36	0.36	0.37	0.38
sum of squares	8.92	6.46	5.48	5.97	7.94
GHB, Hornerstown, conductance, factor	x 0.1	x 0.2	x 1	x 5	x 10
average absolute	0.27	0.27	0.27	0.27	0.27
standard deviation	0.36	0.36	0.36	0.36	0.36
sum of squares	5.54	5.51	5.48	5.47	5.47
GHB, Mount Laurel-Wenonah, ref head, delta ft	-2	-1	0	1	2
average absolute	0.62	0.39	0.27	0.33	0.56
standard deviation	0.44	0.38	0.36	0.38	0.43
sum of squares	23.2	10.4	5.48	8.35	19.1
GHB, Mount Laurel-Wenonah, conductance, factor	x 0.1	x 0.2	x 1	x 5	x 10
average absolute	0.27	0.27	0.27	0.27	0.27
standard deviation	0.36	0.36	0.36	0.36	0.36
sum of squares	5.42	5.45	5.48	5.49	5.49

Table 8
Summary Dewatering Simulation and Sensitivity Results
Dewatering Rates at Times into Simulation

	Flow rates (gpm) after start of dewatering simulation					
	0.48days	1.06 days	90 days	90.6 days	91.3 days	365 days
Base simulation	6,541	4,613	3,434	5,477	4,989	3,566
Sensitivity change to input parameter						
Halve VT/HT Kh to 5.35 ft/d	4,449	2,149	1,955	3,062	2,421	2,223
Double VT/HT Kh to 21.4 ft/d	8,524	6,686	5,170	7,257	6,906	5,345
Halve Navesink Kv to 0.0272 ft/d	6,455	4,532	3,300	5,267	4,797	3,375
Double Navesink Kv to 0.109 ft/d	6,617	4,685	3,549	5,631	5,135	3,727
Decrease Kirwood Kv to 0.001 ft/d	6,507	4,569	3,329	5,315	4,845	3,495
Increase Kirkwood Kv to 0.01 ft/d	6,615	4,717	3,633	5,710	5,211	3,635
Increase MLW Kh to 15 ft/d	6,592	4,473	3,587	5,692	5,072	3,796
Increase VT/HT Kv to 1.0 ft/d	7,022	5,076	3,744	6,129	5,633	3,883

Abbreviations: gpm - gallons per minute
VT/HT - Vincentown and Hornerstown Formations
MLW - Mount Laurel-Wenonah aquifer
Kh - horizontal hydraulic conductivity
ft/d - feet per day
Kv - vertical hydraulic conductivity

Table 9
Estimated Drawdown at Existing Structures During Dewatering Activities

Location	Drawdown - feet	
	Alluvium	Vincentown
Independent Spent Fuel Storage Installation	11.5	40.8
Fuel Oil Tank	11.0	29.2
Waste Water Treatment Plant	9.5	32.8
Hope Creek Switchyard	9.3	33.0
Learning and Development Center	6.4	17.0
Hope Creek Unit 1	4.6	17.3
Low Level Rad Waste Building	2.8	13.3
Nuclear Operations Support Facility	2.3	10.9
Salem Units 1 and 2	0.9	6.4

Note: Estimated drawdown taken from groundwater model at or near the center of the structure using the base calibrated model simulation (see Table 8 for simulated pumping rates).

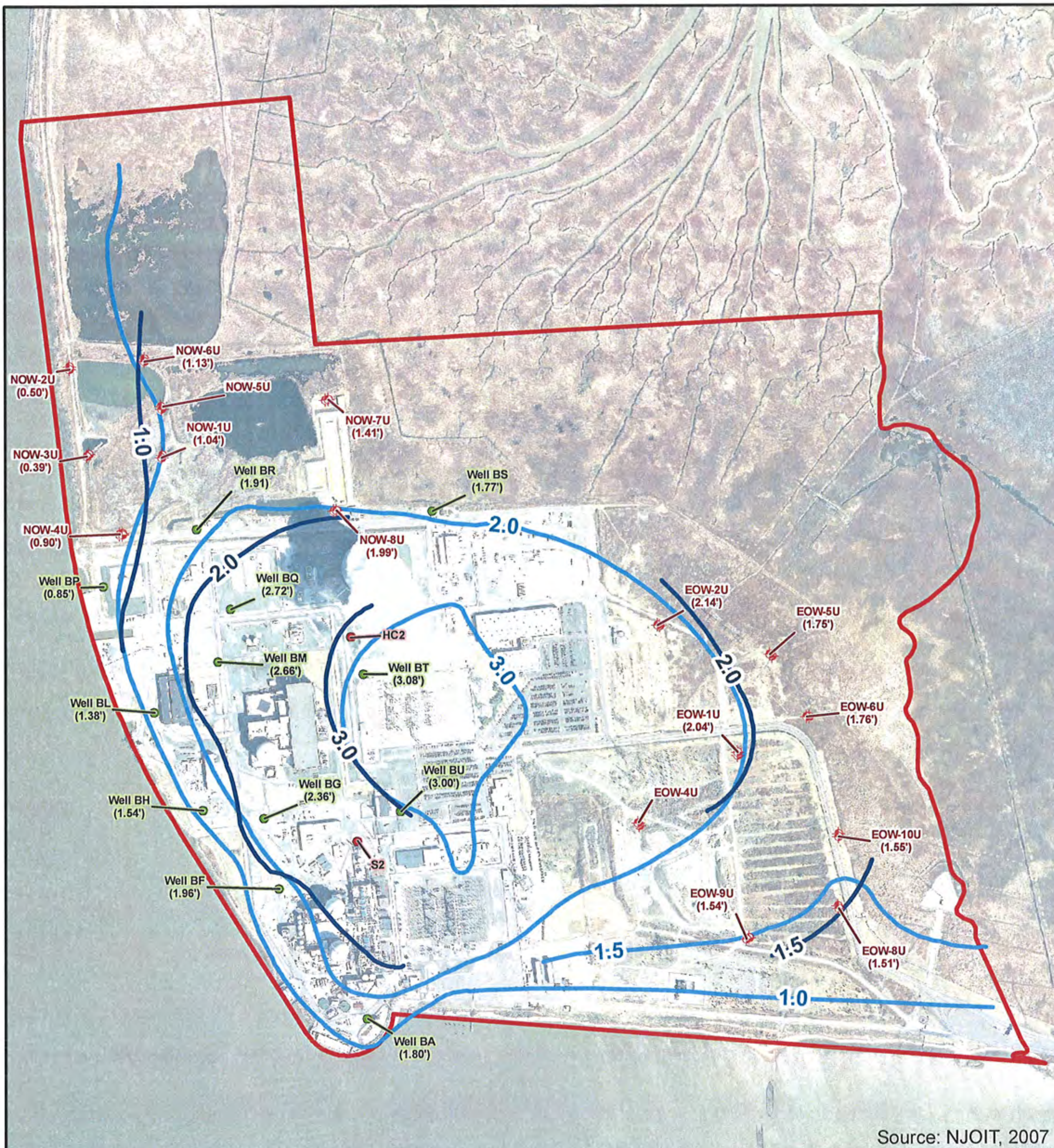
Table 10
Summary Dewatering Simulation and Sensitivity Results
Drawdowns and Heads at Selected Locations

Base simulation			
Drawdown, ft at 365 days	HC Cooling Tower	HC Unit 1	Salem 1&2
Alluvium	9.3	3.3	0.9
Vincentown Formation	33	17.7	6.4
Head, ft at 365 days at nuclear island Vincentown Formation	-68.3		
Halve VT/HT Kh to 5.35 ft/d			
Drawdown, ft at 365 days	HC Cooling Tower	HC Unit 1	Salem 1&2
Alluvium	7.4	2.5	0.6
Vincentown Formation	27.3	14.9	5.4
Head, ft at 365 days at nuclear island Vincentown Formation	-53.9		
Double VT/HT Kh to 21.4 ft/d			
Drawdown, ft at 365 days	HC Cooling Tower	HC Unit 1	Salem 1&2
Alluvium	9.6	3.4	1
Vincentown Formation	34.2	18.4	6.7
Head, ft at 365 days at nuclear island Vincentown Formation	-70		
Decrease Kv of Navesink to 0.0272 ft/d			
Drawdown, ft at 365 days	HC Cooling Tower	HC Unit 1	Salem 1&2
Alluvium	9.2	3.1	0.8
Vincentown Formation	32.8	17.1	6
Head, ft at 365 days at nuclear island Vincentown Formation	-70.3		
Increase Kv of Navesink to 0.109 ft/d			
Drawdown, ft at 365 days	HC Cooling Tower	HC Unit 1	Salem 1&2
Alluvium	9.3	3.4	0.9
Vincentown Formation	33.3	18	6.5
Head, ft at 365 days at nuclear island			
Vincentown Formation	-66.7		
Increase Kh of MLW to 15 ft/d			
Drawdown, ft at 365 days	HC Cooling Tower	HC Unit 1	Salem 1&2
Alluvium	8.7	3	0.8
Vincentown Formation	31.4	16.8	6.2
Head, ft at 365 days at nuclear island			
Vincentown Formation	-68.3		
Increase Kv of VT/HT to 1.0 ft/d			
Drawdown, ft at 365 days	HC Cooling Tower	HC Unit 1	Salem 1&2
Alluvium	8.7	3	0.8
Vincentown Formation	31.4	16.8	6.2
Head, ft at 365 days at nuclear island			
Vincentown Formation	-66.7		
Increase Kv of Kirkwood to 0.01 ft/d			
Drawdown, ft at 365 days	HC Cooling Tower	HC Unit 1	Salem 1&2
Alluvium	20.7	10.2	2.7
Vincentown Formation	31.2	16.2	5.3
Head, ft at 365 days at nuclear island			
Vincentown Formation	-67.6		
Decrease Kz of Kirkwood to 0.001 ft/d			
Drawdown, ft at 365 days	HC Cooling Tower	HC Unit 1	Salem 1&2
Alluvium	2.6	0.4	0.1
Vincentown	34.7	19	7.2
Head, ft at 365 days at nuclear island			
Vincentown	-69.2		

Notes: 1) VT/HT = Vincentown and Hornerstown Formations.
2) MLW = Mount Laurel-Wenonah aquifer
3) Kh = horizontal hydraulic conductivity.
4) Kv = vertical hydraulic conductivity
5) The drawdowns are taken at the approximate centers of the listed structures
6) The head is taken in the upper Vincentown (model layer 5) mid-point in the deeper excavation
7) The nuclear island refers to that of the new unit.

ATTACHMENT A

Comparison of Observed and Computed Water Level Contours



LEGEND

- MACTEC Observation Well
- HCGS/SGS Production Well
- ARCADIS Well (B Series)
- Site Boundary
- Interpreted Contours Average of Water Level Data
- Model Computed Heads Contoured by Groundwater Vistas (Calibrated Model)

N W E S

0 100 200 Meters

0 500 1,000 Feet

Note: Groundwater elevations represent data from average water level set

PSEG Power, LLC

PSEG Site ESPA
Groundwater Model Calc. Package

Comparison of Observed and Computed Water Level Contours

FIGURE A-1 Rev 0

Attachment B

Model-derived Input/Output Figures

List of Model-Generated Input/Output Figures

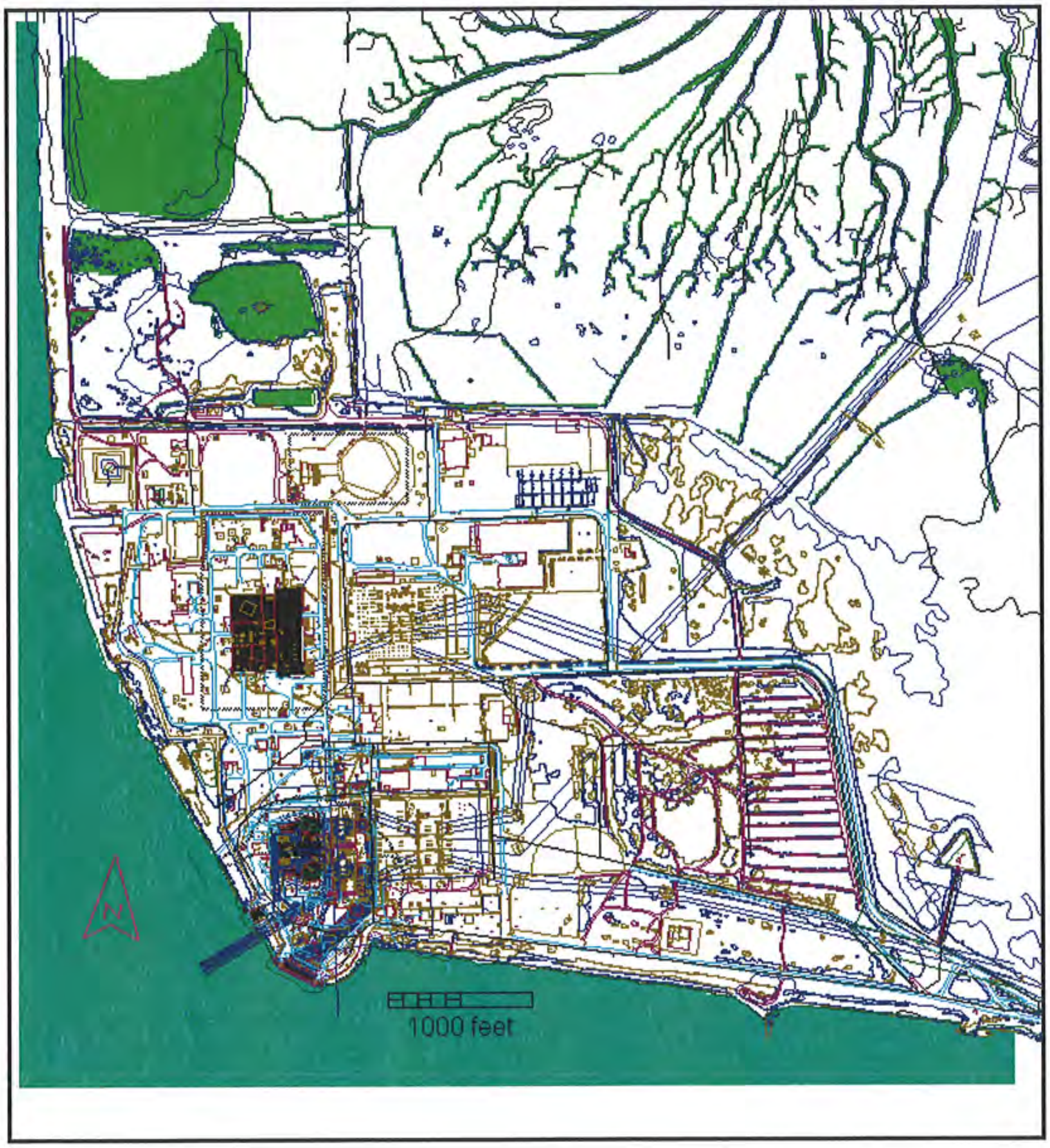


Figure B-1: Model domain and layer 1 boundary conditions. The 20-by-20-foot model grid is not shown as it is relatively fine and obscures the detail in the figure. The model has 376 rows and 350 columns, covering about 1200 acres. The detail in the base map will be deleted in most subsequent figures as it may obscure the focus of certain model outputs and inputs. The green west and south is the Delaware River, represented in the model by MODFLOW river package nodes. The green areas to the north and the northeast represent ponds and wetland areas, again using the MODFLOW river package to represent these boundary conditions. The blackened nodes locate the Hope Creek and Salem units, and use no-flow nodes to indicate impermeable structures into the water table.

Figure B-2: MODFLOW Model Grid in the New Plant Location. Grid blocks are a uniform 20-by-20 feet, north is upwards. The green to the left represents the Delaware River. Green areas in the area proposed for development are perched ponded areas and associated drainage ways.

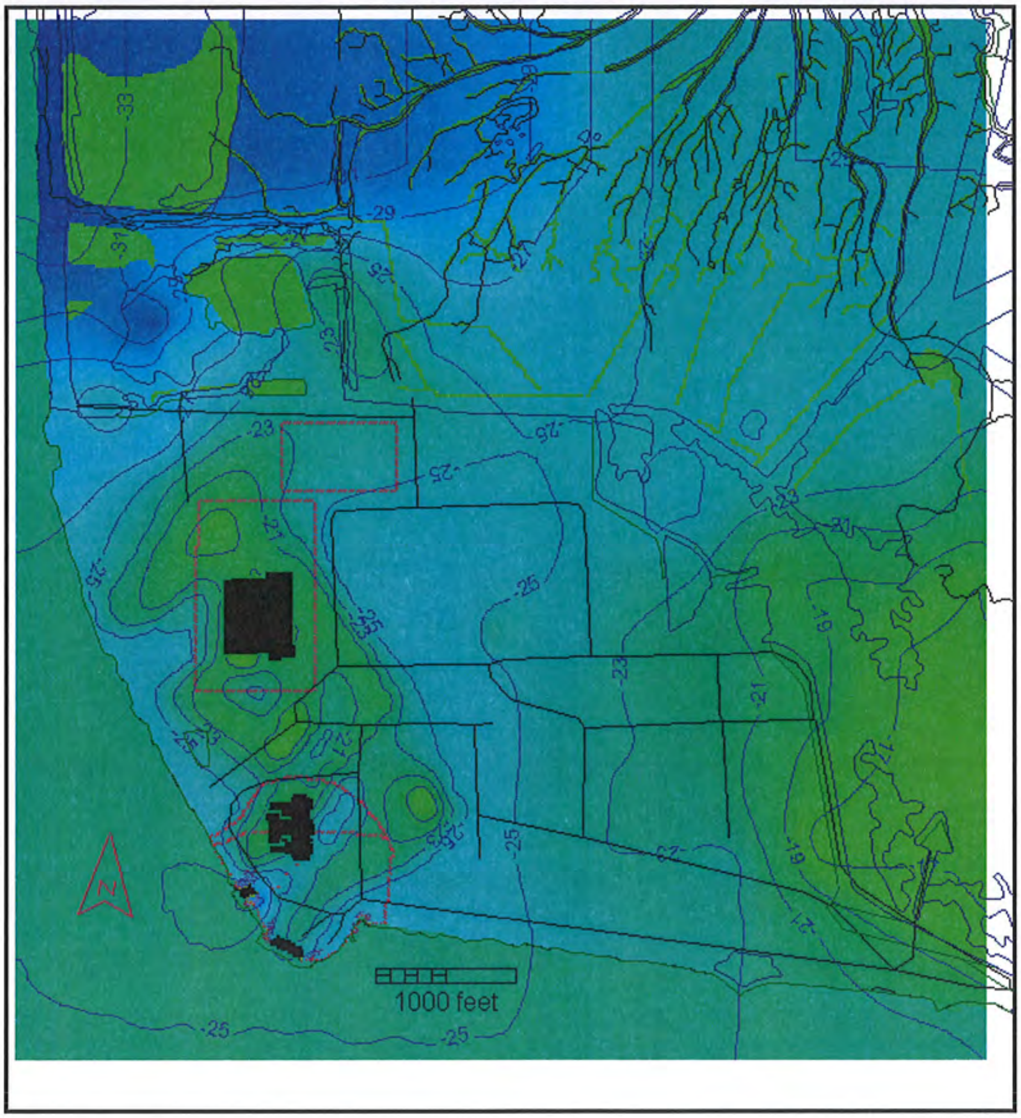


Figure B-3: Bottom of Layer 1 (Fill) Elevation Contours , feet NAVD88 Black areas denote no-flow boundaries in MODFLOW, used to represent impermeable structures extending below the water table through this particular model layer.

