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Comprehensive Groundwater Model Report, U.S. Naval Weapons Industrial Reserve Plant/ Northrop Grumman, Bethpage, New York

ARCADIS

Infrastructure, buildings, environment, communications

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Comprehensive Groundwater Model Report, U.S. Naval Weapons Industrial Reserve Plant/Northrop Grumman, Bethpage, New York

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1. Introduction

ARCADIS, on behalf of the Engineering Field Activity Northeast, Naval Facilities Engineering Command, has prepared this report to provide a single reference document regarding groundwater modeling efforts conducted at the U.S. Naval Industrial Weapons Reserve Plant/ Northrop Grumman facility in Bethpage, New York. The goal of this report is to provide a compilation of key modeling reports that serve to chronicle groundwater flow and contaminant transport modeling efforts in this region. The text of this report is not intended to be a full description of all modeling to date, but rather to provide the goals and rationale for the various modeling efforts and brief conclusions from each. For completeness, however, four of the "key" reports, in their entirety are included as Appendices A through D and are titled as follows:

- Groundwater Flow Model, Northrop Grumman Corporation, Bethpage, New York (October, 1997)
- Updated Northrop Grumman Regional Groundwater Flow and Contaminant Transport Model Report, Northrop Grumman Corporation, Bethpage, New York (October, 2002)
- GM38 Area Remedial Design Modeling Results, Northrop Grumman Regional Groundwater Model, Northrop Grumman Corporation (December, 2002)
- Groundwater Modeling in Support of Determining Locations and Screen Zones for Outpost Monitoring Wells, Northrop Grumman Corporation (December, 2002)

The first known and documented modeling effort specific to this area was conducted by the U.S. Geological Survey in 1992. Details of that effort can be found in the U.S.G.S. Water-Resources Investigation Report 92-4148, titled, "Three-Dimensional Advective Transport of Volatile Organic Compounds in Groundwater Beneath an Industrial/Residential Area of Nassau County, New York".

2. Groundwater Flow Model

In 1997, Northrop Grumman Corporation (formerly Grumman Corporation) contracted ARCADIS (formerly Geraghty & Miller, Inc.) to develop a tool that could assist in the understanding and evaluation of groundwater flow conditions at the U.S. Naval Weapons Reserve Industrial Plant/Northrop Grumman Corporation Facility and surrounding area. The tool would also be used to assess and evaluate potential groundwater remedial scenarios. Introductory text from the 1997 Groundwater Flow Model Report (Appendix A) states:

> *The groundwater system at, and in the vicinity of the Bethpage sites has been designated as a "sole source" aquifer system whereby all major aquifers are considered as a single groundwater resource. Within this hydrogeologic setting, plans for groundwater remediation and water-supply activities must consider the effects of such actions on the groundwater system as a whole. Failure to adopt such an integrated approach risks expending remedial effort without the beneficial result of maintaining a high potable yield from the aquifer for water-supply purposes. The "systems approach," whereby the complexities of the groundwater system are evaluated as intricately related processes, will therefore be used in the modeling effort to allow for assessment of the effects of various remedial scenarios and water-supply alternatives on the groundwater resource. The three-dimensional groundwater flow model will be used as a tool for evaluation of these scenarios and alternatives. The model will be the foundation on which evaluations at both the regional and local scales will be made.*

The objectives of the above report were to document the construction and calibration of the groundwater flow model, and to present the output of the simulation of the groundwater flow regime under calibrated, steady-state conditions. The goal of the report was not to document remedial options.

The finite-difference grid developed after careful consideration of project goals and the factors discussed above consists of 104 rows, 68 columns, and eight layers. The model simulates regional groundwater flow in three dimensions over an area approximately 32,000 feet from north to south and 21,000 feet from west to east. The finest grid resolution is generally used on-site with lateral grid cell dimensions of 150 by 150 ft to enhance computational accuracy and produce results at the desired level of detail. The emphasis on fine-scale discretization on-site and in areas immediately to the south corresponds to critical areas with respect to model uses.

The groundwater flow model was constructed to simulate groundwater flow throughout the entire saturated thickness of the Upper Glacial and Magothy aquifers. As such, the aquifer system was divided into eight layers of grid cells in the vertical direction. Vertical discretization was determined through careful consideration of the vertical distribution of calibration target wells, vertical distribution of pumping stresses, adequate vertical gradient resolution, and major hydrostratigraphic contacts.

Model Layers 1 and 2 generally correspond to the Upper Glacial aquifer. Model Layer 3 is generally representative of the upper portion of the Magothy aquifer. Model Layers 4, 5, and 6 correspond to the mid-Magothy aquifer. Model Layer 7 corresponds to the lower portion of the mid Magothy. Model Layer 8 is representative of the basal Magothy and has a constant thickness of approximately 70 feet. The bottom of the layer coincides with the upper surface of the Raritan Confining unit. For additional details regarding model descretization, boundary conditions, parameter zonation, onsite and offsite pumpage and recharge, etc. see Appendix A

The groundwater flow model was calibrated to steady-state average groundwater conditions represented by groundwater levels measured during two synoptic water-level events (Spring [April] and Fall [September] of 1993). The data for each observation well was averaged to represent conditions under pumping conditions for the calibration period. The early spring and early fall periods are considered the periods of light and heavy on-site pumping. By averaging the data from these periods, the calibration targets are representative of average conditions that would be observed under average pumping. This approach therefore, is also consistent with the approach of applying average pumping rates to the supply wells.

The model contains a total of 129 head calibration targets. Although the targets are not evenly distributed throughout the entire model domain, they are widely distributed nonetheless, and they thoroughly cover the areas of greatest concern. Vertically, the majority of head calibration targets (106 of 129) are located within the Upper Glacial and upper portion of the Magothy. Within the Upper Glacial and upper Magothy, 59, 11, and 36 calibration targets are located in Model Layers 1, 2, and 3, respectively. Of the 106 calibration targets in the Upper Glacial and upper Magothy, 63 of 106 are located on-site. Within the Magothy aquifer, 8, 3, 4, 6, and 2 calibration targets are located in Model Layers 4 through 8, respectively. Of the 23 calibration targets in the middle and basal Magothy aquifer, 8 of 23 are located on-site (see Figure 5-2 in Appendix A for locations of head calibration targets in the Magothy aquifer). Four criteria were considered for the steady-state calibration:

1. Simulated flow patterns will adequately reproduce the flow patterns observed in the field (i.e., groundwater flow lines inferred from groundwater level contours).

2. The average of residuals (residual mean and absolute residual mean), where a residual is defined as the difference between an observed and a simulated water level, will be within 5 percent of the range in target heads.

3. The variation of residuals (residual standard deviation) will be within 10 percent of the range in target heads.

4. The distribution of residuals within the model will not show any spatial bias.

The criteria listed above were satisfied during model calibration. See Appendix A for details regarding achieving the four criteria stated above.

The model report also includes detailed sections regarding model sensitivity testing and model verification runs.

Major conclusions listed in the report are as follows:

- The modeling effort and model design were structured to address critical groundwater issues at and around the Northrop Grumman site. The modeling effort was intended to develop and construct a three-dimensional groundwater flow model that will be used as a tool for evaluation of various scenarios and alternatives at varying scales of interest.

- The Upper Glacial aquifer has the highest and greatest range of estimated values for hydraulic conductivity due to the variation in deposits encountered (from lower permeability morainal deposits to outwash materials). The Magothy aquifer exhibits less variation in hydraulic characteristics than the Upper Glacial aquifer, but is less permeable and exhibits a higher degree of anisotropy due to stratification of the Magothy deposits.

- Artificial stresses imposed on the aquifer system act as internal boundaries and include pumping wells and recharge basins. The horizontal direction of groundwater flow at Northrop Grumman is locally influenced by pumping supply wells and recharge basins. Pumping wells locally depress the water table, while recharge basins may produce local groundwater mounding.

- The modular finite-difference groundwater flow code, known as MODFLOW, was selected for the groundwater flow model. The goal of model design and construction was to provide a consistent numerical representation of the conceptualized groundwater system.

- Discretization of the model domain into a finite-difference grid was conducted after careful consideration of project goals. The grid design also considered several additional factors, such as the level of detail of the data available to define the hydrogeologic framework and hydraulic characteristics, the ability to define and represent boundary conditions and stresses, and the amount and distribution of hydraulic head data for calibration. The grid design addressed all three dimensions by also including a vertical discretization scheme that resulted in eight model layers.

- Appropriate mathematical boundary conditions, based on actual groundwater system boundaries where possible, were specified to define the lateral, upper, and lower boundaries of the flow model. Active pumping wells simulated in the calibrated model included industrial wells located on-site, and public water supply wells located off-site within the model domain. Sources of artificial recharge simulated in the calibrated model included on-site recharge basins, which return much of the supply water to the groundwater system.

- The groundwater flow model was calibrated to steady-state groundwater conditions represented by average 1993 flow conditions. Observed measurements considered as calibration targets included water levels from 129 on-site and off-site wells located within different portions of the aquifer system. In addition, specific water-level calibration criteria were considered, including reproducibility of observed flow patterns (i.e., water level contours) as well as several statistical measures (residual mean, absolute residual mean, residual standard deviation, and distribution of residuals). To increase the level of confidence in the models' ability to simulate the real system, a verification simulation was run. The model successfully simulated observed water levels under a set of hydraulic conditions that were different than those used in the calibration run.

- In conclusion, the resultant model design provides a consistent numerical representation of the conceptualized groundwater system for evaluation of potential impacts on the aquifer system. In addition, because the model was constructed using MODFLOW, widely used transport codes can be readily implemented with additional input for evaluation of advective transport or general evaluations of solute transport.

The completed model was later used for onsite containment system design and testing of various remedial alternatives presented in the Feasibility Study Report. Those alternatives (not included in this report) can be found as Appendix B ("Simulation of Groundwater Flow and Contaminant Transport") of the October 2000 Groundwater Feasibility Study, Grumman Aerospace-Bethpage, NY Site #130003BA and Naval Weapons Industrial Reserve Plant Bethpage, NY Site #130003B.

3. Updated Groundwater Flow and Contaminant Transport Model

ARCADIS had prepared this report (full report included as Appendix B) to document modifications and updates to the Regional Groundwater Flow and Contaminant Transport Model developed for the Northrop Grumman Corporation Site in Bethpage, New York. The updated model is based on the previously constructed flow model documented in Appendix A and described in Section 2 above. This letter report (included as Appendix B and summarized below) describes the differences between the updated model and the 1997 flow model, the basis and intended purpose of the updated model, and the information used to develop the updated model.

The conceptual model for the updated model is consistent with the conceptual model upon which the 1997 flow model is based. Please refer to the October 1997 report (Appendix A) for a detailed description of the conceptual groundwater model.

The updated model was to be used to conduct steady state groundwater flow and contaminant transport simulations for the following purposes:

- To assess the migration of the off-site portion of the TVOC plume associated with the Northrop Grumman and Navy NWIRP sites.

- To support the selection of outpost monitoring well locations and screen settings.

- To support off-site remedial system design via determination of the number, locations, screen settings, and extraction rates of remedial wells, locations of treated water discharge points, and approximate influent concentrations over time at the treatment facility, all in the context of achieving specific remedial goals.

Simulations of groundwater flow were conducted using the modular finite-difference groundwater flow code (MODFLOW) developed by the United States Geological Survey (1988). Contaminant transport simulations were conducted using MT3D, a modular three-dimensional transport model developed for the U.S. Environmental Protection Agency in 1990. MT3D was developed to use MODFLOW simulation output as the basis for advective transport.

The technical objectives defined in the 1997 flow model report are consistent with the objectives of the model update effort on the regional scale. On the site-specific scale, however, the updated model represents a significant improvement with respect to model discretization. Details regarding model discretization and calibration of the updated model, and how it differs from the 1997 model are provided below.

Consistent with the development of the 1997 model, project goals, available data, and other factors affecting the model design were considered in the model update. The updated model was expanded to cover a larger area and consists of 146 rows, 180 columns, and 11 layers. The 1997 and updated models have 56,576 and 289,080 model cells, respectively. The model has been designed to simulate groundwater flow in three dimensions over an area approximately 42,800 feet (north to south) by 29,000 feet (east to west). The finest grid resolution is generally used downgradient of the site with lateral grid cell dimensions of 100 by 100 feet to enhance computational accuracy and produce results at the desired level of detail. Fine-scale discretization downgradient of the site corresponds to critical areas with respect to model uses.

The increase in vertical discretization in the updated model (i.e., 8 layers in the 1997 model vs. 11 layers in the updated model) was based upon data collected from a series of vertical profile borings and monitoring wells installed downgradient of the site (since development of the 1997 model). The hydrogeologic data collected from these wells/borings supports the definition of additional model layers, as wells as changes to hydraulic conductivity zonation as discussed below.

In general, the top and bottom model boundaries (water table and Raritan Clay, respectively) were unchanged from the 1997 model; however, the elevation of the

Raritan clay had been lowered based upon data gathered from recently drilled vertical profile borings. The lateral model boundaries had been expanded primarily to the east and south of the site (in the direction of regional groundwater flow). The original model covered an area of approximately 25.2 sq miles, the updated model represents an area of approximately 44.5 square miles.

Hydraulic conductivity zonation was updated to reflect the presence of several low permeability zones not represented in the 1997 model. Specifically, data collected from the vertical profile borings drilled near BWD Plants 4 and 5 was used to update hydraulic conductivities in the vicinity of GM38.

The areal recharge rate was updated after reviewing precipitation records from January 1984 through November 2001 for the precipitation station at MacArthur Airport located in the Town of Islip, Long Island. A long-term average annual rate was established based on these data. The areal recharge rate in the updated model is 0.00588 feet per day (25.75 inches per year), consisting of fifty percent of the average annual precipitation, and 10% of the modeled municipal pumpage (representing leakage from both municipal supply systems and sewers).

Regional groundwater pumping (from both on-site remedial wells and off-site supply wells) and recharge to on-site basins (Plant 5 and South Basins) were updated as follows. Quarterly monitoring of the on-site Northrop Grumman OU2 Groundwater Remediation system provided extraction well pumping rates. These data along with discussions with Northrop Grumman personnel regarding future development of the site were used as the basis for the on-site pumping and recharge rates used for the calibration and predictive simulation. Off-site pumping rates were developed based on monthly pumping rates (on a well by well basis) provided by the water districts represented in the model. Average production rates for each of the municipal supply wells based on reported pumpage from January 1998 through June 2001 were developed and used in the model to represent the long-term steady state pumping stress (see Table 1 in Appendix B).

Procedures used for the steady state calibration of the updated model are unchanged from those used in 1997. Eighty one calibration targets (water levels) were used in the updated model. The specific calibration criteria were unchanged from those used in 1997. All criteria for assessing if model calibration is acceptable were satisfied.

Conclusions resulting from the model update are as follows:

- Updates and modifications to the 1997 groundwater model were successful.
- The changes enabled the model to be used for advective and solute transport analysis in key off-site (downgradient) areas.
- Specifically, the model is appropriately designed to address both remedial issues in the "GM-38 area", and outpost monitoring well issues related to public water supply wells located downgradient of the site.

4. GM38 Area Design Modeling

One of the purposes of updating the regional model (as described in the preceding section) was to provide a tool that could be used to evaluate remedial alternatives in the offsite GM38 Area. The purpose of the "GM38 Area Remedial Design Modeling Results" memo (Appendix C) was to document the work performed and results of groundwater modeling conducted in support of the Remedial System Design. The so-called GM38 Area is an area of elevated volatile organic compound (VOC) concentrations in groundwater in the vicinity of Monitoring Well cluster GM38. Monitoring Well cluster GM38 is located southeast of the Northrop Grumman facility in Bethpage, New York, between Bethpage Water District (BWD) Plant 4 (supply wells 6915 and 6916), and BWD Plant 5 (supply well 8004).

The goals of the GM38 Area Remedial System (the System) were to provide capture, contaminant mass removal, and treatment of VOCs in groundwater from the area of elevated concentrations in the vicinity of GM38. Specifically, this modeling effort focused on the capture and removal of groundwater with total VOC (TVOC) concentrations in excess of 1,000 micrograms per liter (µg/L), as is required under the Record of Decision (ROD). During this modeling effort, it was determined that the System could capture and remove groundwater with TVOCs down to the 500 µg/L level if the operational timeframe of the System was minimally extended. Therefore, the System described herein can focus on either the 1,000 µg/L or 500 µg/L TVOC level with a slightly longer period of operation required to remove TVOCs at and above 500 µg/L. The groundwater modeling effort documented in this memo was conducted to develop the remedial details (number of wells, their locations, depths, and pumping rates) necessary to achieve the System goals of capture and mass removal.

The design of the proposed remedial system summarized in this memo was based on the results of both groundwater flow, and solute transport modeling. Previously conducted solute transport modeling had predicted that without any remedial effort in the GM38 Area, supply wells of the BWD to the northeast and south would extract groundwater with VOC concentrations of up to 250 µg/L. The model also predicted that the area of elevated VOC concentrations was likely to disperse and impact several downgradient supply wells in the future. Based on this information, the following modeling effort was undertaken to develop a remedial system.

The groundwater flow model was used to track particles representing the leading edge of the 1,000 µg/L portion of the TVOC plume in model layers 5, 6, and 7 (the model layers that correspond to the depths where elevated concentrations have been locally observed) under steady state conditions. The particles were tracked (forward tracking) until they were either intercepted by nearby supply wells or remedial wells, or reached the end of the model domain. Simulated remedial well pumping rates and screen zone locations were optimized to capture (prevent downgradient migration) the TVOC plume at and above 1,000 µg/L.

Reverse particle tracking of particles started in the proposed remedial well screen zones was used to assess the capture zone resulting from the pumping of the simulated remedial wells. An evaluation of the particle paths indicate the source area of water to the proposed remedial wells under the simulated conditions. Additionally, the evaluation provides verification that the proposed well screen locations are appropriate to capture the 1,000/500 µg/L portion of the plume (based on the current pumping by nearby supply wells, and our understanding of contaminant distribution in the aquifer).

The following sections summarize model results following a series of particle tracking and solute transport simulations. The particle tracking and solute transport modeling was conducted in an iterative manner, ultimately leading to the proposed design described below. Although several proposed remedial well designs were simulated, they did not achieve the previously stated goals of plume containment and removal and are therefore not discussed here.