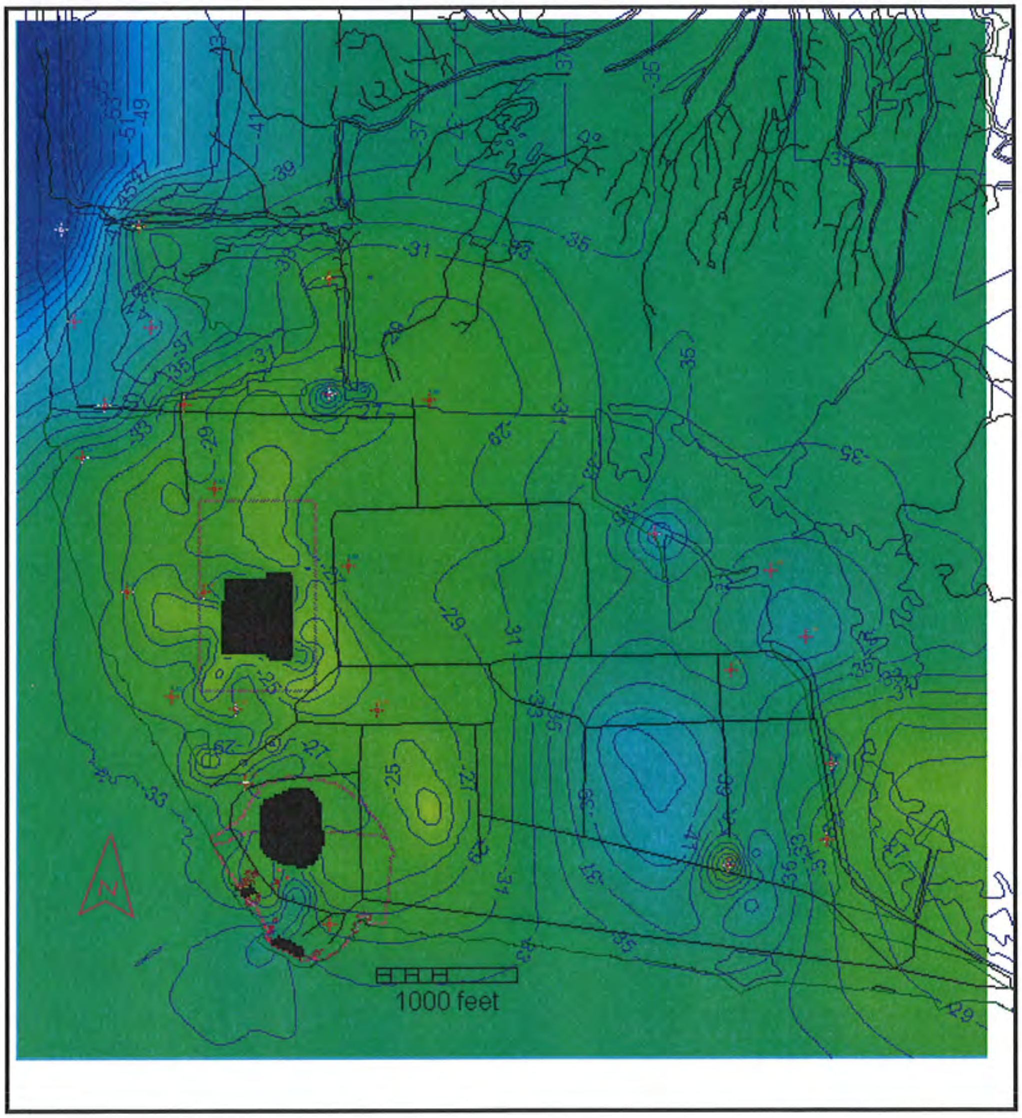


Figure B-4: Bottom of Layer 2 (Alluvium) Elevation Contours, feet NAVD88. Crosses mark locations of water level readings taken in support of the model calibration.

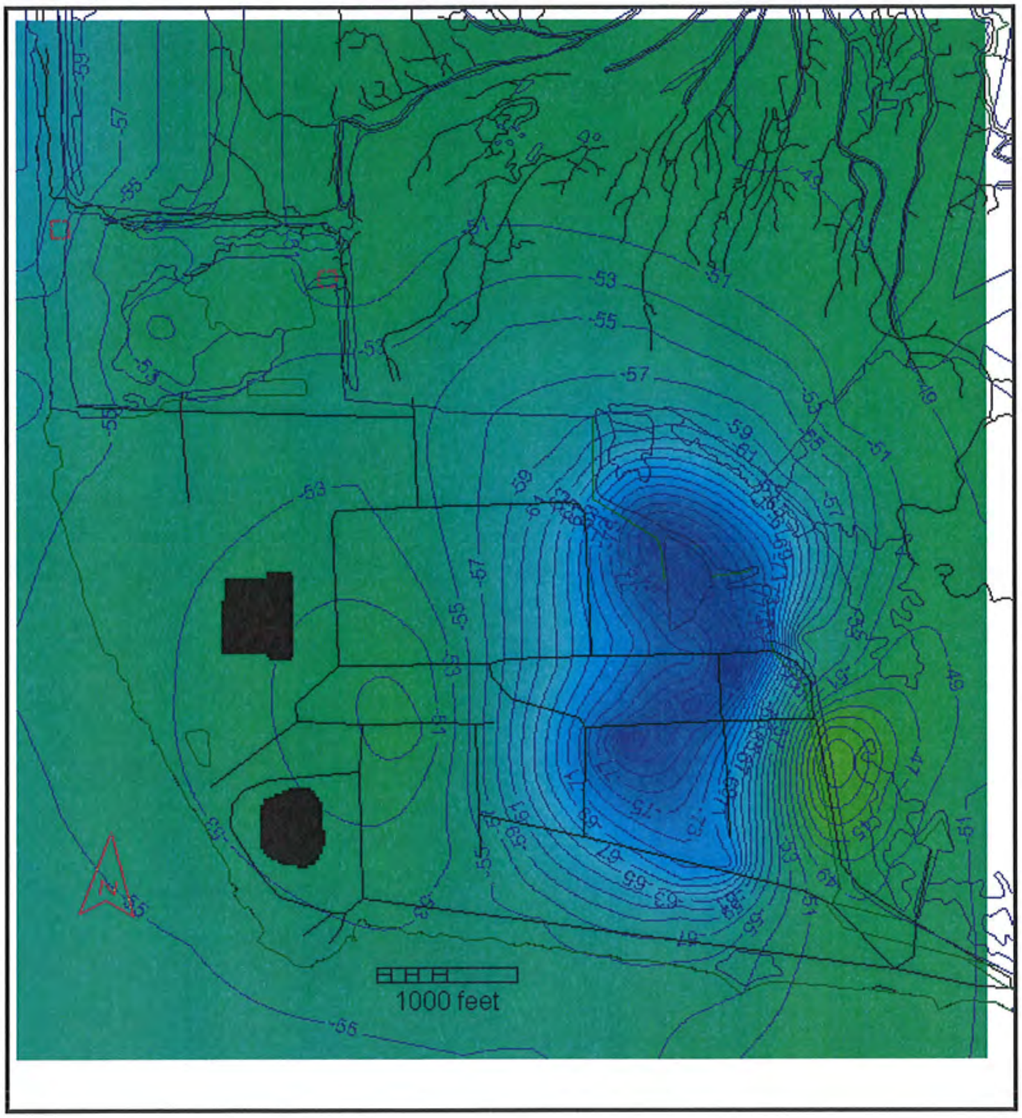


Figure B-5: Bottom of Layer 3 (Kirkwood Aquitard) Elevation Contours, feet NAVD88.

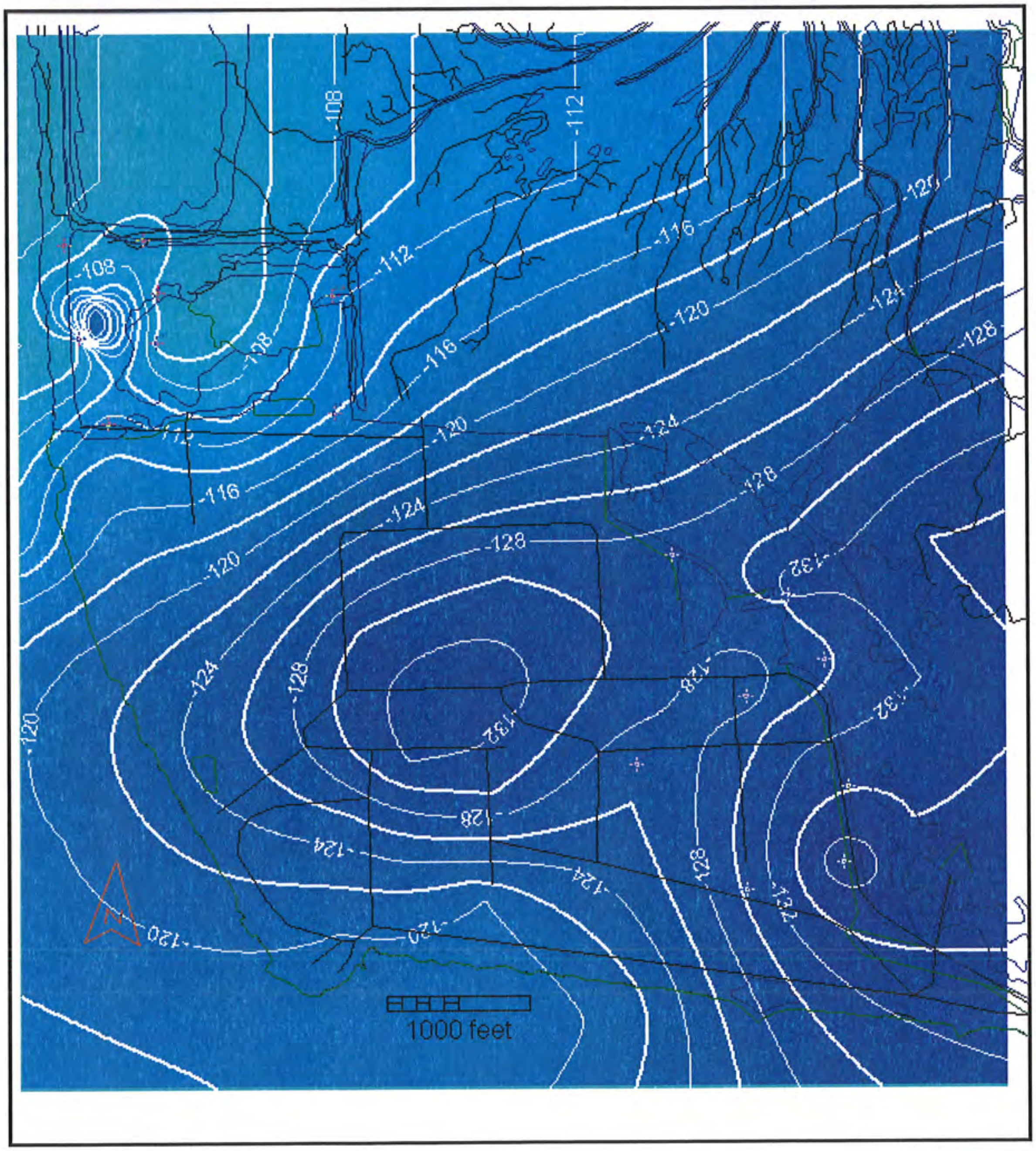


Figure B-6: Bottom of Layer 4 (Vincentown) elevation contours, feet NAVD88. The crosses mark the location of water level data in the formation in support of model calibration.

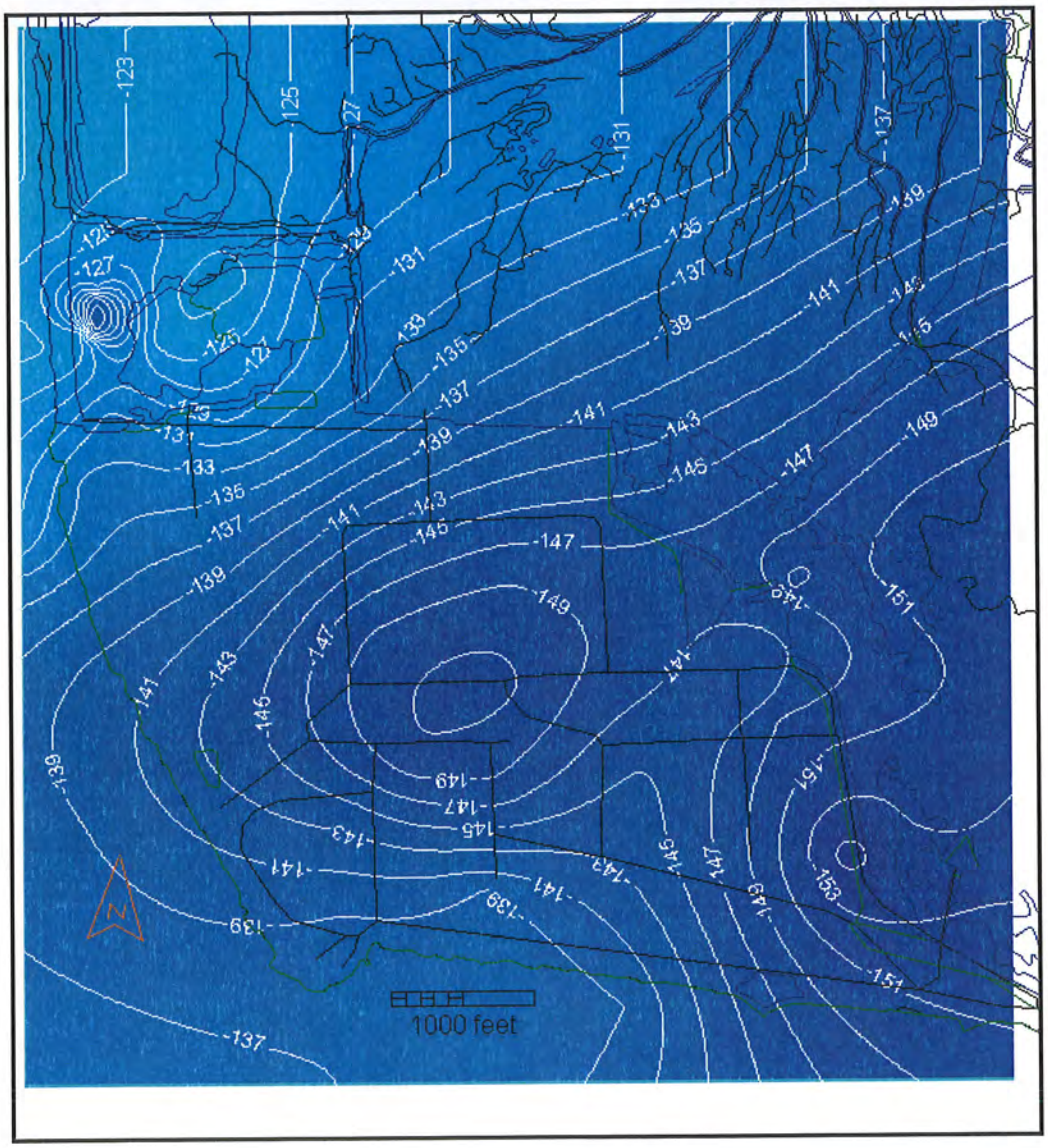


Figure B-7: Bottom of Layer 5 (Hornerstown) elevation contours, feet NAVD88.

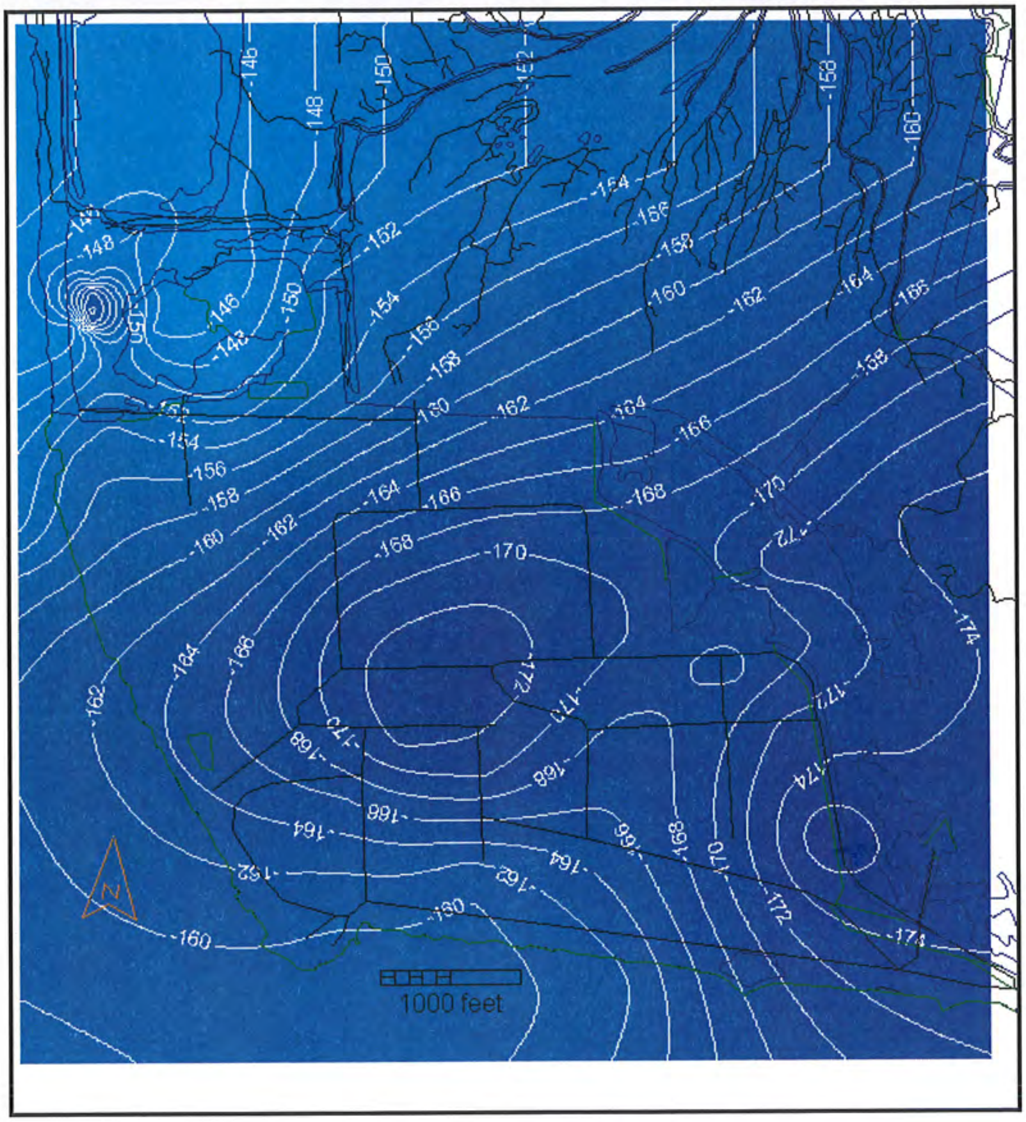


Figure B-8: Bottom of Layer 6 (Navesink Aquitard) elevation contours, feet NAVD88.