Based on the forward and reverse particle tracking described above, a 2-well remedial system was developed. The proposed screen zones and pumping rates for the remedial wells are detailed in Appendix C.

Under steady state conditions, particle-tracking results indicate that the proposed remedial system will prevent the downgradient migration of groundwater containing TVOC concentrations in excess of 1,000/500 µg/L

It is significant to note that the particle tracking evaluation only indicates the potential for groundwater at the plumes leading edge to reach a downgradient receptor, and does not quantify the concentration of TVOCs in the groundwater predicted to impact the well. Solute transport modeling is used to quantify the remedial systems effectiveness with regard to the removal of contaminants from the aquifer, and potential impacts of the VOC plume on nearby supply wells. The proposed systems effectiveness with regard to contaminant extraction was evaluated through a series of solute transport simulations as discussed below.

The proposed system is anticipated to operate for a limited time, as it is designed for the removal of the elevated contaminant mass resident in the aquifer near GM38, and not full plume remediation. As such, three thirty-year simulations were conducted to evaluate remedial well pumping periods of 5, 15, and 30 years. Two part simulations were used to evaluate the 5 and 15-year pumping periods; that is, the remedial wells were simulated to operate only during the first 5 or 15 years of the 30-year simulation. After the appropriate pumping period, the remedial wells were turned off, and the contaminant mass remaining in the aquifer was tracked for the remainder of the 30-year simulation.

A comparison of model predicted TVOC concentrations in remedial wells under the 5, 15, and 30-year pumping periods are shown in Appendix C.

At remedial wells, the model predicts that TVOC concentrations will fall below 100 µg/L after approximately 5 years of remedial system operation. However, following the cessation of pumping, concentrations are predicted to rebound to approximately 140 µg/L and 200 µg/L. Approximately 9 years later the model predicts that TVOC concentrations will fall below 100 µg/L in RW-1; at RW-2, TVOC concentrations fall below 100 µg/L in less than 3.5 years after the system is turned off.

In support of remedial system design efforts, peak TVOC influent concentrations were determined. Modeling results indicate that TVOC concentrations in groundwater will peak at system startup, with concentrations at RW-1 and 2 of approximately 950 and 1,000 µg/L, respectively. The model predicts influent concentrations will steadily decline.

At Bethpage Water District (BWD) Wells 4-1 and 4-2 (NYSDEC Well ID No. 6915 and 6916, respectively), the model predicts peak TVOC concentrations to occur within a half-year of the start of the simulations. At BWD 4-1, the model predicts a peak TVOC concentration of 97 µg/L, with concentrations subsequently declining and then remaining below 20 µg/L after approximately 2.5 years of remedial system operation. At BWD 4-2, the model predicted peak concentration was 182 µg/L, with concentrations then declining and remaining below 65 µg/L after 5 years of remedial system operation. At BWD Plant 5 (NYSDEC Well No. 8004), model predicted TVOC concentrations remain below 3 µg/L throughout the 30 years simulated regardless of the remedial system pumping period.

Although the effect of recharge on the performance of the currently proposed remedial system has not been evaluated, it was assumed that the recharge (to recharge basins or sumps) of treated groundwater would not adversely affect the performance of the proposed remedial system (as long as the recharge occurred at an appropriate distance from the remedial wells). This assumption is supported by in-house modeling previously conducted by ARCADIS, in which groundwater from the GM38 area was pumped, treated, and discharged (as recharge) to New York State Department of Transportation Basin No. 109, located adjacent to Route 135, approximately 2,700 ft south of the remedial system.

Following are recommended locations for extraction and recharge of groundwater, appropriate screen zones, and extraction and recharge rates.

Based on the results of the solute transport and particle tracking simulations described above, remedial well RW-1 should be drilled approximately 100 ft east and 200 ft south of the northern end of South Hermann Avenue and RW-2 should be drilled at the southern end of North Windhorst Avenue. While the modeling simulations indicated that screen zones for RW-1 and RW-2 of -260 to -340 ft msl (feet relative to mean sea level), and -350 to -430 ft msl, respectively (approximately 310-390 and 400-480 ft below land surface) were appropriate, vertical profiling of groundwater quality should be conducted while drilling the proposed remedial wells, and the results should be used in conjunction with the model results to select screen zones.

The proposed remedial system described above achieves the goals of capture and removal of groundwater with TVOC concentrations in excess of 1,000 µg/L or 500 µg/L.

5. Modeling Support for Outpost Monitoring Wells

Similar to using the model to assist in evaluating GM38 area issues (as described in Section 4.), a second purpose for updating the regional model (as described in Section 3.) was to provide a tool that could be used in support of determining locations and screen zones for outpost monitoring wells. The purpose of the memo attached as Appendix D, is to outline the process followed to select potential outpost monitoring well locations for several public water supply wells located south of the Northrop Grumman Corporation/Naval Weapons Industrial Reserve Plant sites in Bethpage, New York. The outpost monitoring wells will be used to monitor groundwater quality between the leading edge of the VOC plume and the supply wells potentially in the path of the plume. Well locations had been chosen to provide approximately 5 years notice to the water districts, specifically, the outpost monitoring well locations developed with this effort would enable detection of the groundwater plume at least 5 years before the supply wells have detections of VOCs.

Groundwater flow modeling with forward particle tracking was used to determine that the following supply wells downgradient of the leading edge of the plume have the potential to have VOC detections related to the plume: N5303 (Town of Hempstead [Levittown] Water District), N8480 and N9338 (New York Water Service), N6150, N4043, and N5148 (South Farmingdale Water District).

The model predicted time to VOC detections in supply wells resulting from the evaluation summarized in this memo is based on the assumption that the steady state groundwater flow conditions simulated by the model remain constant through time. Therefore, if significant changes to pumping rates are made in the supply wells downgradient of the plume, the flow field would change and the potential for VOC detections would require re-evaluation. Recall that the particle tracking evaluation only indicates the potential for groundwater at the plumes leading edge to reach a downgradient receptor. It does not quantify the concentration of VOCs in the groundwater predicted to reach the well. However, solute transport modeling (conducted by ARCADIS) has predicted that the following supply wells would have influent concentrations above 0.5 µg/L within 30 years as a result of the VOC plume; time to VOC detection is shown in parenthesis: N4043 (11 years), N6150 (4 years), N8480 (18 years), and N9338 (24 years).

Although groundwater flow modeling with forward particle tracking indicated that municipal supply wells N5303 and N5148 were potential receptors of the groundwater plume, solute transport modeling indicates that when the plume reaches these wells, influent concentrations will remain below 0.5 µg/L for the 30 year evaluation period. Nevertheless, to be conservative, ARCADIS has developed an outpost monitoring well cluster location and screen zones for supply well N5303. An outpost monitoring well location was not developed for supply well N5148 because it is located in the same well field as supply well N4043 and model results predict a VOC detection in N4043 approximately 15 years before a detection in N5148. For well fields with multiple supply wells (South Farmingdale Well Field 1 and New York Water Service Wells 3S and 4S), locations for outpost monitoring wells were developed for the supply well in the field where the model predicted the first VOC detection to occur.

Following the identification of supply wells with the potential to have VOC detections from the groundwater plume, and after determining the timing of the VOC detections with the model, the locations for placement of the outpost monitoring wells were defined both horizontally and vertically. In addition to being sufficiently distant from the supply well to provide a 5-year notification period, the wells were screened to detect the fastest moving portion of the plume that, based on model predictions, had the potential to cause VOC detections in the supply well. The following sections describe the procedure used to select the location and screen zone for each of the outpost monitoring wells.

Groundwater flow modeling with reverse particle tracking was used to define the appropriate distance upgradient of each supply well for the installation of the outpost monitoring well. Reverse particle tracking was used to define the capture zone resulting from the operation of each supply well, and to determine the distance from the supply well beyond which a particle of groundwater would travel for at least 5 years before reaching the supply well.

The results of the groundwater flow modeling with forward particle tracking were used to evaluate which portion of the plume moved fastest as it approached the municipal supply well. The layer through which the fastest moving portion of the plume traveled as it approached the well was selected as the primary horizon to be monitored for advanced warning of the approaching plume.

Based on the evaluation of the groundwater modeling, ARCADIS recommended:

- The installation of a total of four clusters of outpost monitoring wells. The clusters will consist of two or three monitoring wells, each targeting a specific portion of the aquifer.

- The installation of a three-well cluster to monitor groundwater upgradient of South Farmingdale's Well Field No. 1 (N4043, N5148, and N7377).

- Three, two-well clusters are recommended to monitor groundwater quality upgradient of South Farmingdale's Well Field No. 3 (N6150), the New York Water Service Well Field (N8480, and N9338), and the Town of Hempstead (Levittown) Well Field (N5303).

Figures and Tables showing locations and screen zone depths are included in Appendix D. When dealing with model generated travel times, the recommendations are conservative as the shortest time was always used in the decision making process.

6. Conclusions

Conclusions drawn from the modeling efforts are as follows:

- A three-dimensional groundwater flow model has been constructed that appropriately represents the hydrogeologic and hydrologic conditions at the Naval Weapons Industrial Reserve Plant/Northrop Grumman Facility and surrounding area.

- The model provides the appropriate level of detail regarding both horizontal and vertical groundwater flow to achieve the stated goals and meet the intended purposes of the model.