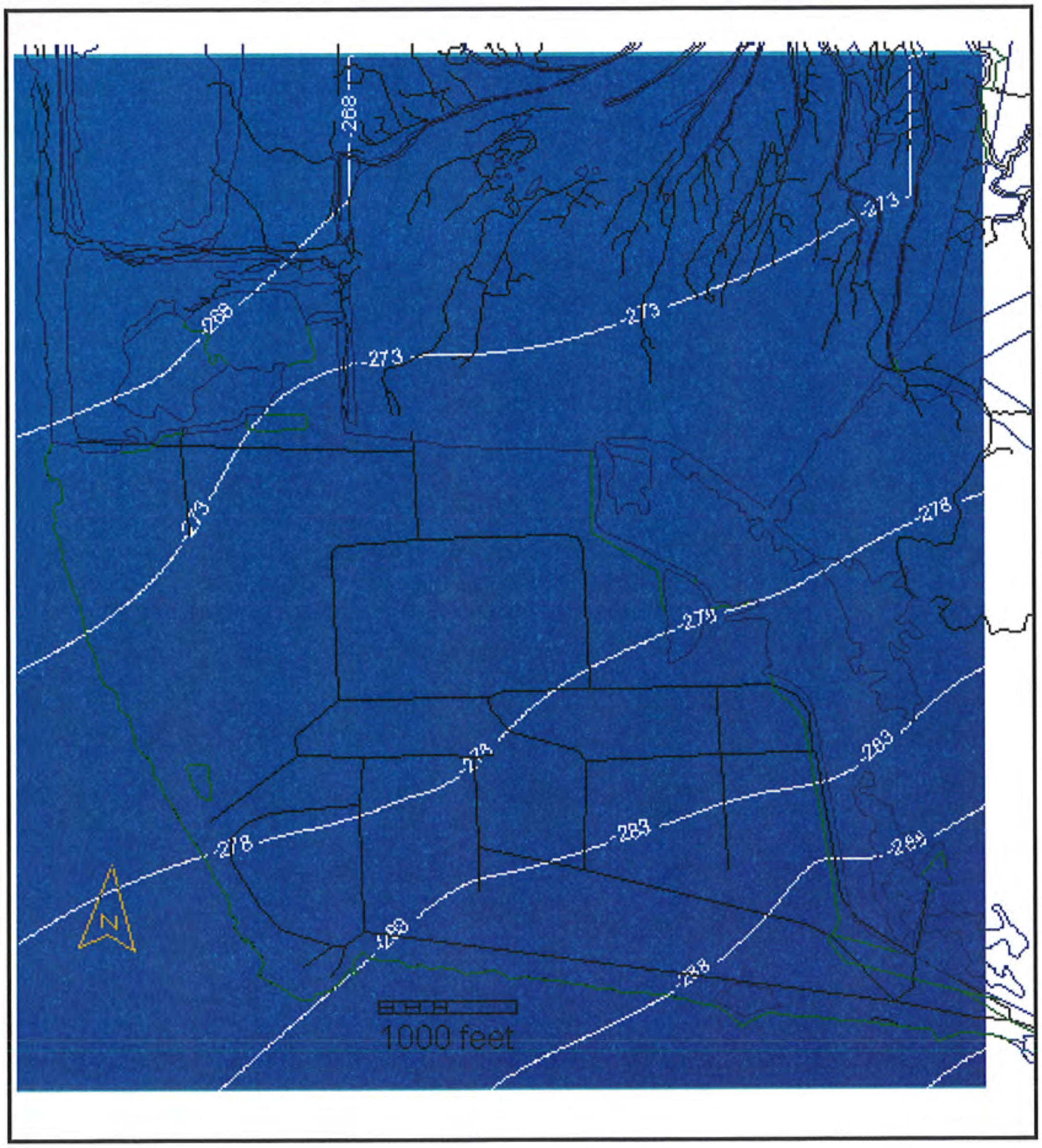


Figure B-9: Bottom of Layer 7 (Mount Laurel-Wenonah) elevation contours, feet NAVD88. This is also the base of the model as the underlying Marshalltown aquitard is thick and competent and is unlikely to allow flow to occur with the next lower aquifer.

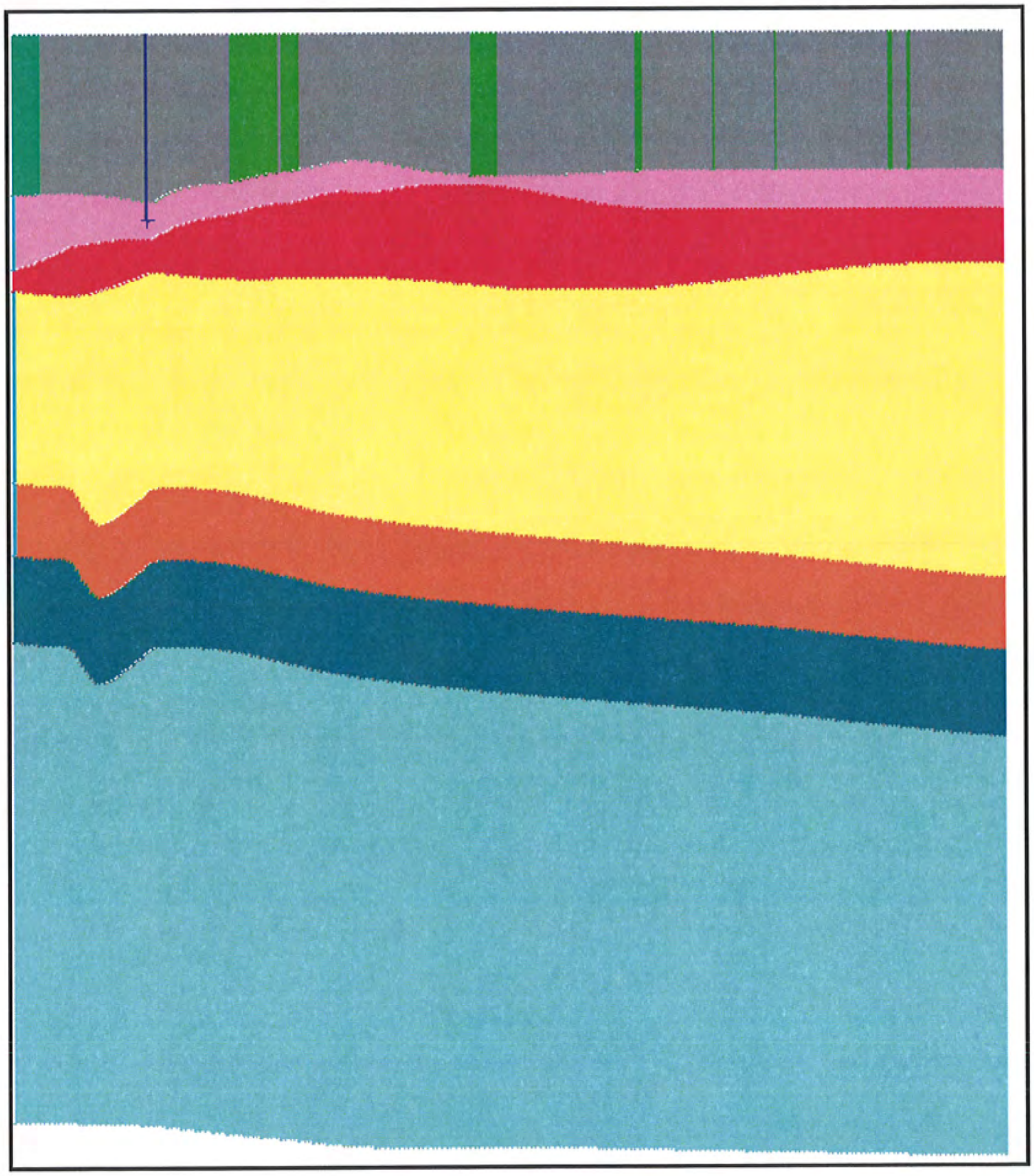


Figure B-10: Section View of model layers along model row 61 and the northern parcel selected for expansion. Starting from the bottom up, the layers represent the Mount Laurel-Wenonah, the Navesink aquitard, the Hornerstown unit, the Vincentown Formation, the Kirkwood aquitard, the alluvium, and the fill materials. Green strips in the fill material layer mark river nodes. The dark blue line in the upper left extending down into the alluvium represents boring NOW-3U.

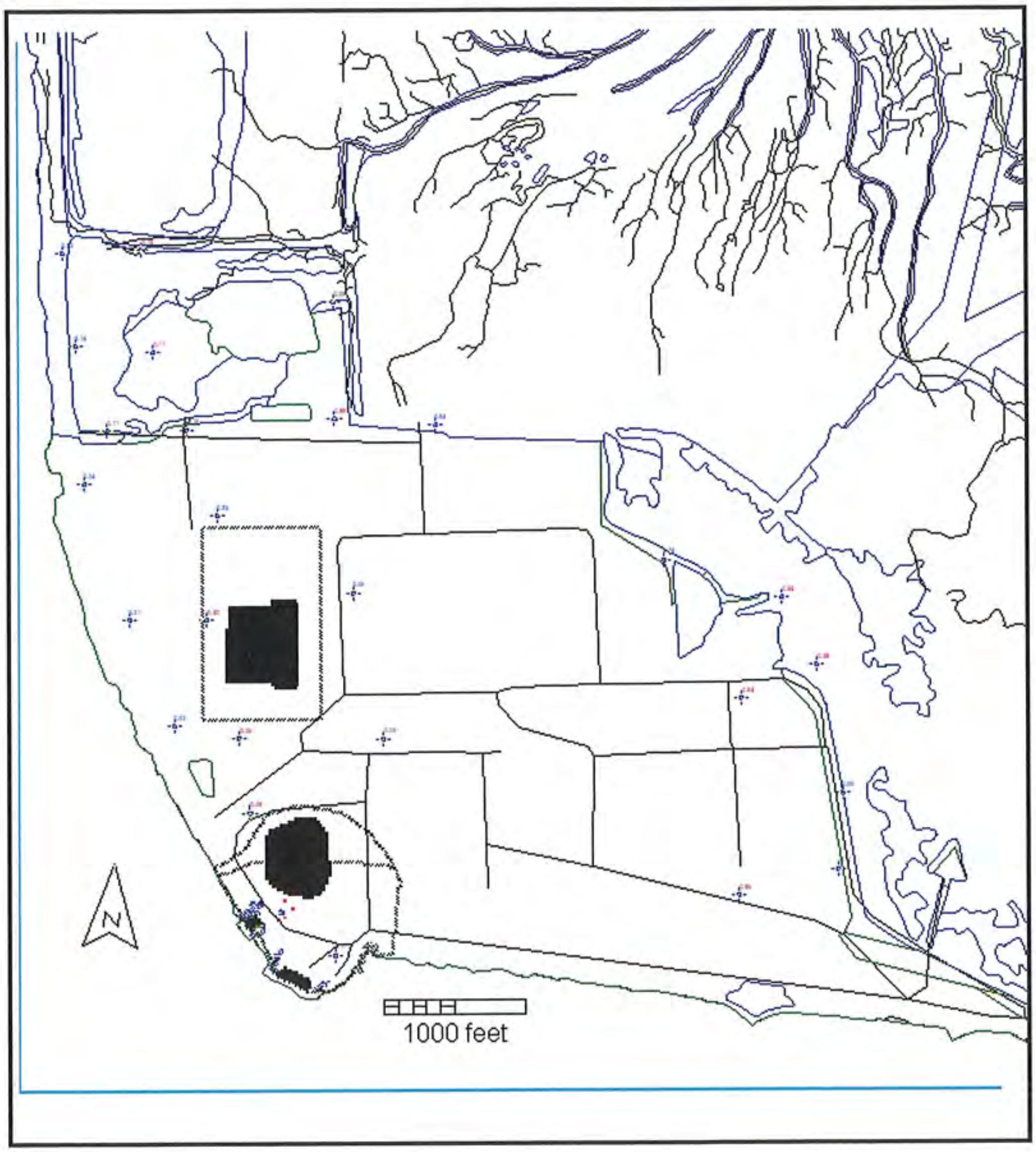


Figure B-11: Boundary conditions in model layer 2 (Alluvium). The light blue lines to the west and south are general head boundaries. The crosses represent locations where water level data was collected in the alluvium for model calibration purposes.

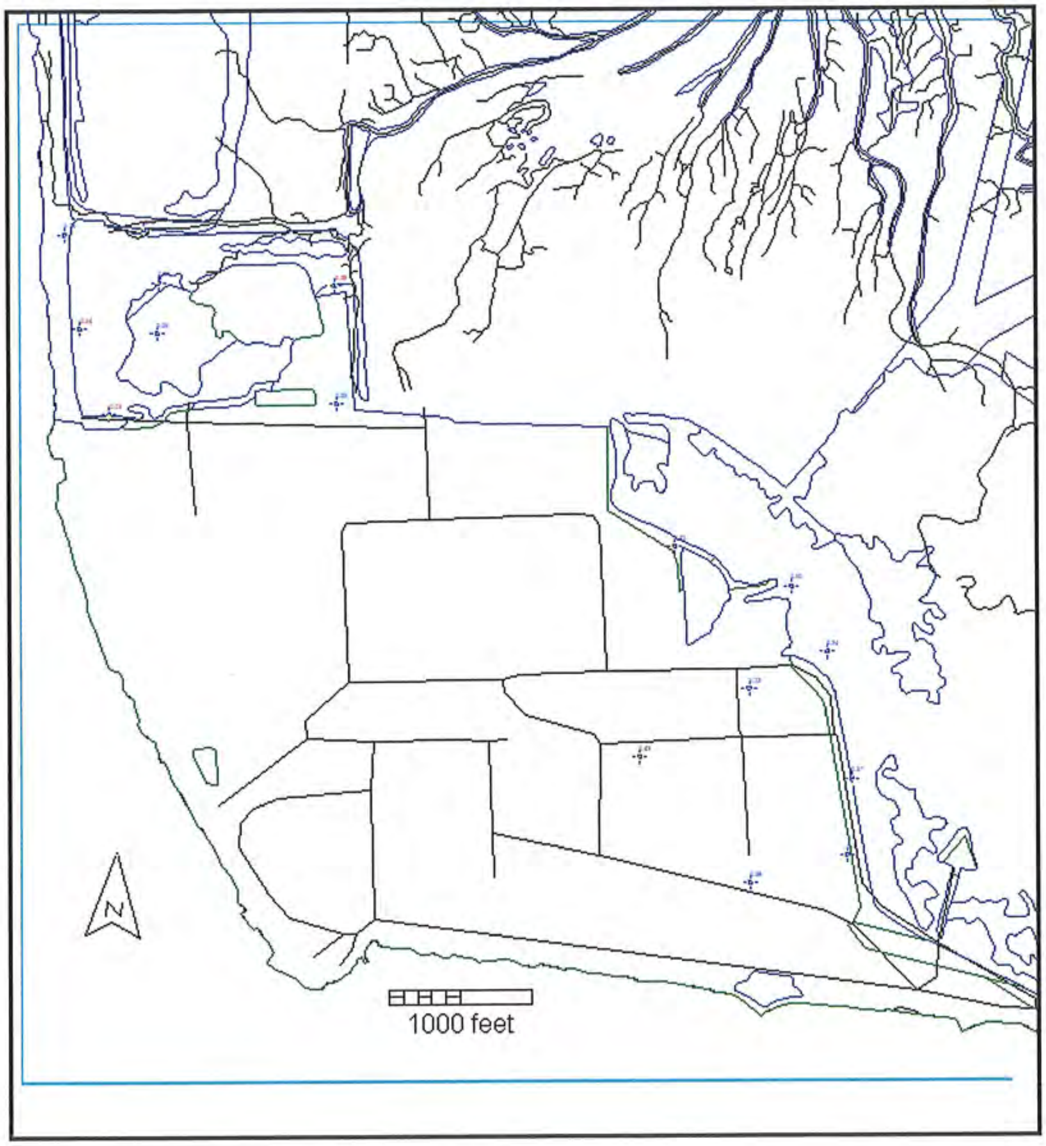


Figure B-12: Boundary conditions in model layers 4 (Vincentown) and 5 (Hornerstown). The light blue lines to the north, west and south represent general head boundaries. The crosses represent locations where data was taken in the Vincentown to aid in model calibration.

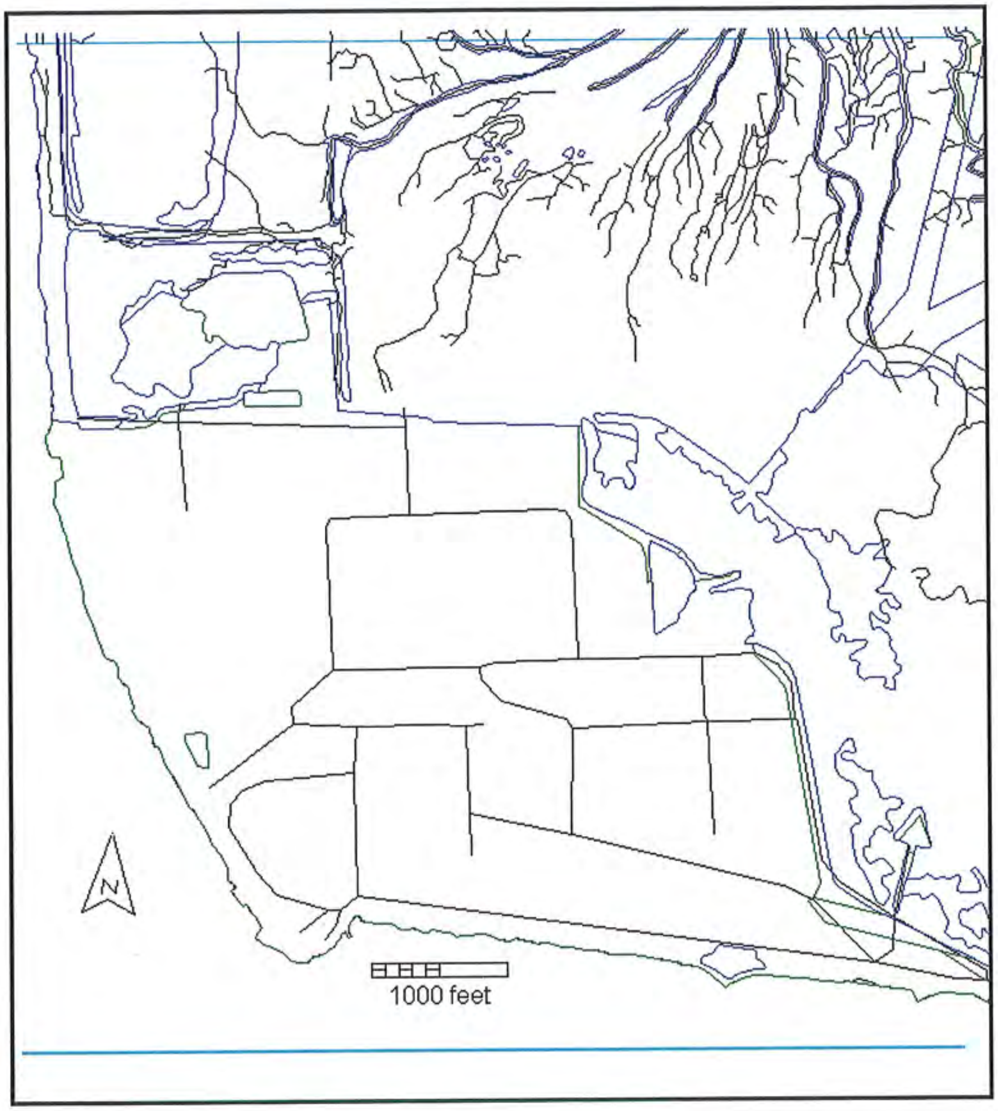


Figure B-13: Boundary conditions in model layer 7 (Mount Laurel-Wenonah). The light blue lines to the north and south create a slight overall gradient to the south.