- The model was successfully calibrated and verified in 1997. The updated model had been successfully calibrated to a different set of hydrologic conditions.

- Groundwater particle tracking has successfully been used to evaluate potential flow paths of VOC impacted groundwater, evaluate capture zones of pumping wells, design remedial systems, and site monitoring and outpost monitoring wells.

- Contaminant transport modeling has been used to approximate the potential migration of VOC impacted groundwater. Influent concentrations expected at both remedial wells and public supply wells have been estimated.

- The model continues to be a valuable tool for use in evaluating various groundwater use pumping scenarios and guiding decision-makers in answering specific questions or taking specific action.

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Appendix A

Groundwater Flow Model,
Northrop Grumman Corporation,
Bethpage, New York

GROUNDWATER FLOW MODEL
NORTHROP GRUMMAN CORPORATION
BETHPAGE, NEW YORK

October 1997

Prepared for

Northrop Grumman Corporation

Prepared by
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88 Duryea Road
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GROUNDWATER FLOW MODEL
NORTHROP GRUMMAN CORPORATION
BETHPAGE, NEW YORK

October 31, 1997

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GROUNDWATER FLOW MODEL
NORTHROP GRUMMAN CORPORATION
BETHPAGE, NEW YORK

1.0 INTRODUCTION

Geraghty & Miller, Inc., on behalf of Northrop Grumman Corporation (formerly known as the Grumman Aerospace Corporation), has developed a three-dimensional groundwater flow model for the Northrop Grumman site and surrounding area. The model represents the culmination of years of investigative efforts and insights gained by numerous parties regarding the groundwater flow system beneath the Northrop Grumman site and surrounding area. This modeling effort was conducted in accordance with standard and accepted scientific and engineering practices for the development of groundwater flow models as documented and established by the U.S. Geological Survey (USGS) and the American Society of Testing and Material (ASTM).

The model has been thoroughly reviewed and used by numerous agencies and consultants for private parties, including: the New York State Department of Environmental Conservation (NYSDEC), the New York State Department of Health (NYSDOH), NUS Haliburton (consultant to the US Navy), Holzmacher, McClendon, and Murrel, P.C. (consultant to Bethpage Water District), and Leggette, Brashears, and Graham and Conestoga-Rovers and Associates (consultants to Occidental Chemical Corp.). The model construction, calibration, and use has been thoroughly presented (in numerous meetings) to the above mentioned parties. In addition, the model (in electronic format) has been distributed to the same parties for their review and use.

1.1 BACKGROUND

In 1983, the Grumman Aerospace Corporation and U.S. Naval Weapons Industrial Reserve Plant (NWIRP) sites located in Bethpage, New York were jointly included on the

NYSDEC's State Superfund List as class 2a. In December 1987, this classification was changed to 2. In 1984, the Occidental Chemical Corporation (OCC)/RUCO Polymer Corporation Site (a neighboring property to the west) was included on the U.S. Environmental Protection Agency's (USEPA) Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) National Priority List (NPL) under Section 120 of CERCLA. Subsequently, a Federal Facilities Agreement addressing the investigation and remediation of environmental impacts associated with the US Navy Bethpage site was negotiated. Under this agreement the Navy site remained under jurisdiction of the NYSDEC Superfund group, the Grumman site was also under the jurisdiction of the NYSDEC Superfund group, and the Ruco Polymer site was under the jurisdiction of the USEPA. The agreement reached was intended to ensure that environmental impacts associated with past and present activities at the Bethpage sites are thoroughly and adequately investigated so that appropriate response actions can be formulated, assessed, and implemented.

The groundwater system at, and in the vicinity of the Bethpage sites has been designated as a "sole source" aquifer system whereby all major aquifers are considered as a single groundwater resource. Within this hydrogeologic setting, plans for groundwater remediation and water-supply activities must consider the effects of such actions on the groundwater system as a whole. Failure to adopt such an integrated approach risks expending remedial effort without the beneficial result of maintaining a high potable yield from the aquifer for water-supply purposes. The "systems approach," whereby the complexities of the groundwater system are evaluated as intricately related processes, will therefore be used in the modeling effort to allow for assessment of the effects of various remedial scenarios and water-supply alternatives on the groundwater resource. The three-dimensional groundwater flow model will be used as a tool for evaluation of these scenarios and alternatives. The model will be the foundation on which evaluations at both the regional and local scales will be made.

1.2 SOURCES OF INFORMATION

Numerous investigations performed at both the regional and local scales have provided information and data used in this modeling effort. Many of those investigations are referenced throughout this document; however, the key investigations and specific topics they address are summarized below.

Hydrogeology/Hydrology: Isbister (1966), Smolensky et al. (1989), Smolensky and Feldman (1990), Warren et al. (1968), Miller and Frederick (1969), Franke and Cohen (1972), McClymonds and Franke (1972), Bailey et al. (1985), Peterson (1987), Doriski (1986), Lindner and Reilly (1983), Feldman et al. (1992)

Modeling: Franke and Getzen (1976), Getzen (1977), Reilly et al. (1983), Reilly and Buxton (1985), Buxton and Modica (1992), Buxton and Smolensky (In Press), Smolensky and Feldman (1995), Buxton et al. (1991)

In addition to the reports listed above, many records and unpublished data (e.g., well logs, water-level measurements) were researched, evaluated, and used. Most of these data were on file at the U.S. Geological Survey (USGS) or the NYSDEC.

1.3 REPORT OBJECTIVES AND FORMAT

The objectives of this report are to document the construction and calibration of the Northrop Grumman groundwater flow model, and to present the output (i.e. heads, potentiometric surface maps) of the simulation of the groundwater flow regime under calibrated, steady-state conditions.

This report has been divided into six major sections that logically follow and build upon preceding sections. A description of each section is provided below.

Sections 1 and 2 present an introduction, background information, and development of the conceptual model of the groundwater system.

Section 3 describes the development of a plan and strategy to model groundwater flow. It includes a description of technical objectives and the modeling approach as well as a discussion of the model code chosen and the rationale for its use.

Section 4 documents the construction of the model. It includes a discussion of discretization, boundary conditions, and hydrologic/hydrogeologic input parameters. This section is tailored to a reader who is familiar with models or the quantitative aspects of hydrogeology.

Section 5 discusses the calibration and verification of the flow model. It also includes a discussion of the sensitivity analysis. This section is tailored to those who are familiar with models or the quantitative aspects of hydrogeology.

Section 6 summarizes the modeling effort.

2.0 CONCEPTUAL GROUNDWATER MODEL

A conceptual groundwater model is simply an understanding of the structure and operation of a given groundwater system. In the Northrop Grumman area, the groundwater system is defined by its hydrogeologic framework, hydraulic parameters, and boundary conditions (including pumping wells and recharge basins). The interrelation of these three factors govern groundwater flow patterns within the system. This section provides a summary of these factors and a brief description of the Northrop Grumman site in order to characterize the conceptual model of the flow system and to provide an understanding of the stresses affecting groundwater quality and quantity in the Northrop Grumman area.

2.1 SITE LOCATION

The Northrop Grumman site (including both the property owned by Northrop Grumman and the property owned by the Federal Government [US Navy] and operated by Northrop Grumman) is located in Bethpage, Nassau County, New York, in the southeast quadrant of Nassau County (Figure 2-1). The Northrop Grumman site includes or has included large office buildings, recreational playing fields, various manufacturing buildings, storage areas and warehouses, and an airstrip (Smolensky and Feldman 1989). The area surrounding the site is primarily residential with some commercial development and transportation corridors. The Northrop Grumman site has an irregular shape that comprises an area of approximately 600 acres.

2.2 HYDROGEOLOGIC FRAMEWORK

The following section describes the configuration of the aquifers and confining units that comprise the groundwater system in the vicinity of the Northrop Grumman site, and describes and compares their water-transmitting properties. This description relates geologic structure to the distribution of water-transmitting properties throughout the groundwater system in the vicinity of the site and is referred to as the hydrogeologic framework.

This summary of the hydrogeologic framework of the site and the surrounding area is based on a review of site data and publications, including the following USGS publications: Smolensky et al. (1989), and Smolensky and Feldman (1990). The site is underlain by approximately 1,200 ft of unconsolidated sediment overlying bedrock. The unconsolidated deposits are subdivided from youngest to oldest (from land surface downward) as follows:

- Upper Pleistocene deposits (Upper Glacial aquifer).
- Matawan Group-Magothy Formation (Magothy aquifer).
- Raritan Formation (Raritan confining unit and Lloyd aquifer).

This sequence dips to the southeast below Long Island. A description of each unit is provided below. Table 2-1 summarizes the stratigraphy beneath the site and provides general information regarding water-transmitting properties.

2.2.1 Upper Glacial Aquifer

The Upper Glacial aquifer is comprised of Upper Pleistocene sediments that were deposited in a glacio-fluvial environment during the Wisconsin glaciation. Pleistocene sediments near and at the Northrop Grumman site consist of outwash deposits (fluvial transport), and moraine material (north of the site). The unconsolidated Upper Glacial deposits are approximately 75 ft thick beneath the site (Smolensky and Feldman 1990). The Upper Pleistocene (Wisconsin) deposits consist of medium-to-coarse grained sand and gravel; some fine-grained sand and silt and local clay lenses are also present. In addition to the glacially derived deposits, a "reworked Magothy" zone (a transitional interval between the Magothy and Upper Glacial aquifers generally located within the lower portion of the Upper Glacial aquifer) may be present locally.

2.2.2 Magothy Aquifer

The Magothy aquifer (continental deposits of the late Cretaceous Magothy Formation Matawan Group undifferentiated) at the Northrop Grumman site unconformably underlies Pleistocene deposits. The Magothy Formation at the site is generally composed of fine-to-medium, gray to white, sand mixed and interbedded with silt and clay, and locally contains pebbles or small lenses of gravel. The lower 75 ft interval of the Magothy aquifer (basal Magothy) has been documented to consist of coarser material. Geologist's logs from wells that penetrate the Magothy aquifer describe zones of solid clay. Attempts to correlate these clay zones show them to be discontinuous and of variable thickness. These clay lenses reflect the highly stratified character of the deposits and contribute to the high degree of anisotropy in the aquifer.

The surface configuration of the Magothy aquifer reflects the severe erosion that occurred during several episodes of Pleistocene glaciation. The well data and geologic correlations indicate that the highest altitude of the Magothy aquifer surface is almost 100 feet above mean sea level (msl) (approximately 1 mile to the northeast of the Northrop Grumman site). The surface of the Magothy slopes from the northeast to the west to its lowest elevation in the area (more that 25 ft below msl). The Magothy also generally slopes down to the south towards the south shore of Long Island. Maximum thickness of the Magothy aquifer at the site is approximately 650 ft.

2.2.3 Raritan Confining Unit

The Raritan Clay underlies the Magothy aquifer at an approximate elevation of 600 ft below msl. The confining unit is approximately 175 ft thick (Smolensky and Feldman 1990). The Raritan Clay is comprised of clay, silt and sandy clay with some thin zones of fine sand. The clay may be red, yellow, gray, or white.

2.2.4 Lloyd Aquifer

The Lloyd aquifer underlies the Raritan confining unit and immediately overlies the bedrock. The Lloyd aquifer is approximately 300 ft thick (Smolensky and Feldman 1990). It consists predominantly of coarse to fine sands and some clay. The upper surface of the Lloyd aquifer dips to the southeast, similar to the dip of the bedrock surface.

2.2.5 Bedrock

The bedrock is probably of Precambrian or Paleozoic age and consists primarily of schist and gneiss. The bedrock slopes to the southeast and represents an advanced erosional surface with little relief. It is overlain by a tough white clay that was derived from the bedrock through weathering.

2.3 WATER-TRANSMITTING PROPERTIES

McClymonds and Franke (1972), estimated the distribution of hydraulic conductivity for each of the three major aquifers by evaluation of specific capacity data and pumping tests throughout Long Island. In addition to the data in McClymonds and Franke (1972), results of several pumping tests conducted in the southern half of Nassau county were also used to provide information on water-transmitting properties of specific aquifers within the aquifer system (Lindner and Reilly 1983).

The Upper Glacial aquifer has the highest estimated values of horizontal hydraulic conductivity (up to approximately 300 feet/day [ft/d]) of the three major aquifers, which reflect the sand and gravel deposits comprising the aquifer. North of the site, abrupt changes in conductivity occur around the area of the Ronkonkoma terminal moraine. Although horizontal conductivities are defined, it should be noted that these values approximate an average conductivity for the entire aquifer thickness or significant portions thereof. However, abrupt vertical changes in the lithology of the deposits results in variations of vertical conductivity values at different depths. Stratification in these deposits is common and has a pronounced effect on the vertical hydraulic conductivity of the deposits. The anisotropy (ratio of horizontal to vertical hydraulic conductivity) of the Upper Glacial aquifer is approximately 10:1, however, anisotropy values for the aquifer have been reported as low as 3:1 or 4:1.

The Magothy aquifer can be divided vertically into three approximate zones with contrasting ranges of horizontal hydraulic conductivity. The upper Magothy zone is representative of the Upper Glacial aquifer/ upper Magothy aquifer transition zone and has a value of approximately 200 ft/d. The middle Magothy aquifer zone generally contains more silt and clay and has conductvities between 30 and 70 ft/d. The basal Magothy zone is slightly more permeable due to higher gravel content and has conductivities ranging from 60 to 100 ft/d. Vertical conductivities for the three zones are 2 to 15 ft/d, 0.4 to 1.2 ft/d, and 0.6 to 1.2 ft/d, respectively. These anisotropy values reflect the highly stratified character of the Magothy aquifer. Aquifer tests from the underlying Lloyd aquifer are uncommon; however, some available regional data indicate conductivity ranges of 35 to 75 ft/d and an anisotropy ratio of 100:1.

Little data are available to estimate vertical hydraulic conductivities of the Raritan confining unit; however, its high clay and silt content would suggest vertical conductivities several orders of magnitude lower than those for adjacent aquifers. Franke and Cohen (1972) and Franke and Getzen (1976) estimated the average vertical hydraulic conductivity of the Raritan confining unit to be approximately 0.001 ft/d.

Estimates of specific yield (effective porosity) for outwash deposits on Long Island are as follows: 0.18 (Getzen 1977), 0.22 (Reilly and Buxton 1985), 0.24 (Warren et al. 1968), 0.24 (Perlmutter and Geraghty 1963), and 0.30 (Franke and Cohen 1972). Estimates as low as 0.10 have been proposed for morainal deposits (Getzen 1977). Specific storage for the Magothy aquifer is approximately 6.0×10^{-7}/ft (Reilly and Buxton. 1985).

2.4 BOUNDARY CONDITIONS AND GROUNDWATER FLOW

The fresh groundwater beneath Long Island exists as a distinct well-defined system, bounded completely by natural hydrologic boundaries. The Northrop Grumman site and surrounding area are part of this system and share some common hydrologic boundaries. The system is bounded above by the water table and many streams and fresh surface-water bodies; it is bounded below by consolidated bedrock. The entire system is bounded laterally by salty groundwater and surface-water bodies. Under natural conditions, all water enters and leaves the system across these boundaries. The occurrence of precipitation in the hydrologic environment is described below as an aid in understanding the function of major boundaries in the operation of the groundwater system.

Recharge is derived solely from precipitation, which falls at a long term average rate ranging from 41.5 to 43 inches per year (in/yr) (Miller and Frederick 1969; Bailey et al. 1985) in the vicinity of the Northrop Grumman site. Recharge enters the saturated groundwater system at the water table, the upper boundary of the groundwater system. In Nassau County, it is estimated that between 50 and 52 percent of precipitation recharges the saturated groundwater system. In addition to direct recharge from precipitation, approximately 20 percent of the public supply water used in the area is returned to the groundwater system as leakage from the sewer systems (Smolensky and Feldman 1990). Only 1 percent of precipitation is lost to overland runoff because of the high infiltration capacity of the unconsolidated deposits at land surface and the relatively flat topography; the remaining 47 to 49 percent is lost to evapotranspiration. Groundwater recharge was estimated as follows: direct recharge from precipitation, approximately 52 percent of 43 inches per year or 0.0051 ft/day. In addition, 20 percent of 3,166,781 cubic feet per day of groundwater pumped from public supply wells is returned to the groundwater system as leakage and non-consumptive water use, which amounts to approximately 0.00105 ft/day. The total recharge rate is therefore estimated to be 0.00615 ft/day.

The consolidated bedrock that underlies the unconsolidated deposits of Long Island is considered the bottom boundary of the groundwater system. There is no evidence of any water-bearing zones within the bedrock and therefore, this bottom boundary is considered impermeable.

Long Island is surrounded by tidal water bodies that form the lateral boundaries of the fresh groundwater system. Groundwater discharges from the Upper Glacial aquifer along the shoreline directly to the near shore bottom of these saltwater bodies. Assuming the characteristics of a typical static and sharp freshwater/saltwater interface in the aquifer, groundwater in deeper portions of the Upper Glacial aquifer will flow upward along the interface to the discharge zone, the thickness of which is only a portion of the entire thickness of the Upper Glacial deposits.

At the offshore position of the freshwater/saltwater interfaces in the Magothy and Lloyd aquifers, fresh groundwater flows vertically upward across the overlying confining units. Where the overlying groundwater is salty, the water discharges from the fresh groundwater system and mixes with the salty groundwater. These areas are referred to as subsea discharge boundaries and identify Long Island as a classic staggered interface hydrogeologic environment. North and south of the site (near the shorelines) groundwater in the Magothy and Lloyd aquifers flows towards subsea discharge boundaries. Confining units that are present near these boundaries impede groundwater discharge upward to the shoreline; as a result, the freshwater/saltwater interface is displaced seaward.

Under natural conditions, river flow is maintained year-round by groundwater seepage (baseflow) from the Upper Glacial aquifer into the river or stream channel. The portion of stream flow derived from overland runoff is very small because of Long Island's relatively flat topography and the high infiltration capacity of soils. The rate of seepage is controlled by the difference in head between the local aquifer and the stream bed, the channel geometry, and the water-transmitting properties of the aquifer and bed material. Therefore, baseflow and the length of flowing stream vary with changing conditions in the groundwater system. When the water table falls to a level below the channel elevation, seepage stops and the channel becomes dry. No streams or rivers exist in the immediate vicinity of the Northrop Grumman site.