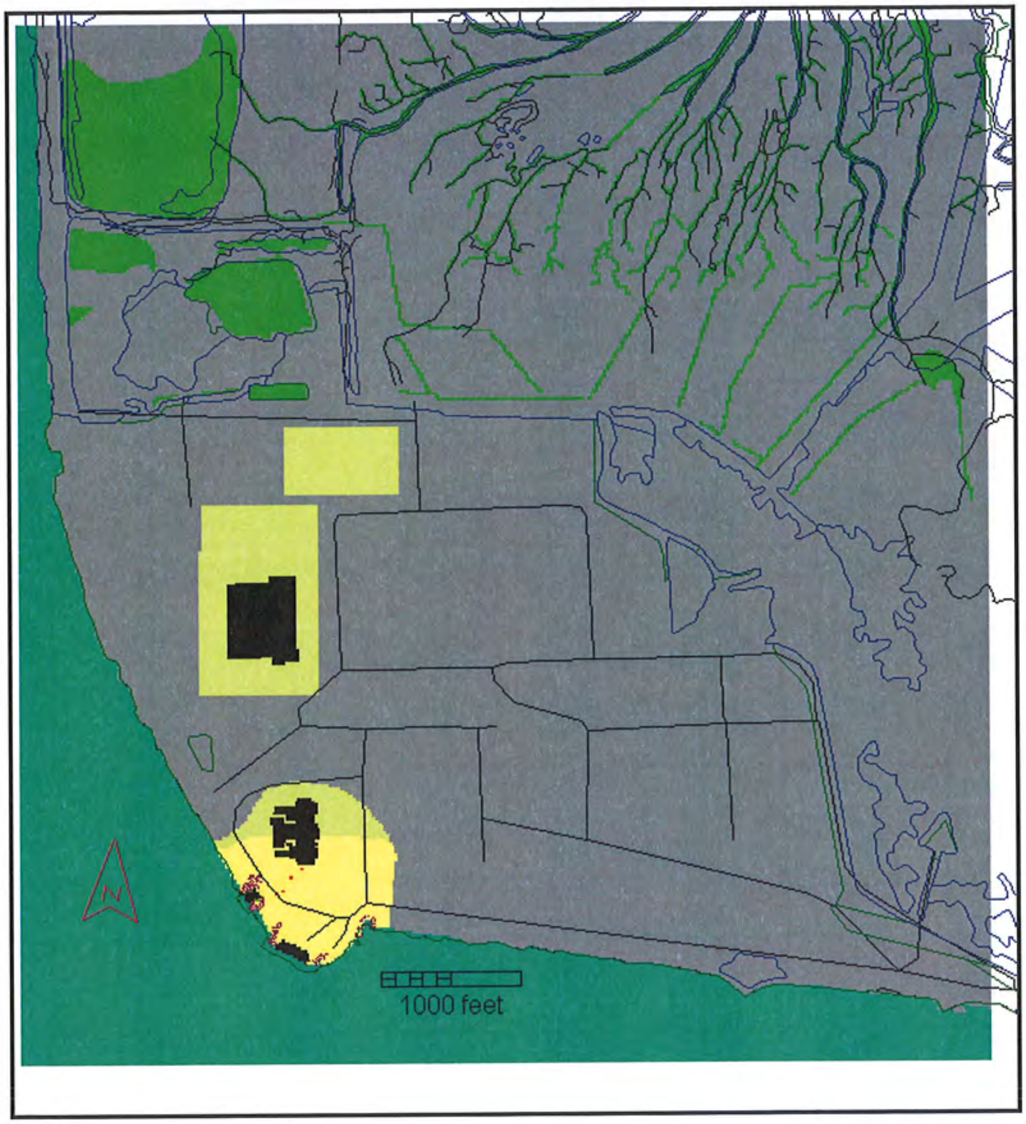


Figure B-14: Zones of hydraulic conductivity in model layer 1 (fills). The grey area represents the lower permeable hydraulic fill and the light yellowish areas estimated or assumed extents of structural fill associated with the Salem and Hope Creek units and probable disturbed areas of hydraulic fill associated with piles driven to support the Hope Creek Cooling Tower. The black areas are no-flow nodes representing impermeable structures extending below the water table. In the model, the hydraulic fill has a relatively low horizontal hydraulic conductivity of about 0.1 ft/d, while the structural fill has one of 6.5 ft/d.

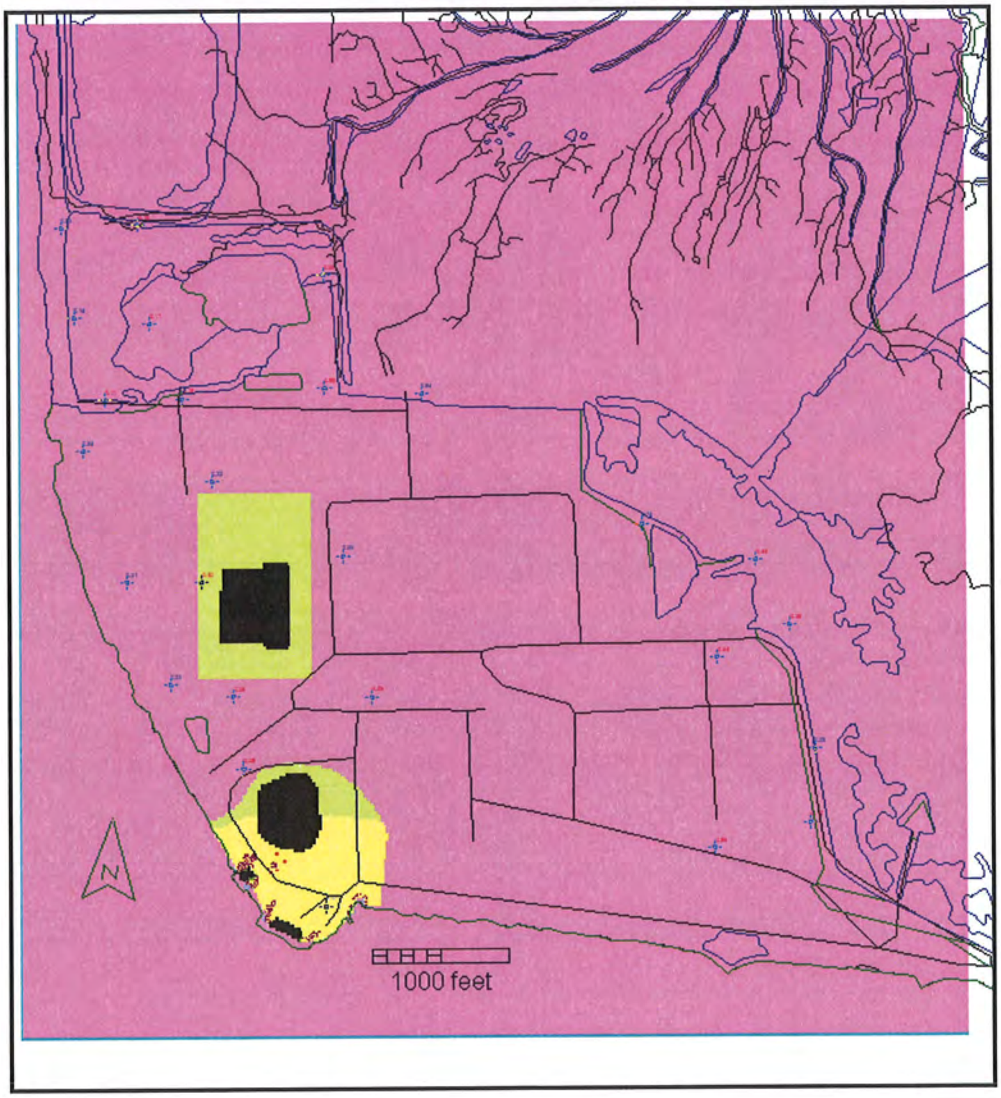


Figure B-15: Zones of hydraulic conductivity in model layer 2 (alluvium). The light yellowish areas indicate estimated or assumed presence of structural fill within this layer (Kh = 6.5 ft/d). The pink areas are alluvium with a specified Kh of 3.89 ft/d.

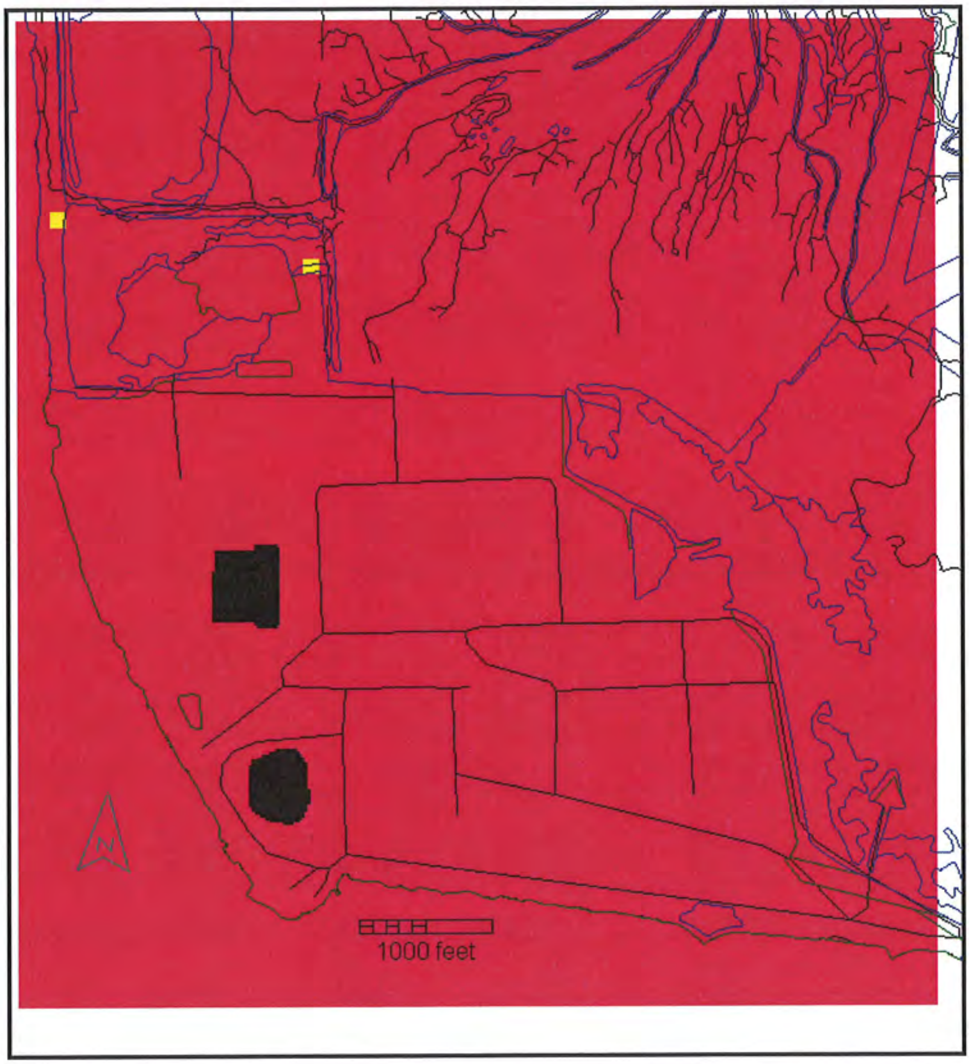


Figure B-16: Zones of hydraulic conductivity in model layer 3 (Kirkwood aquitard). The two light squares in the northern parcel for expansion indicate locations where the Kirkwood was noted to be absent. The extents of these areas are not known, and may allow some communication between the alluvium and the Vincentown. This may not be very significant as the mean head differential between these units is not great. The hydraulic conductivity of the alluvium was assigned to these areas. It is also likely that some gaps in the Kirkwood may exist around the nuclear islands as a result of excavations there; however, these gaps may be small and insignificant when compared to the domain of the model. Further, backfill material in excavated areas contained fines that may have effectively sealed these small gaps in the Kirkwood aquitard where breached.

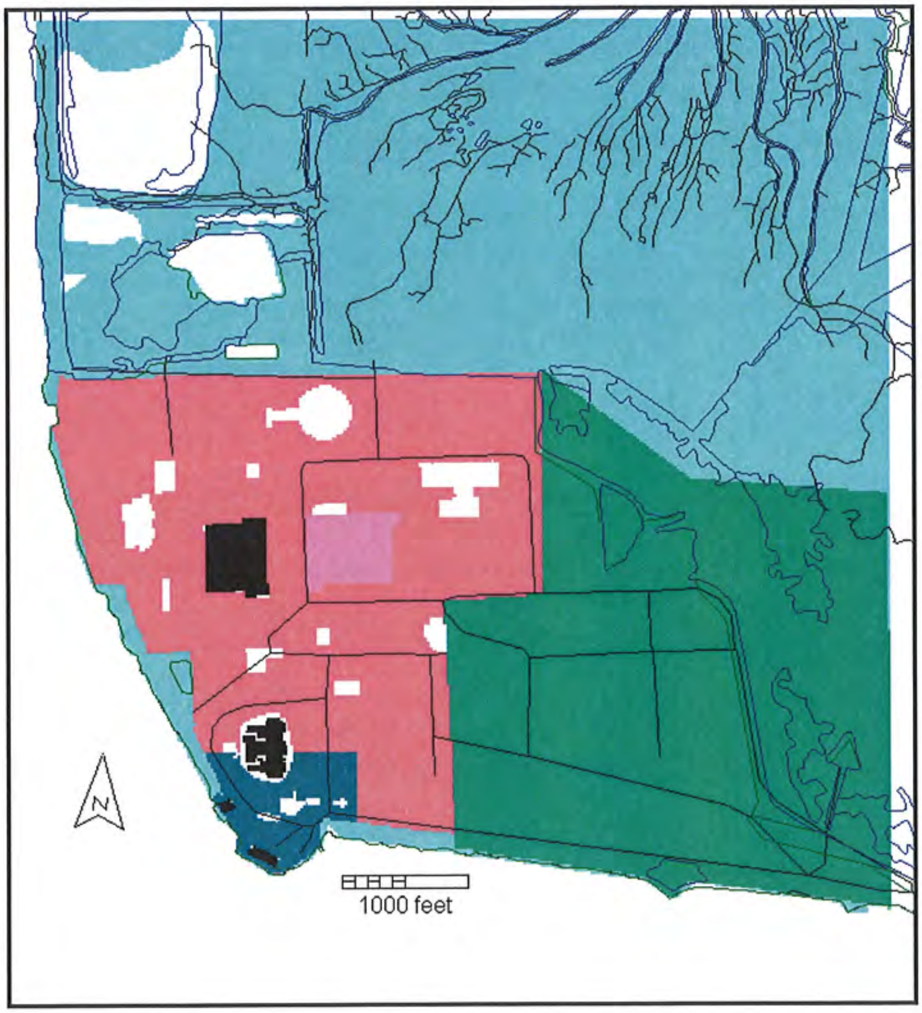


Figure B-17: Zones of net recharge in the calibrated model – layer 1. The light blue area (Zone 1) is 0.15 inches per year (in/yr) and the light green area (Zone 4) is also of low net recharge at 0.61 in/yr due to the low permeability of the hydraulic fill and evapotranspiration potential of the vegetation in the undeveloped areas. The red colored area (Zone 3) in the central portion of the facility is assigned a rate of 1.27 in/yr based on calibration results. The dark area (Zone 6) south of Salem units is assigned a rate of 8 inches per year based on ARCADIS modeling and that the structural fill presents a pathway directly to the river (except where sheet piling was left in place). The light purple area (Zone 5) at the switchyards is considered relatively impermeable, but autocalibration suggested a higher than expected rate (1.83 in/yr) and may represent runoff which recharges at the perimeter of the area. White open areas (Zone 2) are zero net recharge, essentially at surface water bodies (which are discharge locations or allow seepage through the MODFLOW river package) and large buildings.

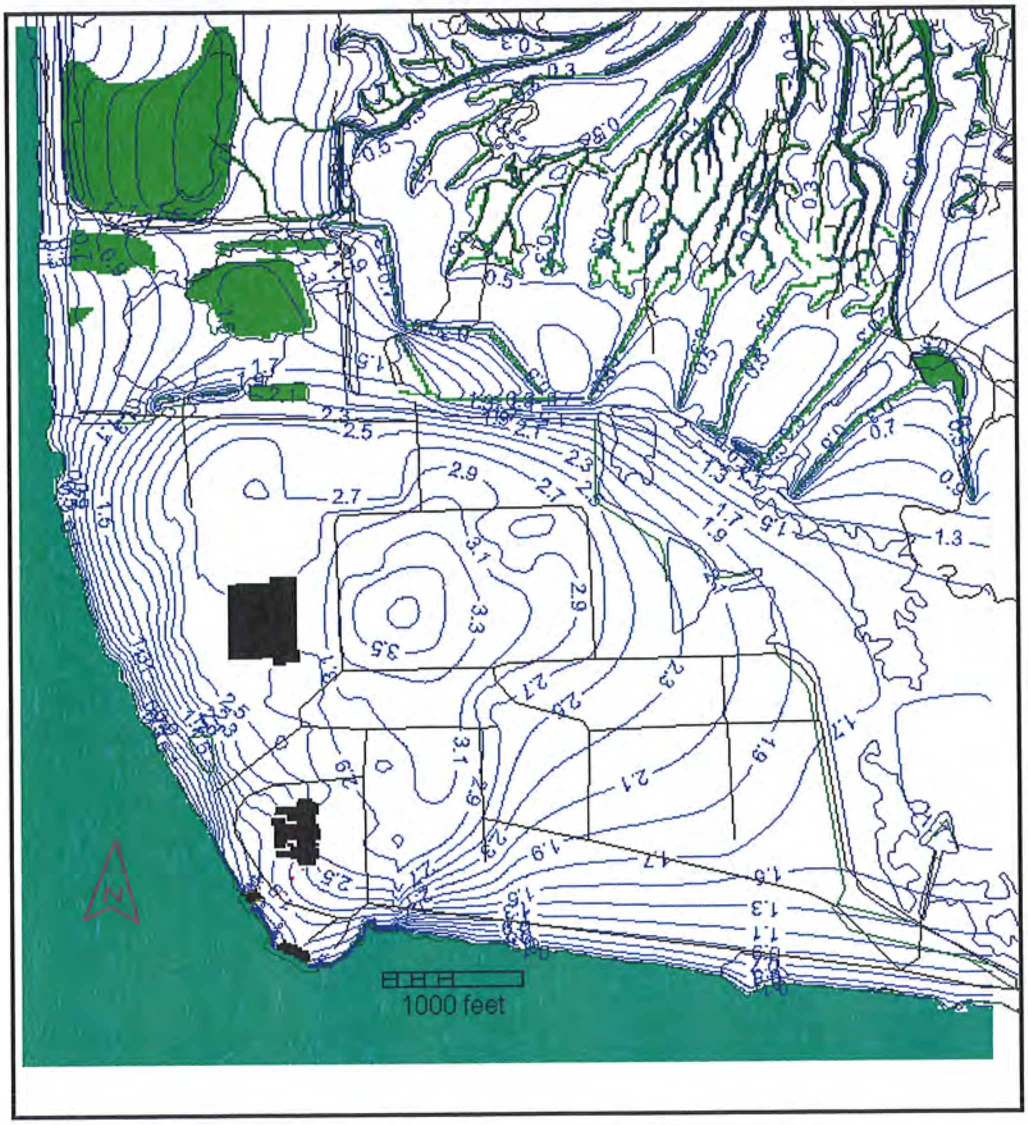


Figure B-18: Calibrated model piezometric contours (ft NAVD88) in model layer 1 –fills. The contours show a general pattern of higher heads near the middle of the model domain with flow radially to sinks, i.e., the Delaware River, wetland areas, and vertically downward. Highs within the layer reach a high of about 3.9 feet NAVD88.