Groundwater in the Upper Glacial aquifer beneath and in the vicinity of the Northrop Grumman site generally exists under unconfined conditions. However, if locally continuous low permeability zones exist within the aquifer, semi-confined conditions will prevail locally. Where the Magothy aquifer is in direct hydraulic connection with the Upper Glacial aquifer and not separated by a distinct confining unit, conditions within the Magothy are semi-confined to unconfined. Although the Magothy aquifer does not contain regionally extensive continuous clay layers, its many clay lenses tend to increase the degree of confinement with depth.

Groundwater in the Lloyd aquifer exists under confined conditions. The low vertical hydraulic conductivity of the overlying Raritan confining unit (approximately 0.001 ft/d) greatly limits the downward movement of water into the Lloyd aquifer. Because only a small percentage of the groundwater that flows through the system ever enters the Lloyd aquifer, the aquifer is very sensitive to groundwater pumpage. For this reason, and because of the abundance of potable groundwater in the overlying aquifers, the Lloyd aquifer is not used as a source of water-supply in the vicinity of the Northrop Grumman site.

An east/west trending groundwater divide is located to the north of the site with resultant regional groundwater flow in the vicinity of the Northrop Grumman site being primarily to the south (Figure 2-2). Under natural conditions, groundwater eventually discharges either into streams located along the south shore of Long Island or directly to the Great South Bay and Atlantic Ocean as underflow.

The horizontal direction of groundwater flow is locally influenced by active supply wells, recharge basins, and natural hydrogeologic conditions. Pumping wells locally depress the water table, while recharge basins may produce local groundwater mounding. Within the Northrop Grumman site boundary, surface discharge occurs at several recharge basin locations. At these locations, artificial recharge results in the formation of localized groundwater mounds. In the vicinity of the mounds, shallow groundwater flows radially away until it becomes more strongly influenced by regional groundwater flow patterns. It then flows in a southerly direction until it is either captured by pumping wells, or is discharged naturally from the groundwater system.

The vertical component of groundwater flow at and in the vicinity of the Northrop Grumman site is downward. To the south however, in areas proximal to rivers and streams, and in areas further south underlain by regional confining units such as the Gardiners Clay, the direction is upward, at least locally. In addition, near the north and south shores the direction is also upward. This interpretation of vertical flow is supported by well cluster data, numerous regional investigations, and the widely accepted conceptualized model of the Long Island groundwater system.

Although pumping wells and active recharge basins are boundary conditions, they are considered to be internal artificial boundaries and are therefore not described in this section. These boundaries are discussed in Section 4.4 (Groundwater Pumpage and On-Site Recharge).

3.0 MODELING STRATEGY

This section presents the objectives of the modeling effort, as well as the concepts and strategies used to simulate groundwater flow at, and in the vicinity of, the Northrop Grumman site. Given the various technical objectives, potential model uses, and varying scales of interest discussed in the following sections, as well as the physical and chemical complexities of flow and transport, a clear modeling plan and strategy was required and therefore, developed. This modeling plan and strategy was followed throughout the modeling effort to allow the model to be used confidently as a tool for meeting the various technical objectives.

3.1 TECHNICAL OBJECTIVES

The technical objectives of the modeling effort are described below.

3.1.1 Regional

The regional model was developed to provide a tool for evaluation of groundwater flow, contaminant transport, and remedial alternatives, where such processes, concerns, or actions may have impacts that extend across extensive areas beyond the site boundary. The model was also developed to evaluate those impacts as a function of depth within the groundwater system. This model is considered the foundation from which all subregional or site-specific models will be developed. As such, it will ensure that all subsequently developed groundwater models are both hydrogeologically and hydrologically consistent with each other and with regional interpretations and processes. This consistency will be critical in areas where site-specific data is inadequate or lacking.

One objective of the regional model is that its design enables it to be, in many instances, an appropriate tool for addressing specific concerns that apply over a large geographical area. It is critical, therefore, that not only knowledge of both the physical system and the existing groundwater problems/concerns at the site be incorporated into the development of the regional model, but also that the model be developed with foresight as to what the potential remedies or future scenarios might be. It may be appropriate for the discretization scheme to be driven not only by the physical and chemical processes that occur in the system, but also by the remedies and scenarios that may be expected to be simulated.

3.1.2 Site-Specific

It may be determined that the regional model may not be an appropriate tool for use in evaluating all specific concerns. Geraghty & Miller has assumed that such a determination will be based on differences in scale. Specifically, the discretization scheme used in the regional model may not allow for accurate or adequate simulation of various transport processes that occur or must be addressed at a very site-specific scale. Such limitations could be related to either horizontal and/or vertical discretization. For example, transport simulations involving dispersive processes, require use of the Peclet number as a stability criterion. The Peclet number is a function of grid cell spacing and dispersivity. In cases where grid spacing is large relative to dispersivity, the Peclet number criterion may be violated, introducing unacceptable levels of numerical dispersion. In such cases, the horizontal and/or vertical discretization scheme may need to be refined.

3.1.3 Uses of the Model

Some of the potential uses of the model are described below.

3.1.3.1 Feasibility Study

One of the benefits of having the model available for use will be the ability to test the feasibility of various groundwater remedial scenarios. The model will be used to evaluate the impacts of combinations of remedial pumping and recharging scenarios; to optimize existing well pumpage to contain, control, and/or remediate groundwater; to assess specific no-action scenarios; and to evaluate other feasibility options.

3.1.3.2 Remedial Design

Following the selection of specific groundwater remedies, the groundwater flow model will be used to assist in final remedial designs. Assuming that groundwater extraction will be considered as a preferred remedy, modeling efforts may include running simulations to locate the optimal location(s), screened intervals, pumping rates, etc. for proposed extraction wells. These simulations may be used to approximate potential influent concentrations to treatment facilities, potential concentration changes over time, and expected length of the treatment period.

3.2 SIMULATION APPROACH

This modeling effort and model design were structured to address critical groundwater issues at and around the Northrop Grumman site. The approach adopted to model the groundwater system in these areas emphasizes consistency in addressing both regional and subregional/site-specific issues. An important aspect of the overall technical approach adopted includes definition of the scale of the model.

Several factors should be given serious consideration during definition of the scale of a discrete representation of a groundwater system in a numerical model. These factors include both considerations for system geometry and considerations for adequate resolution of the distribution of head throughout the system.

Resolution of the hydrogeologic framework in the vicinity of the site obviously will affect the accuracy of the model. Representation of internal features such as the shape and extent of aquifers and thickness of layers and their spatial relationship, will have a major impact on the pattern and distribution of groundwater flow. The external geometry of the system is defined by the configuration of its natural boundaries or selected artificial hydrologic boundaries.

Additional geometric considerations include the location and shape of characteristics imposed by humans. These factors are often involved in simulations of stressed conditions or predictions used to evaluate resource-management strategies and remedial scenarios. At the Northrop Grumman site, such characteristics include pumping wells or centers and recharge basins.

An additional consideration in defining the scale of the model's representation is spatial changes in hydraulic head in the groundwater system. At the Northrop Grumman site, where gradients change rapidly (such as near wells or basins) the model may require finer grid spacing to accurately describe changes in gradient. Errors in the simulation of steep gradients are related to truncation error, which is inherent in finite-difference approximations and is discussed in greater detail in Bear (1972) and Remson et al. (1971).

3.3 MODEL CODE

The modular finite-difference groundwater flow code, known as MODFLOW, developed by the USGS (McDonald and Harbaugh 1988), was selected for the groundwater flow model. MODFLOW is publicly available, widely used, and features extensive documentation. The program is capable of simulating transient or steady-state flow in two or three dimensions for many different types of boundary conditions, including specified head, specified flux, and head-dependent flux. MODFLOW simulates groundwater flow using a block-centered finite-difference formulation. Model layers, which may be of variable thickness, may be simulated as confined, unconfined, or a combination of both. MODFLOW can simulate various external stresses, such as extraction or injection wells, areal recharge, evapotranspiration, drains, and streams or rivers. In the program, the finite-difference equations are solved using the strongly implicit procedure, the slice-successive over relaxation method, or the preconditioned conjugate gradient method.

All of these features make MODFLOW well suited for modeling the groundwater flow system at the Northrop Grumman site. The hydrogeologic framework and the dynamics of the system require a code capable of simulating three-dimensional flow with dipping layers. The unconfined nature of the upper portion of the aquifer necessitates a code option for simulating a free-water surface and groundwater/surface-water interactions. Simulation of various boundary conditions (specified flux and free-surface) is required, as is the ability to simulate the distribution of various aquifer and hydrologic parameters. MODFLOW meets all of these requirements.

4.0 MODEL CONSTRUCTION

The steps followed to construct the model are described in this section.

4.1 DISCRETIZATION

Computer programs such as MODFLOW approximate the mathematical equations for groundwater flow by numerical discretization techniques. MODFLOW uses the method of finite differences to approximate the groundwater flow equations. Spatial discretization consists of subdividing the entire model domain into a grid or mesh of blocks or cells. In the discretized system, hydraulic heads are computed at the center of each grid block. In general, computational accuracy increases as the number of rows and columns in the grid increase (cells become smaller).