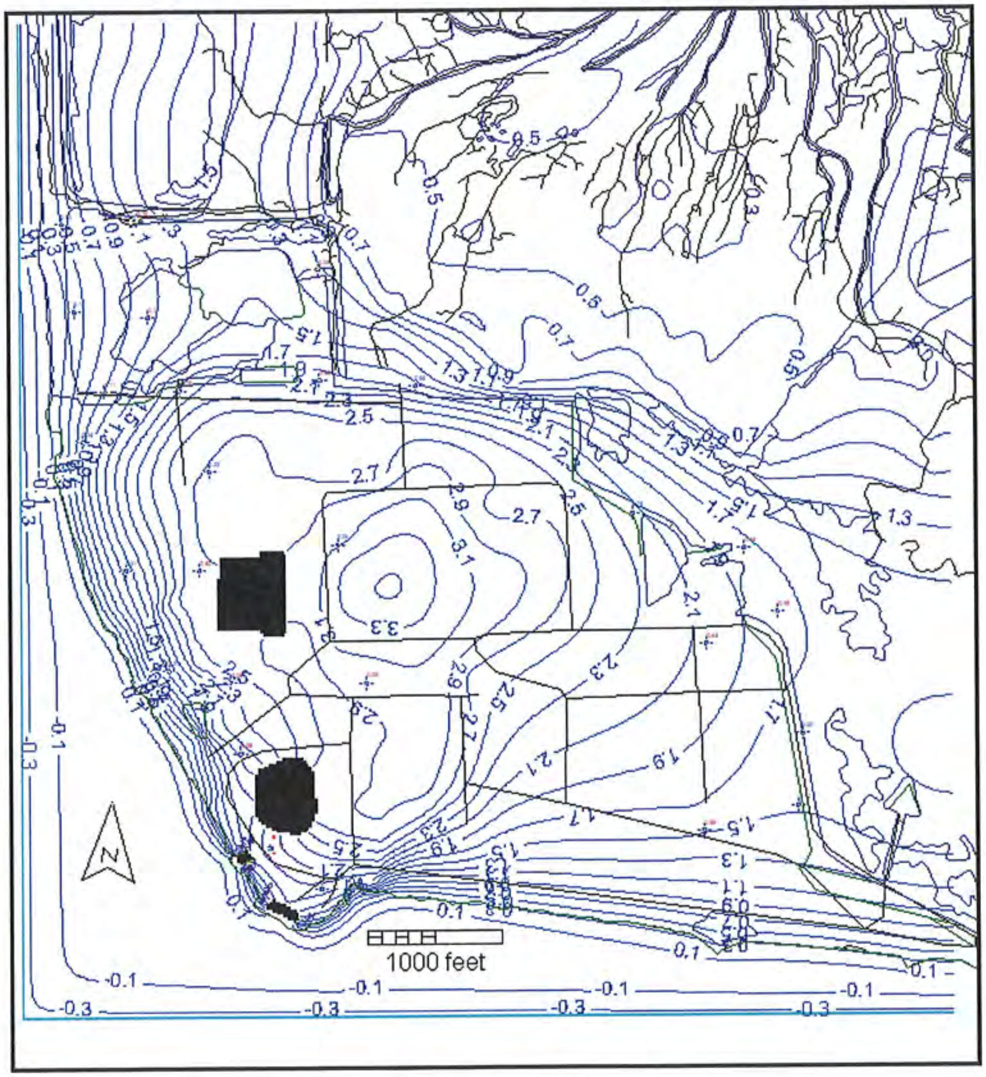


Figure B-19: Calibrated model piezometric contours (ft NAVD88) in model layer 2 – alluvium. These are very similar to those in the fill layer, but slightly lower, with a maximum head in the layer of about 3.5 ft NAVD88.

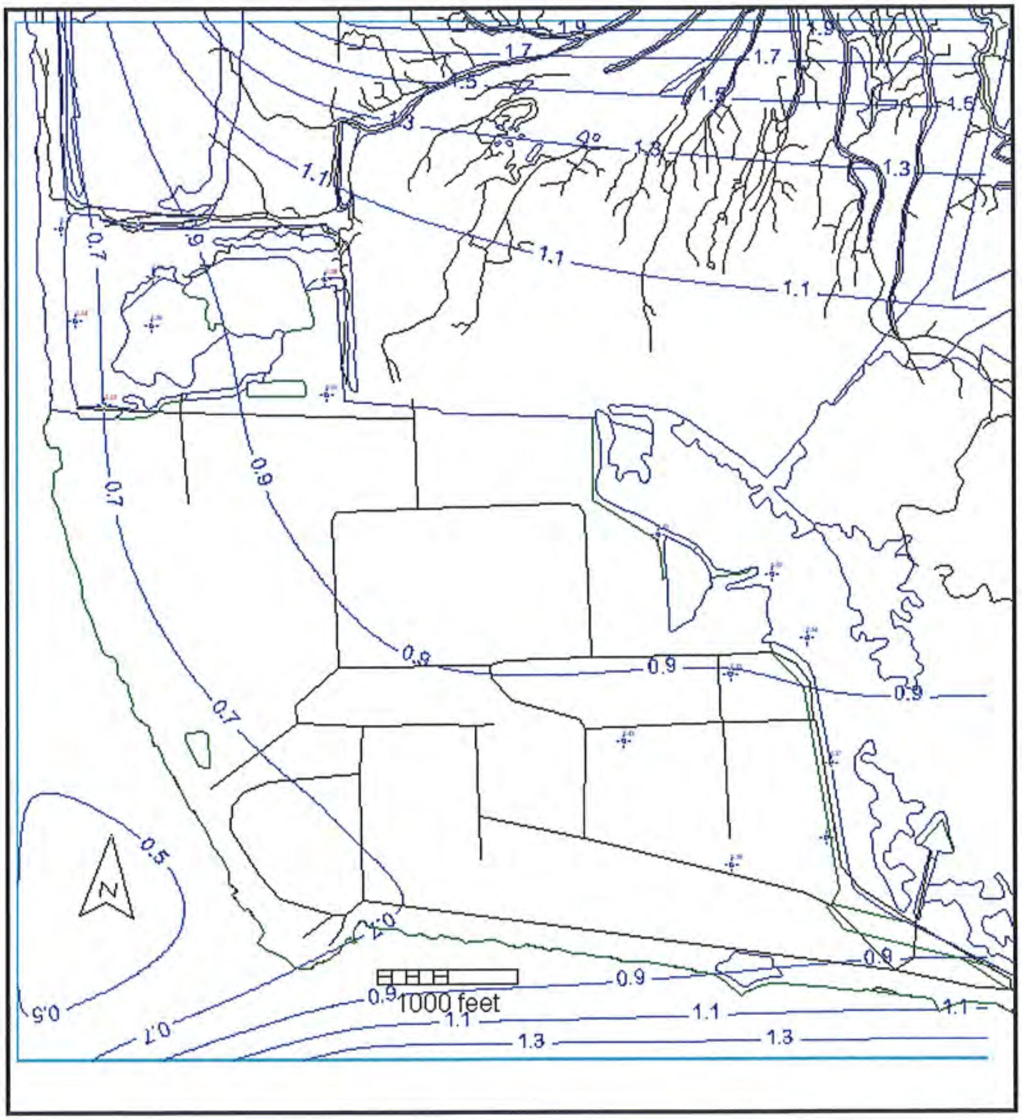


Figure B-20: Calibrated model piezometric contours (ft NAVD88) in model layer 4 – Vincentown. Flow is in from the north and out to the west and south towards the Delaware River.

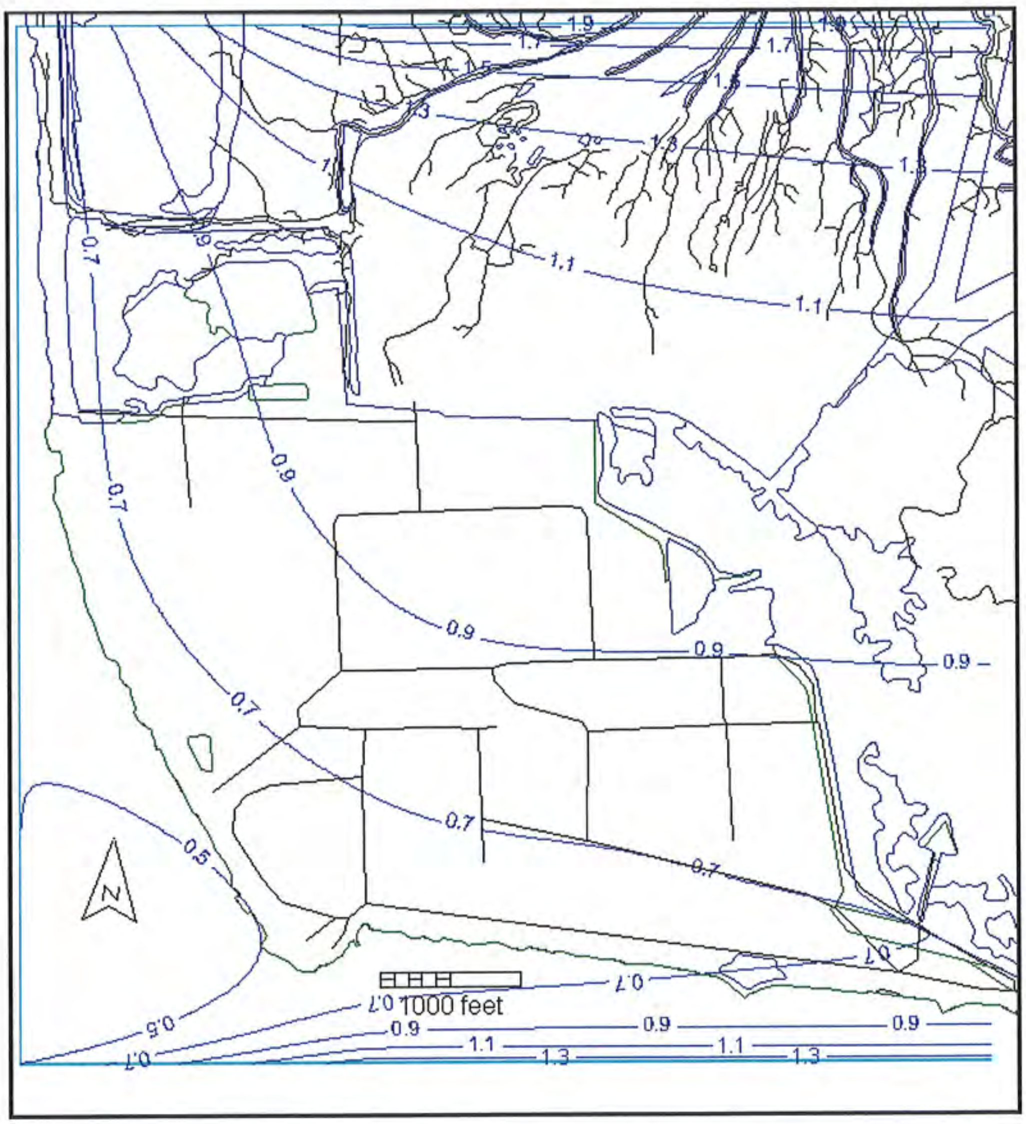


Figure B-21: Calibrated model piezometric contours (ft NAVD88) in model layer 5 – Hornerstown unit. These are very similar to those for the Vincentown as the boundary conditions in the two layers are alike. There is some slight difference as this layer is closer to the leaky Navesink aquitard and the underlying Mount Laurel-Wenonah.

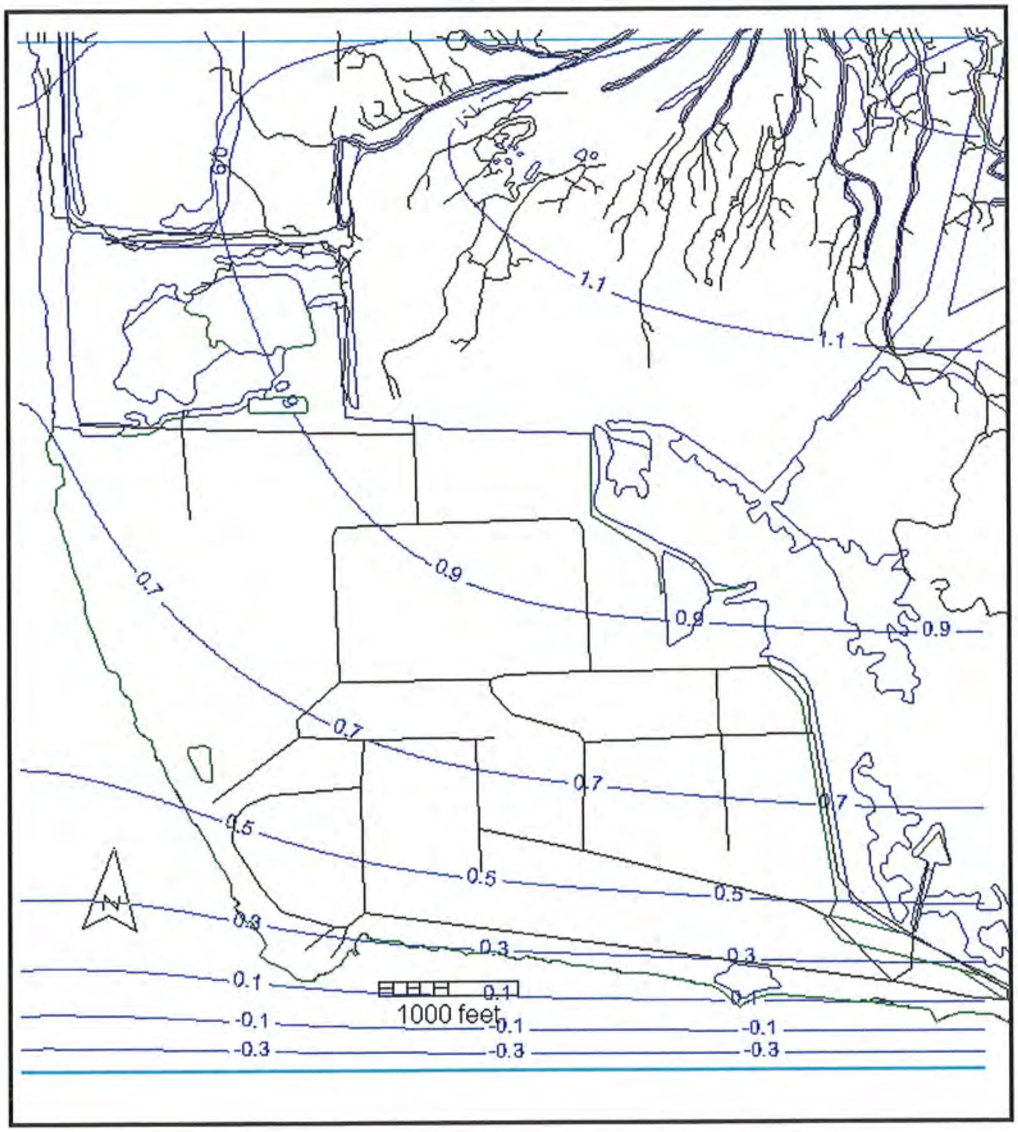


Figure B-22: Calibrated model piezometric heads (ft NAVD88) in model layer 7 – Mount Laurel-Wenonah aquifer. The influence of the leaky aquitard with seepage from the overlying aquifers is apparent in the mounding as opposed to a simple linear monotonic gradient across the layer that would be expected if the layers were isolated.

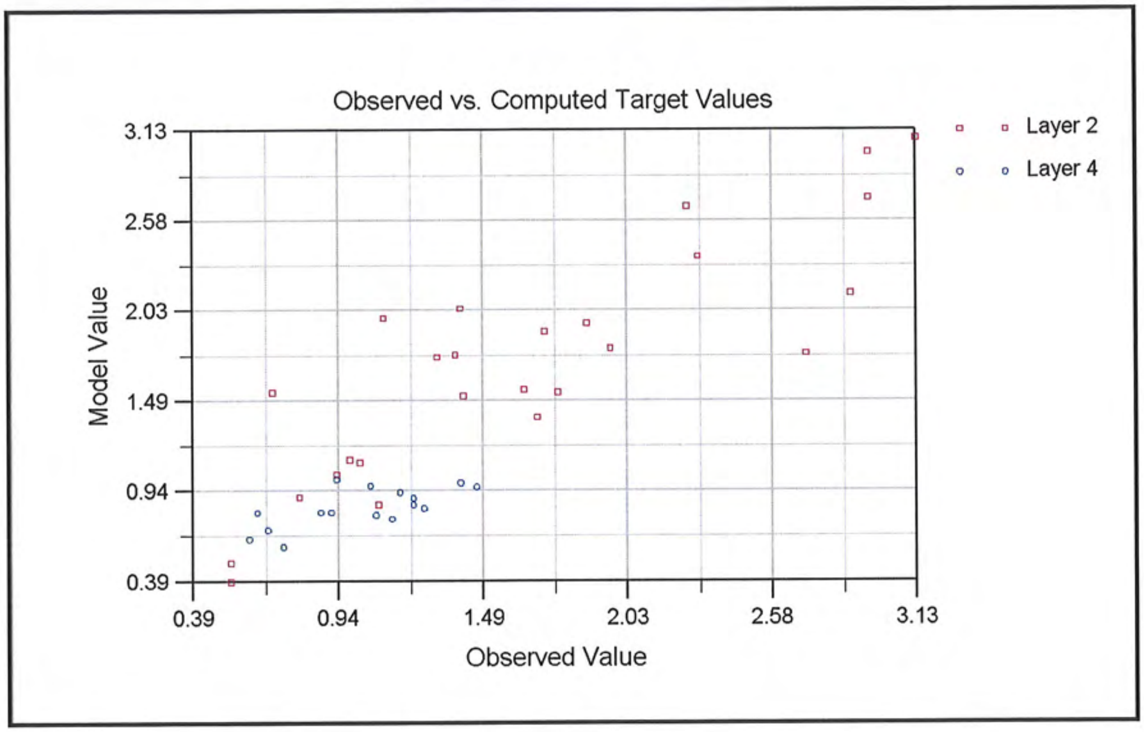


Figure B-23: Plot of Model-Computed Heads (feet NAVD88) versus Observed Water Levels

Figure B-24: Location of soil retention barrier and simulated dewatering wells in alluvium – modified model layer 3. The purple line is the barrier, represented in MODFLOW with the horizontal flow barrier package as an equivalent 1-foot thick barrier with effective hydraulic conductivity of 1×10^{-5} centimeters per second. The small red squares represent the dewatering wells in this model layer, and are approximately 100 feet apart. Wells are represented in this model using the drain package with high conductance and reference elevation set just above the bottom of the layer or to a depth that achieves the target dewatering levels. This configuration is not meant to define any design components but is intended only to simulate potential dewatering of the area in the shallow zone to estimate a dewatering rate. The dewatering simulation is to some degree hypothetical as the final extent of the areas to be dewatered will not be determined until the COLA stage when the final unit technology and layout are fixed. The extent of the area shown above is about 1950 feet in a north-south direction and 1650 feet in an east-west direction. This outer barrier also extends from elevation 5 ft NAVD88 down to -90 ft NAVD88 (from surface fill down through the Kirkwood into the upper portion of the Vincentown) (see figure B-25).

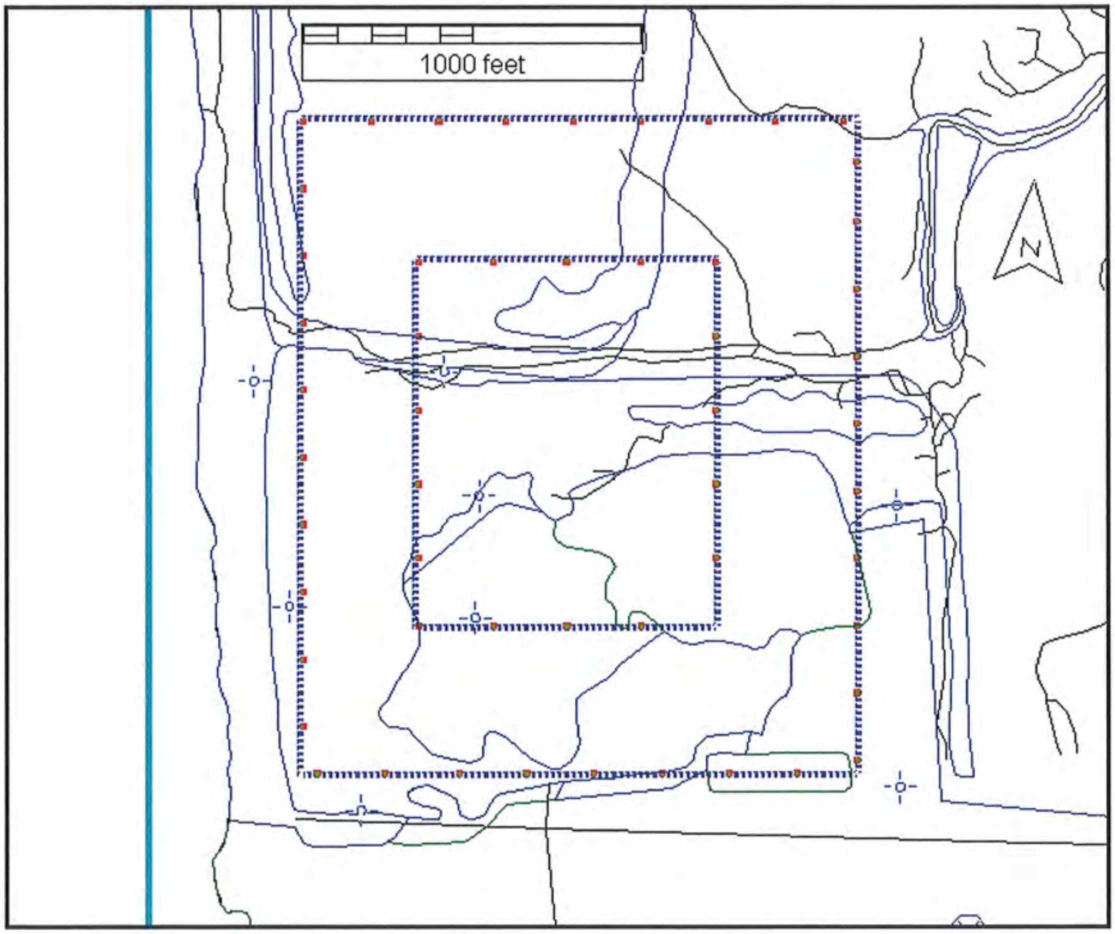


Figure B-25: Locations of soil retention barriers in upper Vincentown - model layer 5. Both inner and outer barriers penetrate the Kirkwood aquitard and extend down into the Vincentown to approximate elevation -90 ft NAVD88. The dimensions of the inner ring are 1095 ft in a north-south direction and 900 ft in the east-west direction. Well locations, as represented in the model with drain nodes, are shown as the small red squares.

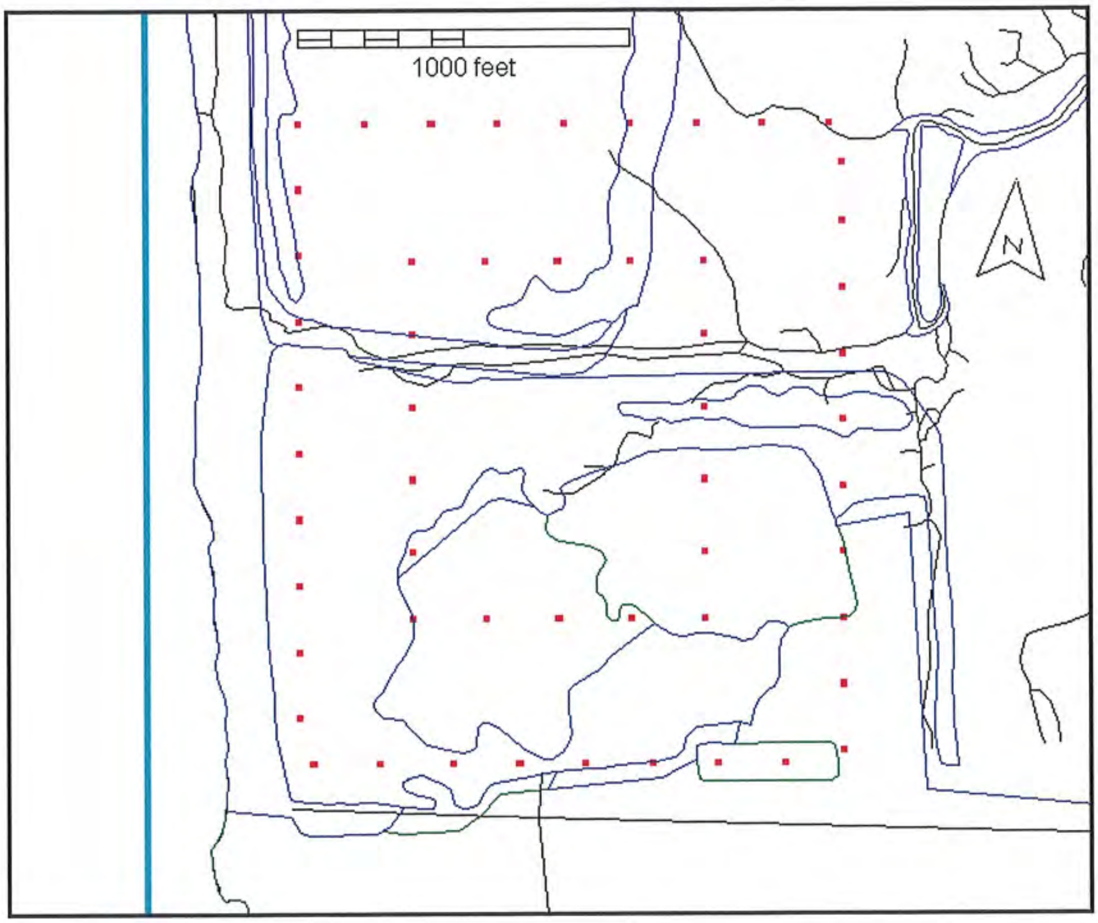


Figure B-26: Locations of simulated dewatering wells in the lower Vincentown unit. The locations of the wells follow the alignment of the barriers, and are about 200 feet apart. This depth is compatible with depth of deep dewatering wells employed at the Hope Creek unit dewatering. The wells are represented using the drain package in MODFLOW as they were for the alluvial and upper Vincentown aquifers.

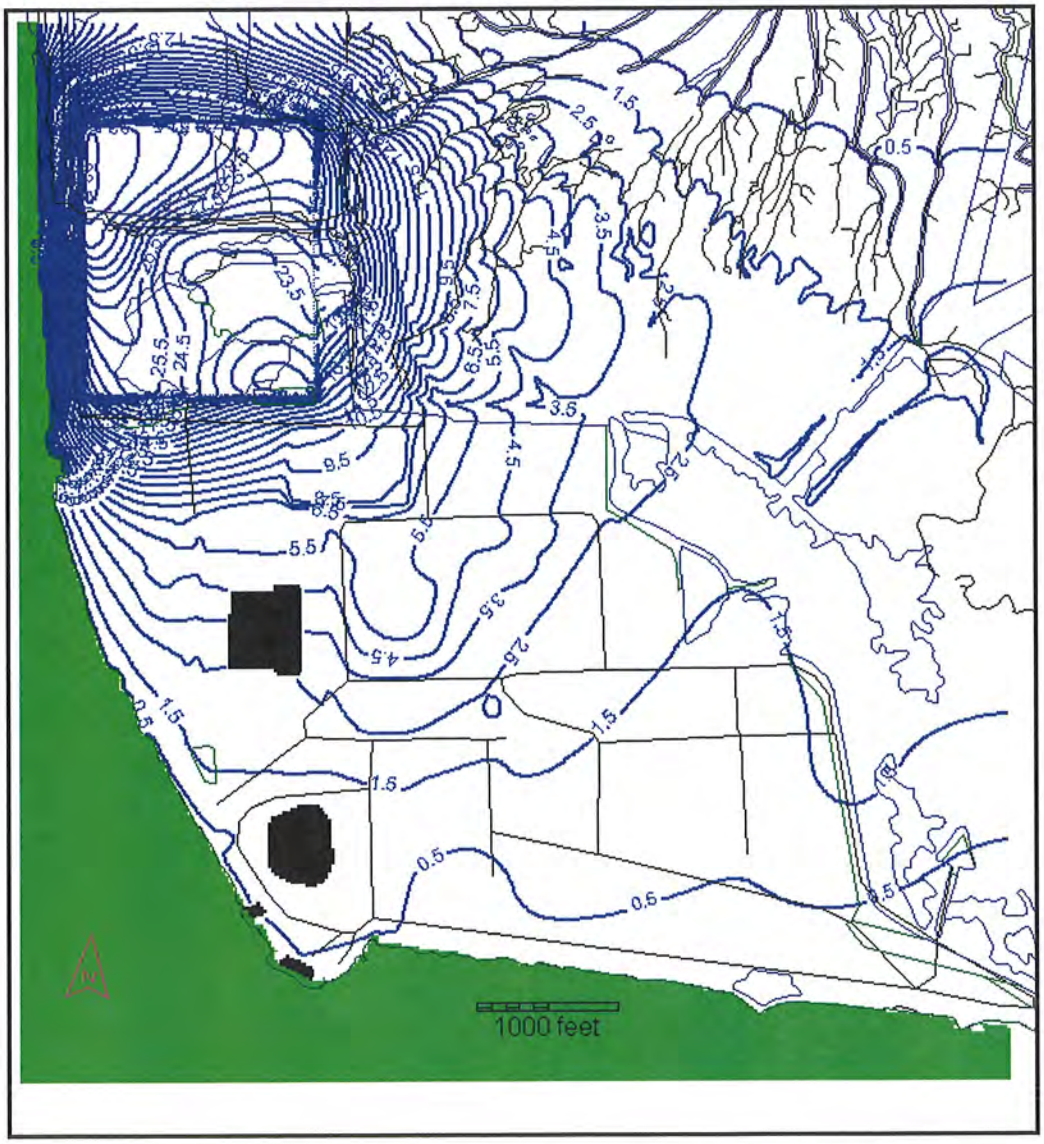


Figure B-27: Contours of drawdown (ft below static condition) at one year of dewatering in fills.

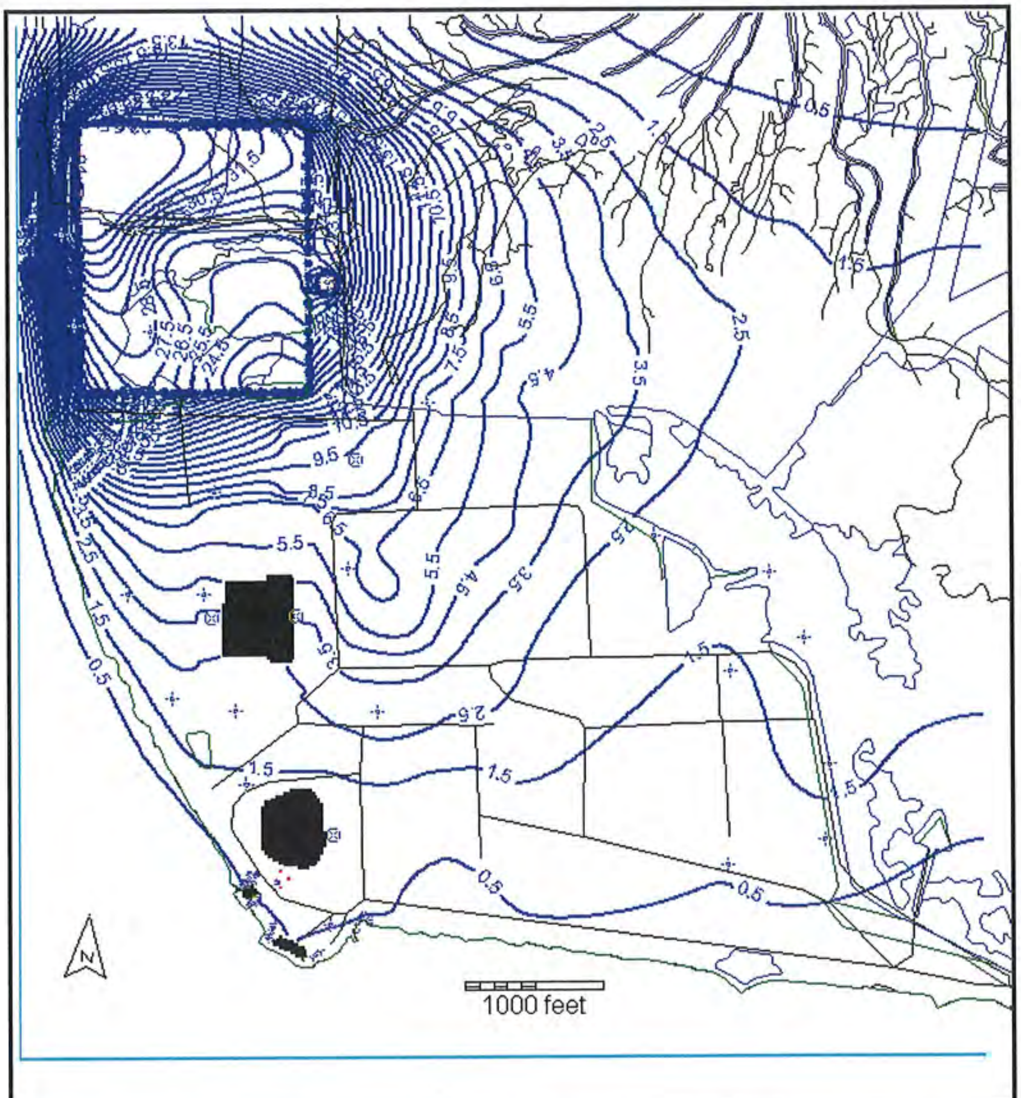


Figure B-28: Contours of drawdown (feet below static condition) at one year of dewatering in the alluvium.

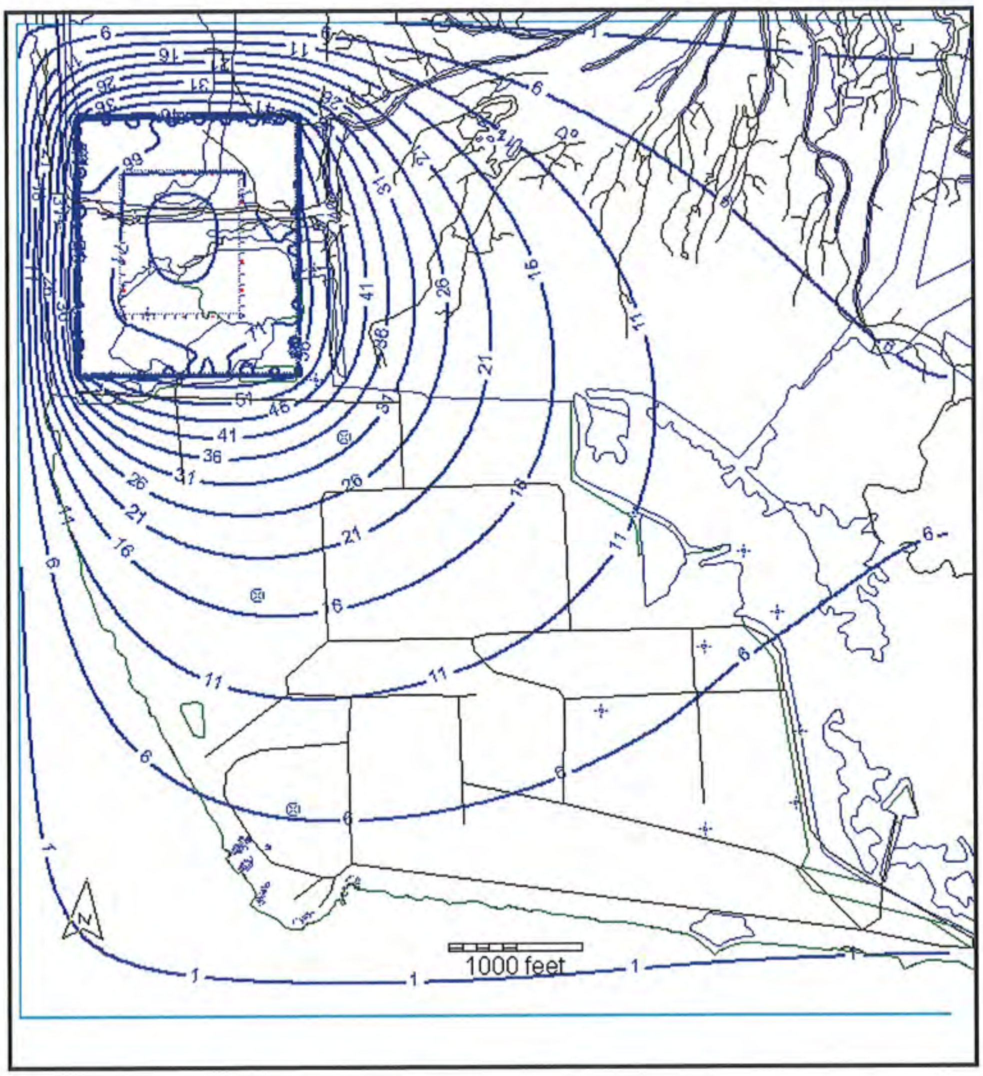


Figure B-29: Contours of drawdown (feet below static condition) at one year of dewatering the upper Vincentown.