In most cases, the need for computational accuracy in a computer model is greatest in the area of greatest concern, which, in this instance, is the Northrop Grumman site and areas to the west (OCC/RUCO site) and south (downgradient flow direction from the site). Therefore, a variable-spaced grid (one in which the finite-difference mesh is designed with smaller grid blocks in areas of interest and grades to larger blocks near the edges of the model) was used in this model. Grid design must address all three dimensions and, therefore, includes not only the horizontal grid, but also the vertical layering scheme. The actual grid was designed considering several additional factors as follows:

- The level of detail of the data available to define the hydrogeologic framework and hydraulic characteristics.

- The ability to define and represent boundary conditions and stresses placed on the system.

- The amount and distribution of hydraulic head data from which the model was to be calibrated.

- The desired resolution of model output.

- Computation effort and model stability.

The finite-difference grid developed after careful consideration of project goals and the factors discussed above consists of 104 rows, 68 columns, and eight layers. The model simulates regional groundwater flow in three dimensions over an area approximately 32,000 feet from north to south and 21,000 feet from west to east. The model grid is shown on Figure 4-1. Dimensions of cells along row (west-east) and column (north-south) directions range from 150 to 1,000 ft. The finest grid resolution is generally used on-site with lateral grid cell dimensions of 150 by 150 ft to enhance computational accuracy and produce results at the desired level of detail. The emphasis on fine-scale discretization on-site and in areas immediately to the south corresponds to critical areas with respect to model uses. A general rule-of-thumb was followed when increasing the grid spacing systematically from areas of finer resolution to areas of coarser resolution, in order to minimize numerical dispersion. Generally, the variation in grid spacing progressed such that the maximum change in spacing did not exceed 1.5 times the abutting grid spacing.

The groundwater flow model was constructed to simulate groundwater flow throughout the entire saturated thickness of the Upper Glacial and Magothy aquifers. As such, the aquifer system was divided into eight layers of grid cells in the vertical direction. The model was discretized vertically by specifying bottom elevations to define the bottom surface of each model layer. Table 4-1 presents the model layering scheme correlated with a generalized stratigraphic column. Vertical discretization was determined through careful consideration of the vertical distribution of calibration target wells, vertical distribution of pumping stresses, adequate vertical gradient resolution, and major hydrostratigraphic contacts. A threshold of maximum change in vertical grid dimensions was not specifically considered. Eight model layers sufficiently represent the system to the level of detail of the data. The model discretization is a balance among cost-effectiveness, available data, and the resulting accuracy of the model. Increased vertical discretization would not necessarily improve the quality of the calibration. The majority of the hydrologic data that the model is based on corresponds to Model Layers 1 through 4; thus, these shallow layers of the model are more finely discretized. Generally, in the vicinity of the site, the layer thicknesses gradually increase between Model Layers 5 and 8. Finer discretization of the lower layers (Model Layers 7 and 8) is not likely to improve the overall calibration of the model since there are relatively few calibration targets in these layers.

Model Layer 1, an unconfined layer, is approximately 20 feet thick throughout the model with the top defined by the water table. Because the top is simulated as a free-surface, the thickness of the layer will vary as the water table rises and falls. The elevation of the interface between Upper Glacial and Magothy was based on findings in Smolensky and Feldman (1990) and from available well logs.

Model Layers 1 and 2 generally correspond to the Upper Glacial aquifer. The bottom elevation of Model Layer 2 (in discrete format) is shown on Figure 4-2 The general north to south slope of the contact between the Upper Glacial aquifer and the Magothy aquifer is evident. Also evident are two local areas where the glacial deposits exist are lower elevations than would normally be expected (in the northwest corner and in a small pocket in the mid-western area) This relatively detailed vertical discretization was necessary to properly utilize groundwater monitoring data from wells with different screen elevations

Model Layer 3 is generally representative of the upper portion of the Magothy aquifer. The bottom elevation of Model Layer 3 was set at -50 feet mean sea level (msl). Model Layers 4, 5, and 6 correspond to the mid-Magothy aquifer. The bottom elevations of Model Layers 4, 5 and 6 were set at -140 msl, -235 msl, and -365 msl, respectively. Model Layer 7 has a variable thickness. Model Layer 8 is representative of the basal Magothy. It has a constant thickness of approximately 70 feet. The bottom of the layer coincides with the upper surface of the Raritan Confining unit and slopes from approximately -450 msl at the northern model boundary to approximately -700 msl at the southern model boundary.

Given the density of data available for system conceptualization and model construction, the hydraulic gradients, the boundary conditions to be simulated, the level of detail desired for model output, and the general objectives of the regional modeling effort, the level of discretization described above is appropriate.

4.2 BOUNDARY CONDITIONS

The boundary of a groundwater system can be thought of as a continuous closed surface that completely encloses the system of interest. Successful simulation of that groundwater system requires that all points on the boundary surface be defined or approximated. During the development of a numerical model, the selection of boundary conditions typically involves considerable simplification of actual groundwater system boundaries. This section describes the lateral, upper, and lower model boundary conditions used in the Northrop Grumman flow model. Although pumping wells, and recharge basins are technically considered a type of model boundary (internal boundaries), they are not discussed in this section; they are discussed in detail in Section 4.4 (Groundwater Pumpage and On-Site Recharge).

Generally, boundary conditions describe groundwater head and/or flow at the boundaries of the model area. A variety of boundary conditions was used in the construction of the Northrop Grumman three-dimensional model. In general, these boundary conditions include constant head and constant flux. In a constant head boundary condition, the head remains fixed at a given value throughout all model simulations. Constant head cells were placed along the lateral boundaries of the model area. In a constant-flux boundary condition, the groundwater flow rate into or out of the model cell is assumed to be constant. Constant flux cells represent pumping wells, recharge areas, and the special condition of "no flow" (a boundary where the flux is always zero).

The lower boundary of the model corresponds to the upper surface of the Raritan confining unit. This unit is characterized by solid and silty clay with few lenses and layers of sand. The low vertical hydraulic conductivity (approximately 0.001 ft/day) and overall thickness (about 175 ft) of the Raritan Clay cause this unit to act as a regional confining unit, which severely restricts the flow of groundwater vertically through it. This boundary was, therefore, modeled as a constant-flux or no-flow boundary. A flow analysis on a representative cross section through the entire thickness of the Long Island groundwater system was performed by Buxton and Modica (1992). This analysis, which generally approximated groundwater conditions along the Nassau-Suffolk county border, showed that although some groundwater does flow through the Raritan confining unit (between the Magothy and Lloyd aquifers), the amount has been estimated to be only approximately 2 to 3 percent of the total water flowing in the system. This analysis supports the approach of simulating this upper surface of the Raritan confining unit as the bottom boundary of the model.

The groundwater flow model was constructed to simulate groundwater flow throughout the entire saturated thickness of the Upper Glacial and Magothy aquifers. As such, the upper boundary of the model corresponds to the water table and is simulated as a free surface. This boundary represents the interface between the saturated flow field and the atmosphere (neglecting the capillary zone). It is the only boundary that is not fixed in its position, as it may rise and fall based on hydrologic changes in the system.

No natural lateral groundwater system boundaries exist in the vicinity of the Northrop Grumman site. To minimize the introduction of error that could potentially be introduced in the definition and specification of lateral model boundaries, the lateral boundaries assigned in the model were chosen to be at significant distances from the site. The northern model boundary generally corresponds to the regional groundwater divide that is oriented west-east and is located approximately 10,000 ft north of the site (see Figure 2-2). From a regional perspective, the location of this divide has not changed with time, and therefore, it was chosen as the northern model boundary. South of the groundwater divide, under natural conditions, all recharge to the groundwater system eventually discharges to the Great South Bay/Atlantic Ocean or streams located along the south shore of Long Island. Within the modeled area, this general north to south flow pattern has also not changed appreciably over time. Therefore, the location of representative flow lines east and west of the site were used to select the eastern and western model boundaries. These boundary locations were chosen considering both their distance from the site (approximately 10,000 and 9,000 ft to the western and eastern model boundaries, respectively) and their general orientation relative to the site and the groundwater divide. Finally the southern boundary location was chosen at sufficient distance from the site (approximately 14,000 ft). The southern boundary does not correspond directly to any natural boundaries.

Because the locations of the lateral model boundaries for the most part do not correspond exactly to the location of specific limiting flow lines or the groundwater divide, the specification of boundary conditions at each of the selected locations was accomplished by assigning constant head values. Through the use of constant head boundaries, minor departures from the actual location of limiting flow lines and the groundwater divide compared to the model selected locations could be compensated for. Regional water-level maps published by the USGS (Doriski 1986) and groundwater monitoring data obtained from the Nassau County Department of Public Works were used to specify the hydraulic head at the lateral model boundaries. Long-term hydrographs of water levels from monitoring wells in the vicinity of the site show that the regional elevation of the potentiometric surfaces of the Upper Glacial and Magothy aquifers and the hydraulic gradients within each aquifer do not vary greatly from year to year (negelecting the impact of the regional drought of the mid 1960's). Therefore, water levels that are representative of average conditions were used to assign head values to each constant head boundary cell.