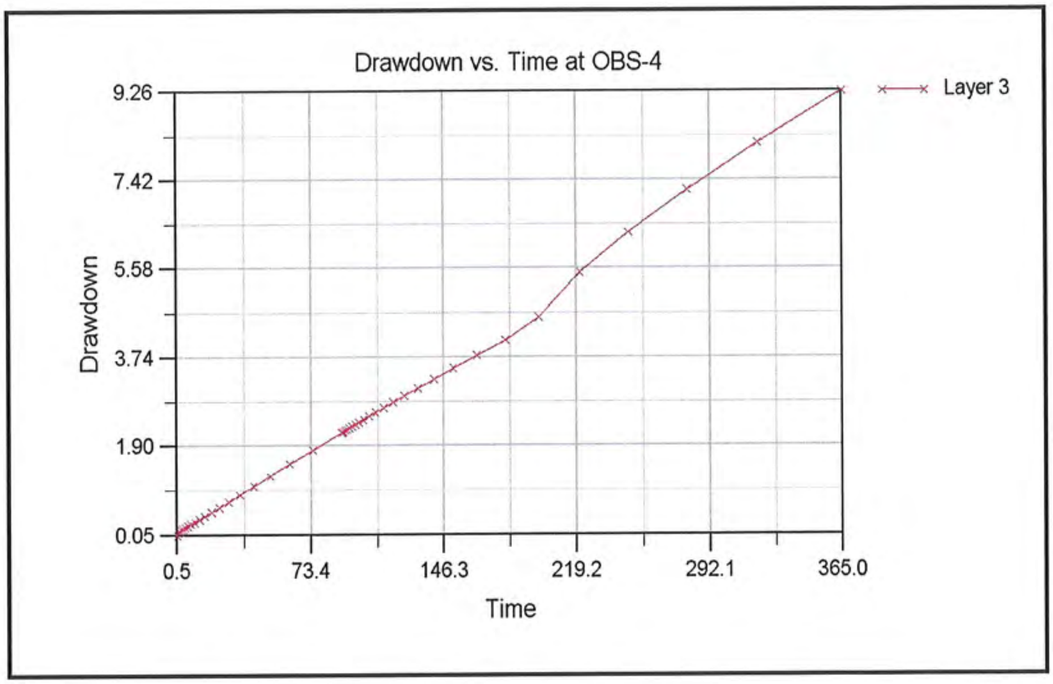


Figure B-30: Hydrograph - Simulated drawdown feet below static condition in the vicinity of the Hope Creek cooling tower in the alluvium. OBS-4 is a hypothetical observation point used to create the hydrograph for this location. Units are feet for drawdown and days for time.

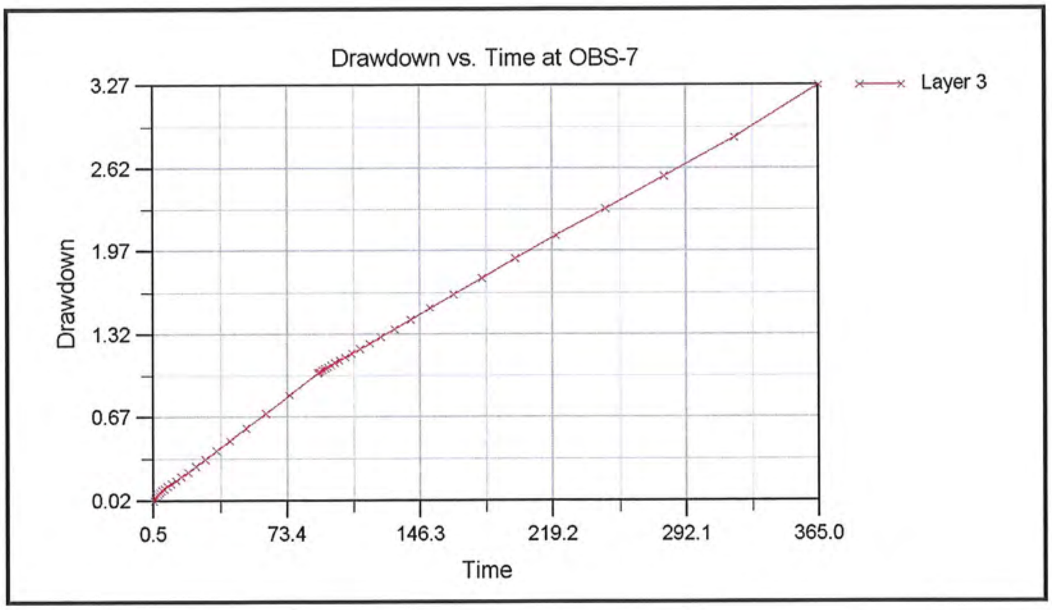


Figure B-31: Simulated drawdown (ft below static condition) in the vicinity of Hope Creek Unit 1 in the alluvium. OBS-7 is a hypothetical observation point used to create the hydrograph for this location. Units are feet for drawdown and days for time.

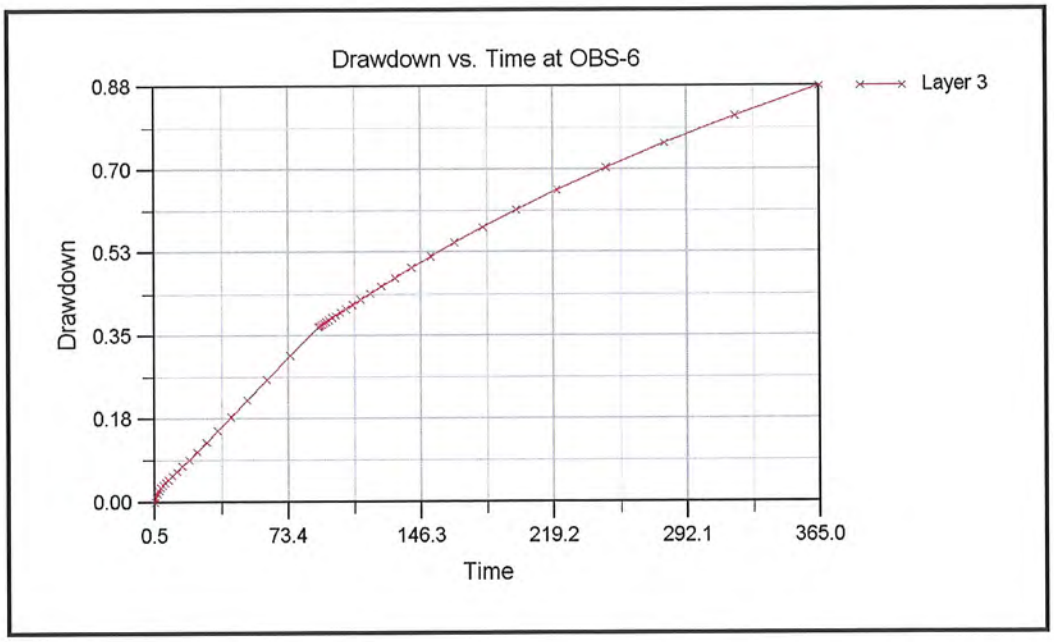


Figure B-32: Simulated drawdown (feet below static condition) in the vicinity of Salem Units 1 and 2 in the alluvium. OBS-6 is a hypothetical observation point used to create the hydrograph for this location. Units are feet for drawdown and days for time.

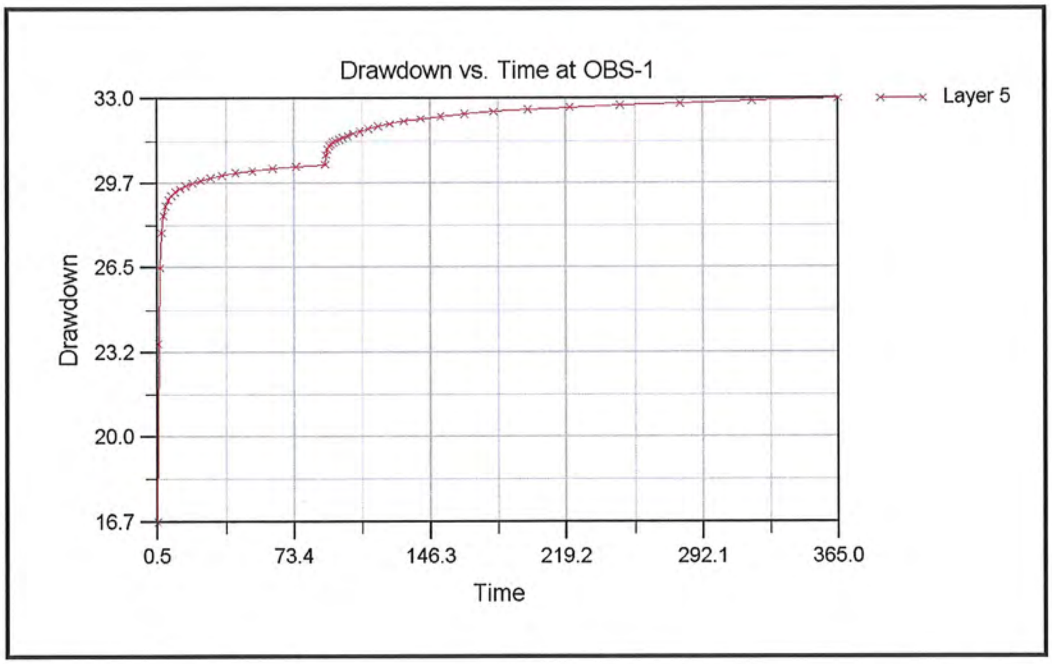


Figure B-33: Simulated drawdown (feet below static condition) in the vicinity of the cooling tower in the Vincentown. OBS-1 is a hypothetical observation point used to create the hydrograph for this location. Units are feet for drawdown and days for time.

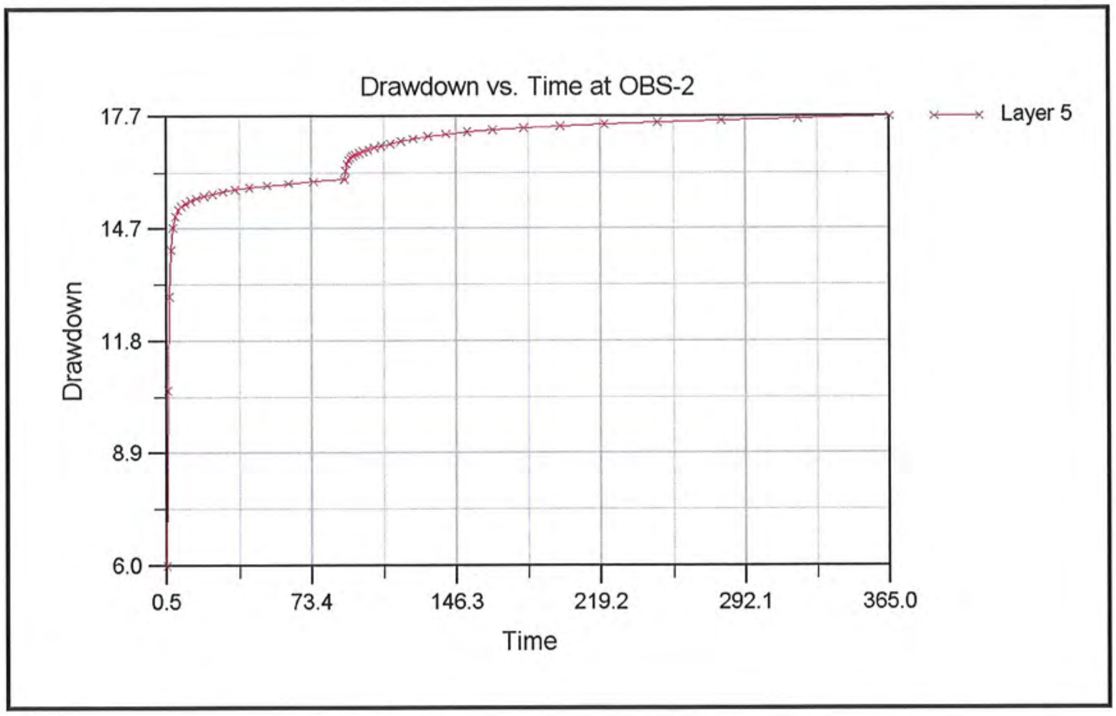


Figure B-34: Simulated drawdown (feet below static condition) in the vicinity of the Hope Creek Unit 1 in the Vincentown. OBS-2 is a hypothetical observation point used to create the hydrograph for this location. Units are feet for drawdown and days for time.

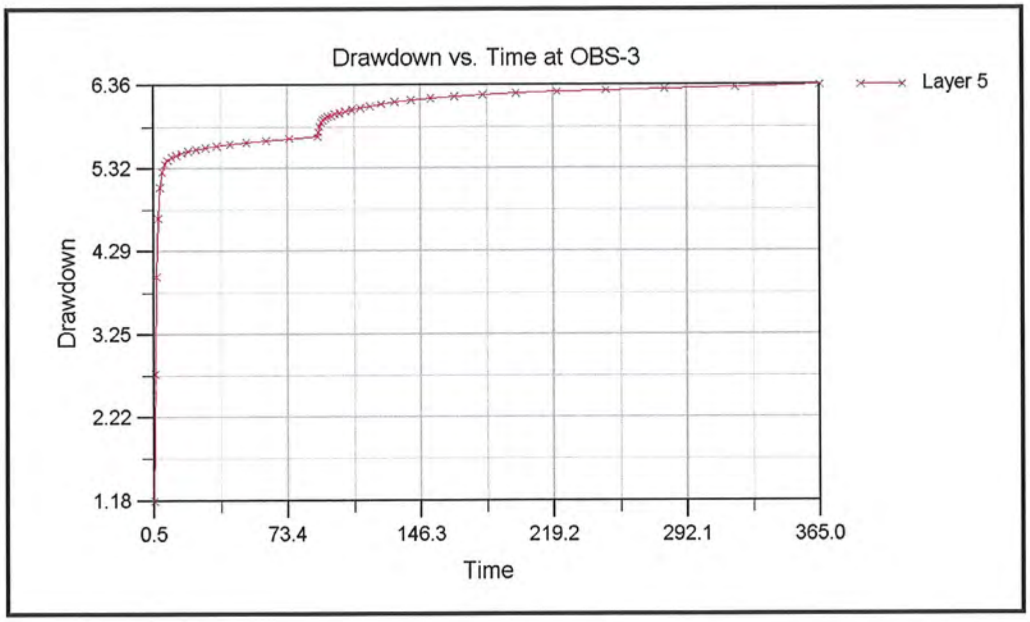


Figure B-35: Simulated drawdown (feet below static condition) in the vicinity of the Salem Units 1 and 2 in the Vincentown. OBS-3 is a hypothetical observation point used to create the hydrograph for this location. Units are feet for drawdown and days for time.

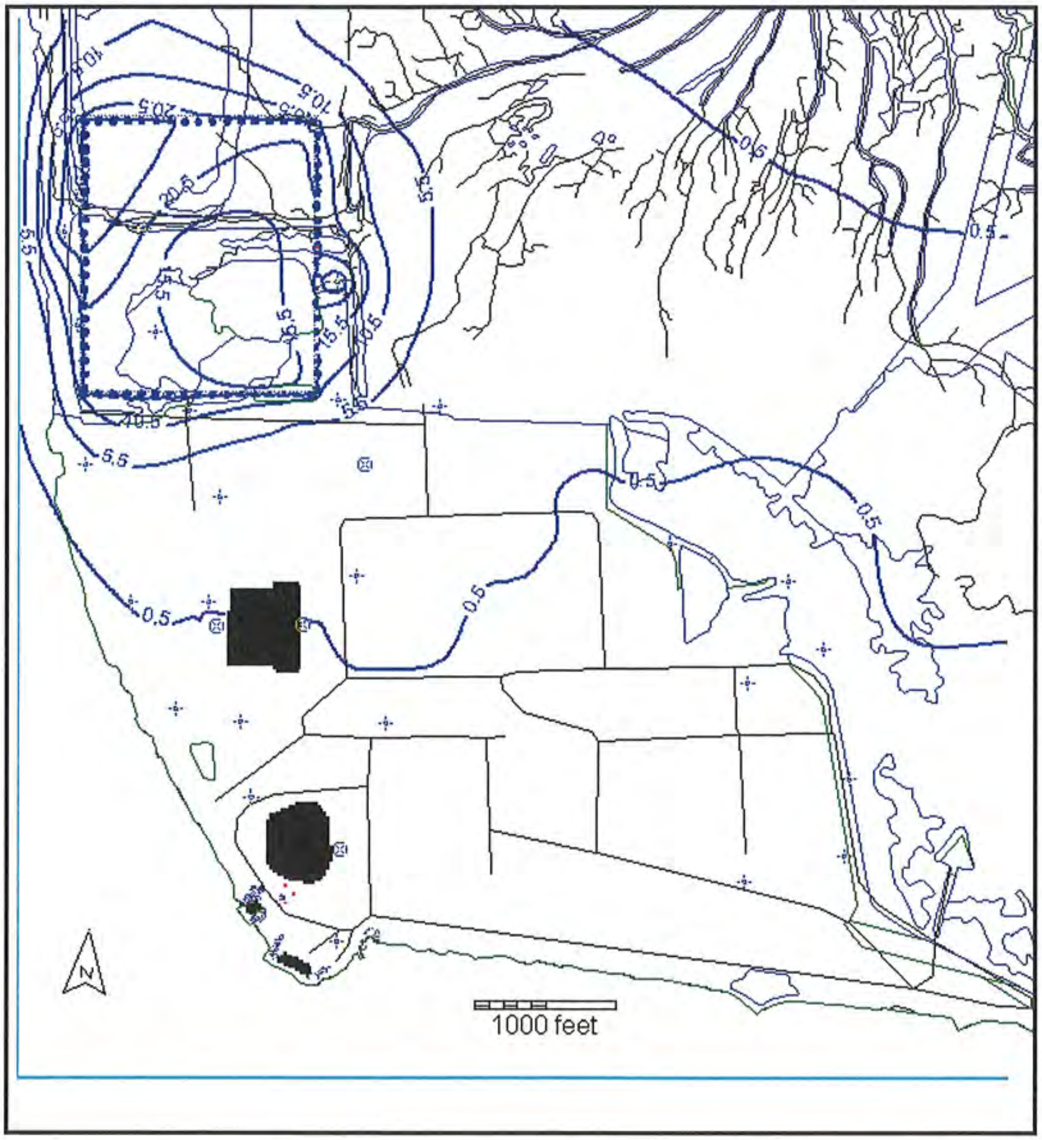


Figure 36: Contours of drawdown (feet below static condition) at one year of dewatering in the alluvium – low vertical hydraulic conductivity in the Kirkwood. In this sensitivity run, the vertical hydraulic conductivity of the Kirkwood aquitard has been decreased to 0.001 feet per day.

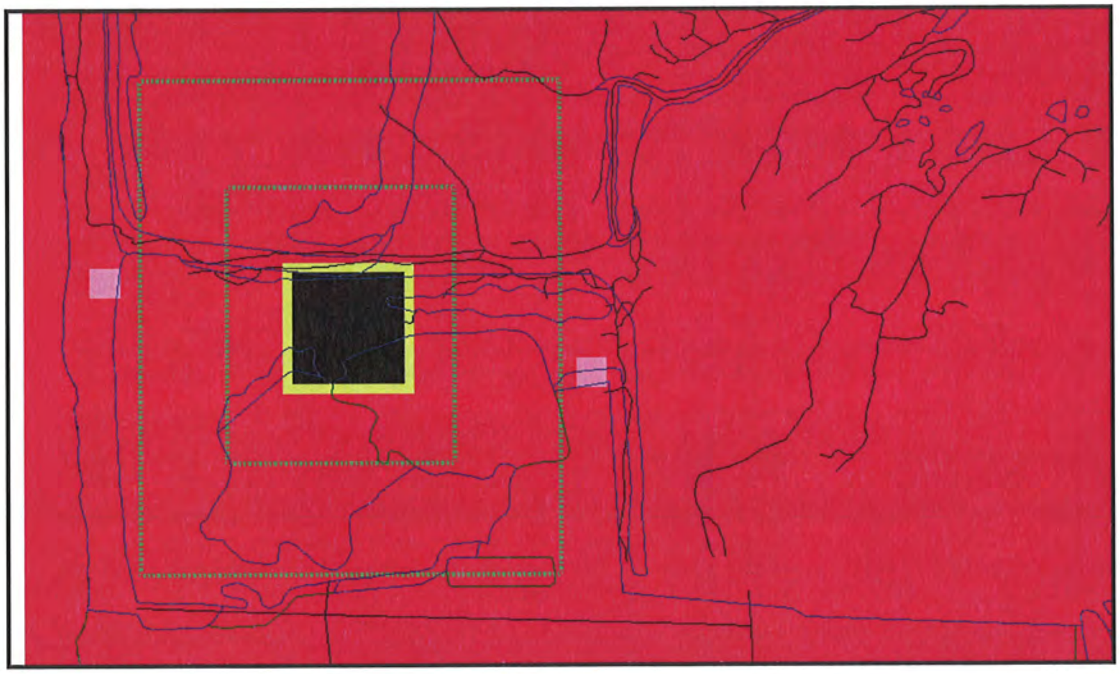


Figure B-37: Extent of assumed breach in the Kirkwood for assessing hydrostatic loading. The light yellow band around the black square illustrates the gap in the Kirkwood aquitard created to accommodate the nuclear island (a 440-foot square area). The larger yellow line rectangles show the location of the inner and outer soil retention barriers.

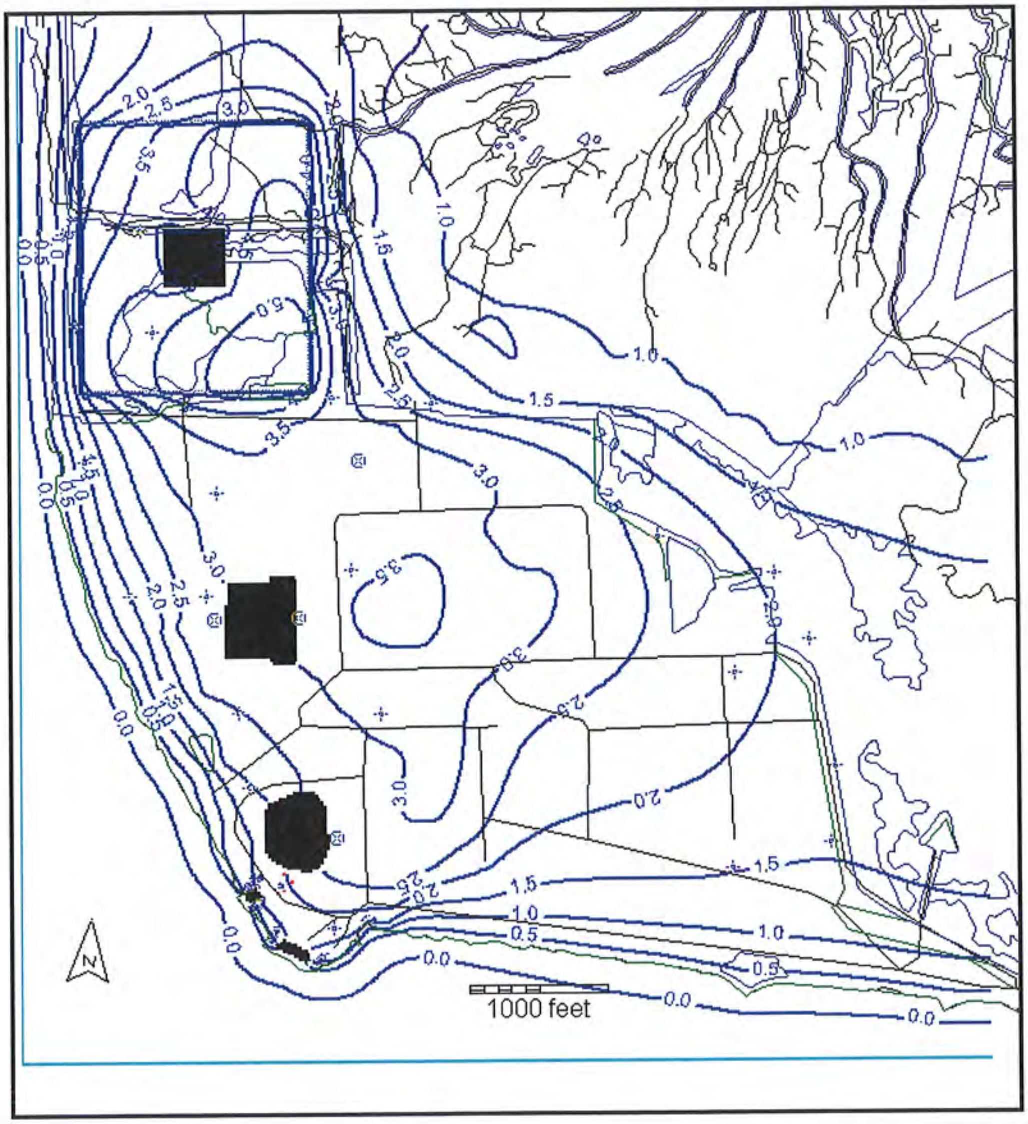


Figure B-38: Simulated post-construction piezometric heads (feet NAVD88) in the alluvium or structural fill. The breach in the Kirkwood at the site of the new unit is as shown on Figure B-37. At existing site structures, the maximum estimated hydrostatic loading under average conditions is about 3.5 feet NAVD88. Within the soil retention barrier, heads approach 5.3 feet NAVD88.

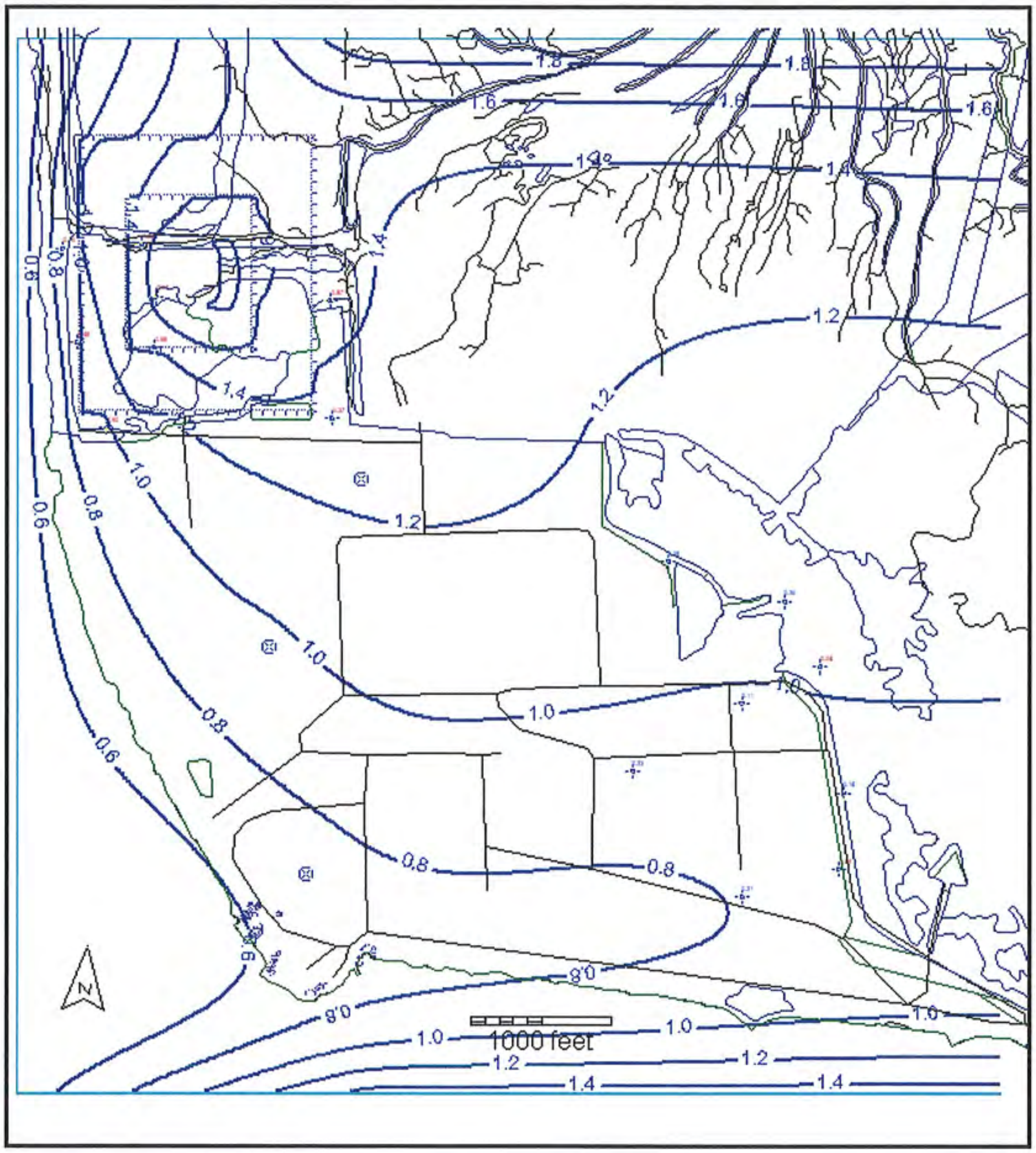
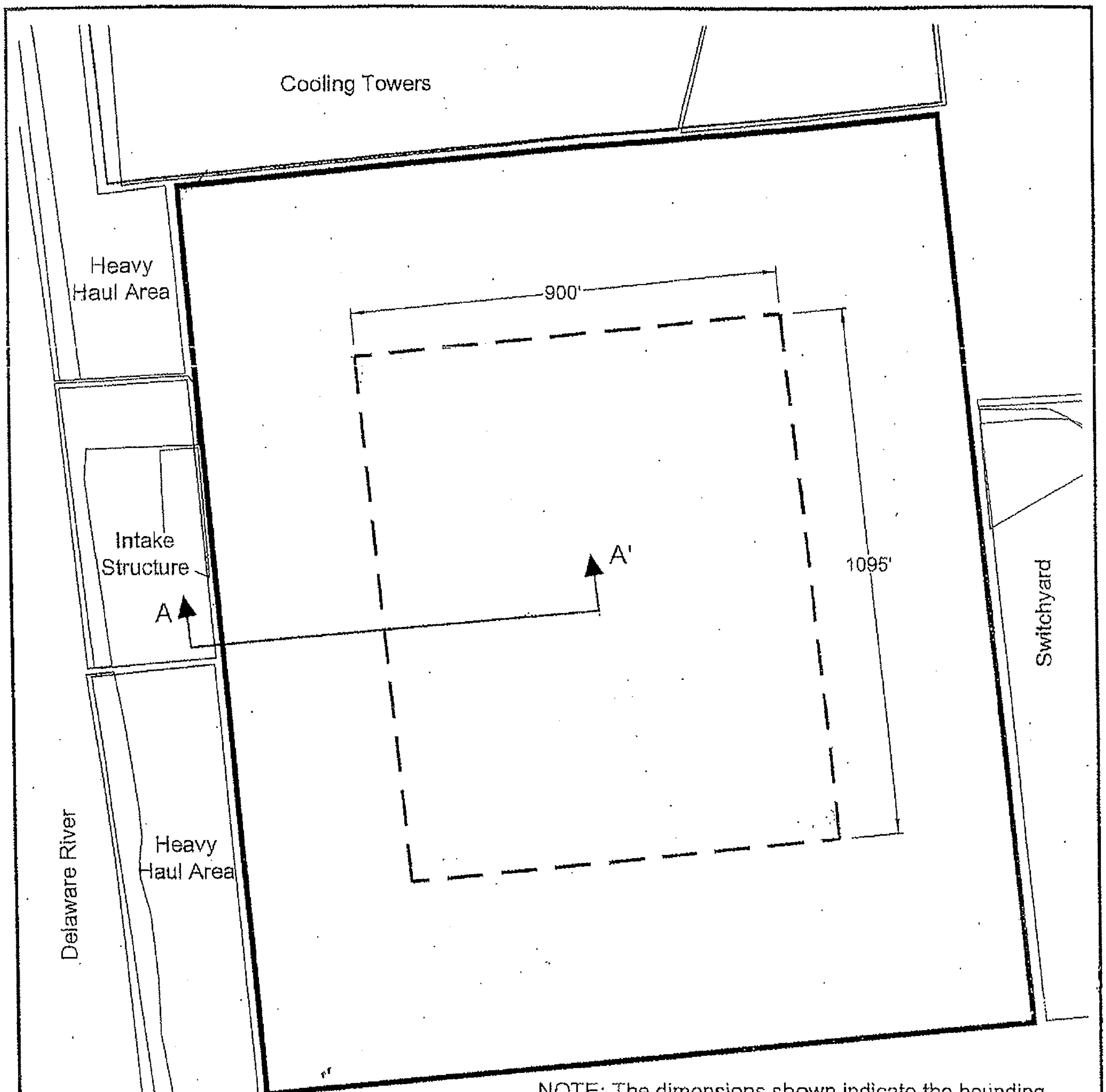


Figure B-39: Simulated post-construction piezometric heads (feet NAVD88) in the upper Vincentown. The breach in the Kirkwood at the site of the new unit is as shown on Figure B-37. Differences in heads across most of the model domain from pre- to post-construction are slight.

Attachment C

Figures Depicting Bounding Conditions for the Proposed Excavation and Dewatering



To Salem and
Hope Creek Units

NOTE: The dimensions shown indicate the bounding excavation extent for safety-related structures at the top of the competent layer based on information in Table 2.5.4.5-1. They may not represent the actual dimensions of the excavation limits, or their spatial relationship to each other and to the Power Block.

LEGEND

Power Block - Limit of Mass Excavation for General Power Block Grading

Approximate Lateral Limits of Excavation to top of competent layer for PPE Safety - Related Structures

N W E S

0 150 300 Feet

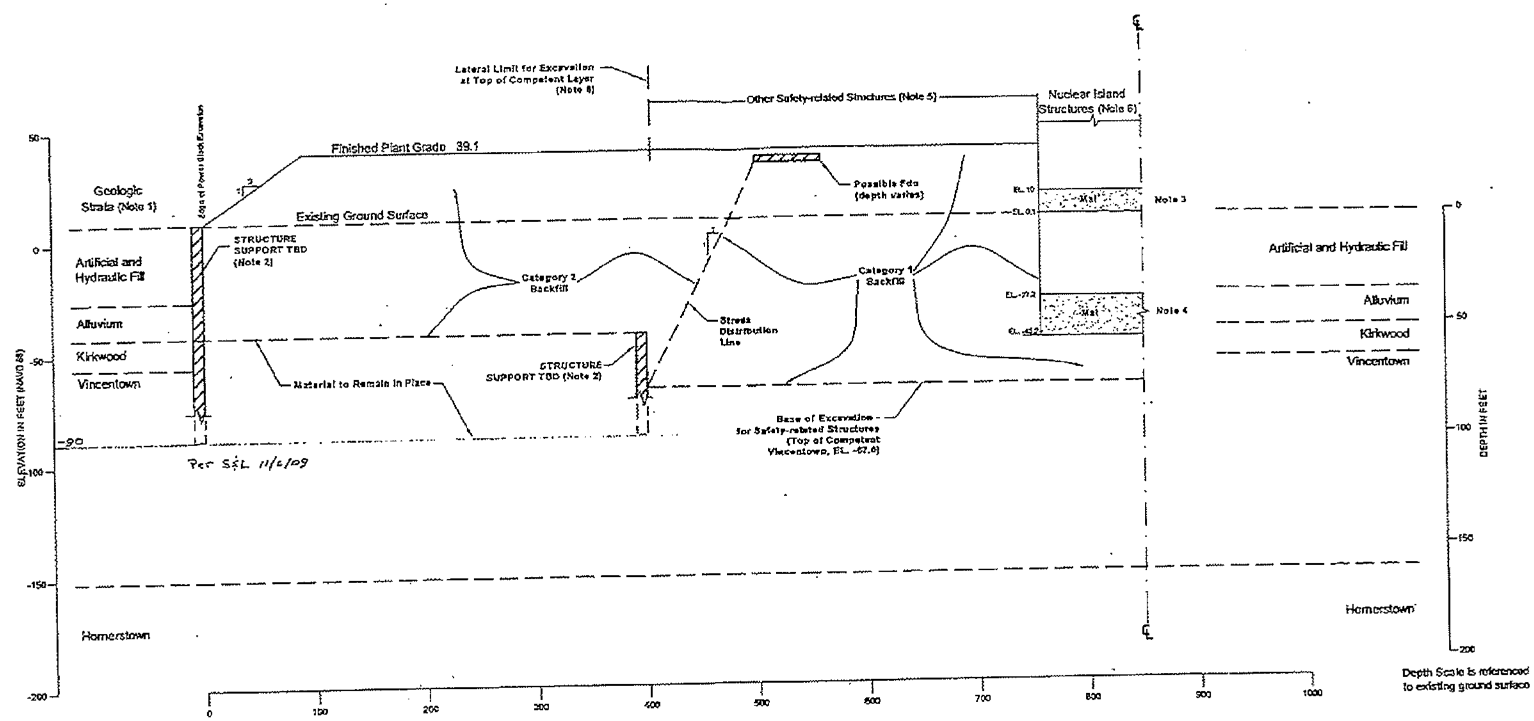
PSEG Power, LLC

PSEG SITE ESPA

Conceptual Lateral Limits of Excavation

FIGURE 2.5.4.5-1

Rev 0



Notes:
1. Geologic Layers Based on Boring NB-1.
2. Structural support for excavation may consist of cellular cofferdams, sheet pile/tie-back walls or other methods as evaluated in the COLA.
3. Upper bound nuclear island mat (category 1 backfill below extends to top of competent Vincentown).
4. Lower bound nuclear island mat (category 1 backfill below extends to top of competent Vincentown).
5. Boundary of lateral extent of safety-related structures considering all technologies.
6. Width of nuclear island varies.
7. Category 1 backfill is placed below and against walls of Safety-Related structures. Category 1 backfill may include concrete fill, roller-compacted concrete or compacted granular material. Category 2 backfill is placed outside Safety-Related structure areas and may consist of Category 1 materials, materials removed from the excavation or other materials meeting engineering requirements.
8. The lateral excavation limit shown is determined at the top of the competent Vincentown formation and encompasses the estimated area of stress distribution below foundations.

HORIZONTAL SCALE - IN FEET
100' 50' 0 100' 200'

VERTICAL SCALE - IN FEET
50' 25' 0 50' 100'

PSEG Power, LLC

PSEG SITE ESPA
Part 2, Site Safety Analysis Report

Conceptual Excavation
Section A-A'
FIGURE 2.5.4.5-2
Rev 0

ATTACHMENT D

Hand Calculation for Dewatering Well Rate Balance

MACTEC

MACTEC Engineering and Consulting, Inc.
511 Congress Street, P.O. Box 7050
Portland, ME 04112-7050

JOB NO. 6468-08-2251	SHEET 1 OF 1
PHASE	TASK GWRPT
JOB NAME PSEG Salem ESP	
BY R. Lewis	DATE 1/11/10
CHECKED BY NSC	DATE 1/12/10

Hand Calculation for Dewatering Well Rate Balance

This calculation sums and compares simulation dewatering rates for wells closer to the model boundaries with those further away to see if the proximity to the model boundaries has an overly great influence on pumping rates and possibly the projected drawdowns at safety-related structures.

The following well rates are for the end of the 365-day simulation period and are in units of cubic feet per day. The rates are summed using the mass balance/window tool in Groundwater Vistas and transcribed here.

Layer	North	South	West	East	
Layer 3	1597	981	3023	880	
Layer 5	36969	21013	42152	26891	outer wells
	3769	1259	3182	2426	inner wells
Layer 6	106976	105251	141316	122022	outer wells
	39524	37693	52145	44404	inner wells
Totals	188835	166197	241818	196623	

North vs. South

Fraction North = 188835/(188835+166197) = 0.53

West vs. East

Fraction West = 241818/(241818+196623) = 0.55