With respect to overall vertical groundwater flow between aquifers, assignment of constant head values along model boundaries in the Upper Glacial and Magothy model layers was consistent with the conceptual model of regional vertical groundwater flow between the Upper Glacial and Magothy aquifers. Generally, assigned head values for these model layers reflect the regional vertical downward gradients between the Upper Glacial and Magothy aquifers in the vicinity of the recharge area/groundwater divide, and the regional lessening of downward vertical gradients between aquifers as distance from the divide increases. The regional potentiometric maps described in the preceeding paragraph indicate a regional vertical hydraulic gradient from the water table down to the Magothy aquifer. The head difference (which causes the hydraulic gradient) between the water table and the potentiometric surface of the Magothy is approximately 2.5 feet at the northern boundary of the model, approximately one foot near the area of interest, and approximately 0.5 feet at the southern model boundary. The head difference was assigned (at all lateral model boundaries) across all eight model layers based on the thickness and vertical hydraulic conductivity of each of the boundary cells in each model layer.

For Model Layer 1, assigned constant head values along the northern model boundary from northwest to northeast ranged from 82.42 ft msl to 80.42 ft msl, respectively. Along the western model boundary, from the groundwater divide in the northwest to the southern boundary, assigned constant head values decreased from 82.42 ft msl to 36.92 ft msl, respectively. Along the eastern model boundary, from the groundwater divide in the northeast to the southern model boundary, assigned constant head values decreased from 80.42 ft msl to 35.92 ft msl, respectively. Along the southern model boundary, assigned constant head values ranged from 36.92 ft msl to 35.92 ft msl from west to east.

4.3 PARAMETER ZONATION

Hydraulic parameter values for the final calibrated flow model are described in this section. Some of the parameter values used in this model (e.g., hydraulic conductivity and recharge) were initially estimated and later adjusted during calibration (see Section 5.0 [Model Calibration]).

Simulation of groundwater flow requires the definition of hydraulic parameters in each model cell. The following model input parameters are defined and discussed below: horizontal and vertical hydraulic conductivity and areal recharge. In the modeling approach used in this study, parameters are defined by zones of equal value. Zones are identified with both an integer number and a parameter value. Each cell in the model is then assigned a zone for each parameter. For example, hydraulic conductivity Zone 11 is assigned a horizontal hydraulic conductivity value of 275 ft/d.

4.3.1 Hydraulic Conductivity

Hydraulic conductivity values used in the model were initially based on published values for geologic formations on Long Island (McClymonds and Franke 1972), on results of aquifer tests (Lindner and Reilly 1983), on previous modeling efforts of the area (Smolensky and Feldman 1995), and on other regional modeling efforts in Nassau County (Reilly and Buxton 1985, Buxton and Smolensky [in press]). Initial values and distributions were adjusted during model calibration. Final calibrated horizontal (K_h) and vertical (K_v) hydraulic conductivity values varied greatly across the three-dimensional model domain. Overall, 5 zones of hydraulic conductivity were used in the model to define hydraulic conductivity variations.

Horizontal hydraulic conductivity (300 ft/day) and vertical hydraulic conductivity (60 ft/day) values corresponding to that of the Upper Glacial aquifer were assigned in most of Model Layer 1. In the northeast, where Upper Magothy type deposits exist at elevations that are typical of only glacial deposits, hydraulic parameters that are representative of this reworked/transitional zone were included. A horizontal hydraulic conductivity of 200 ft/day and a vertical hydraulic conductivity of 15 ft/day (values representative of the transitional zone between Upper Glacial and upper Magothy aquifers) were assigned (see Figure 4-3). The hydraulic conductivity distribution in Model Layer 2 differs from that in Model Layer 1 in that the area representative of the transitional zone extends further south (see Figure 4-4).

Model Layer 3 is generally representative of the upper portion of the Magothy aquifer (see Figure 4-5). In most of this layer, the horizontal hydraulic conductivity (120 ft/day) and the vertical hydraulic conductivity (2.0 ft/day) correspond to the type of hydraulic properties common in the upper Magothy. In a few relatively small areas the hydraulic conductivity corresponds to that of the Upper Glacial (where glacial deposits have been reported to locally exist at lower than normal elevations).

Model Layers 4, 5, 6, and 7 correspond to the mid-Magothy aquifer. The horizontal hydraulic conductivity and vertical hydraulic conductivity were set at 50 ft/day and 0.8 ft/day respectively.

Model Layer 8 is representative of the basal Magothy. The horizontal hydraulic conductivity (80 ft/day) and the vertical hydraulic conductivity (1.2 ft/day) correspond to the increase in coarse material typical of the basal zone.

4.3.2 Areal Recharge

Recharge to the model area occurs only at the water table (Model Layer 1) and can technically be considered to be a constant flux boundary condition. Each active cell in the uppermost model layer receives a constant influx of water, which is computed by the model by multiplying the area of the grid cell by the recharge rate. Recharge is discussed as part of parameter zonation because recharge is defined in the model with zones of equal value.

Recharge enters the saturated groundwater system at the water table, the upper boundary of the groundwater system. Recharge is derived solely from precipitation, which falls at a rate ranging from 41.5 to 43 inches per year (in/yr) (Miller and Frederick 1969; Bailey et al. 1985) in the vicinity of the Northrop Grumman site. In Nassau County, it is estimated that between 50 and 52 percent of precipitation recharges the saturated groundwater system. In addition to direct recharge from precipitation, approximately 20 percent of the public supply water used in the area is returned to the groundwater system as leakage from the sewer systems (Smolensky and Feldman 1990). Only 1 percent of precipitation is lost to overland runoff because of the relatively flat topography and high infiltration capacity of the unconsolidated deposits at land surface; the remaining 47 to 49 percent is lost to evapotranspiration. Groundwater recharge was estimated as follows: direct recharge from precipitation, approximately 52 percent of 43 inches per year or 0.0051 ft/day. In addition, 20 percent of 3,167,051 cubic feet per day of groundwater pumped from public supply wells is returned to the groundwater system as leakage and non-consumptive water-use (approximately 0.00105 ft/day). The total recharge rate is therefore estimated to be 0.00615 ft/day.

4.4 GROUNDWATER PUMPAGE AND ON-SITE RECHARGE

Active pumping wells simulated in the Northrop Grumman model were represented by constant-flux internal boundary conditions at cells corresponding to each well's horizontal and vertical location (screen zone). Active pumping wells within the model domain included industrial wells located on-site and public supply wells located off site. Figures 4-6 and 4-7 show locations of on-site and off-site pumping wells, respectively. Tables 4-2 and 4-3 summarize pumpage used in the calibrated model for on-site and off-site pumping wells, respectively. These tables also summarize the model cell location (row, column, layer) of each well used in the calibrated model, as well as the distributed pumping rate in cases where a well is screened within more than one model layer.

Pumping rates used in the calibrated model were based on pumpage records provided by Northrop Grumman and on available pumpage records from local public water suppliers.

Pumpage records from 1991, 1992, and 1993 were reviewed and averaged for use during model calibration. Averages of pumpage are suitable for model calibration because seasonal variations in the data are minimized. The on-site wells are screened in model layers 5, 6, and 7 and pump a total of 880,741 cubic ft per day (approximately 4,600 gpm). The public supply wells are primarily screened in model layers 5, 6, and 7 and pump a total of 3,166,781 cubic ft per day (16,450 gpm).

The vertical distribution of pumpage in the calibrated model was proportionately distributed among appropriate, corresponding model layers in cases where a screened zone extended beyond the thickness of a single model layer. As summarized in Tables 4-2 and 4-3, active on- and off-site supply wells are screened in, and withdraw water from, the Magothy aquifer (primarily Model Layers 5, 6, and 7). None of the on-site supply wells identified within the model area is screened in Model Layer 8.

The sources of on-site artificial recharge (discharge to basins) simulated in the calibrated model are summarized in Table 4-4. Most of the supply water withdrawn at the Northrop Grumman site is returned to the groundwater system via recharge basins. Records of discharge to basins for the years 1991, 1992, and 1993 were reviewed and used in the model as part of the calibration. Discharge rates over the three year period were averaged and simulated as discharge to Model Layer 1 (the model layer corresponding to the water table) at the appropriate locations. Total basin discharge is approximately 818,000 cubic ft per day or 4,250 gpm. This rate is approximately 92 percent of the rate pumped from on-site wells. It was assumed that a small percent of the water pumped was lost during the use and transmission of the water prior to final discharge at one of the on-site basins.

5.0 MODEL CALIBRATION

The following three sections describe the calibration of the groundwater flow model.

5.1 GENERAL CALIBRATION PROCEDURE

Calibration of a numerical groundwater flow model is the process of obtaining a reasonable match between observed or measured field conditions and model-generated or simulated conditions. The calibration procedure is generally carried out by varying estimates of hydraulic properties and boundary conditions from a set of initial values until an acceptable match of simulated results to observed conditions is achieved. Examples of hydraulic properties that may be varied from a set of initial estimates are hydraulic conductivity and recharge. The measured or observed field conditions to be matched are commonly referred to as calibration targets. Calibration targets are used to evaluate the results generated by the model for a given set of input parameters. Observed hydraulic head data measurements are examples of calibration targets used in the Northrop Grumman model.

5.2 STEADY-STATE FLOW MODEL CALIBRATION

This section describes the flow model calibration using MODFLOW.

5.2.1 Calibration Targets

The groundwater flow model was calibrated to steady-state average groundwater conditions represented by groundwater levels measured during two synoptic water-level events (Spring [April] and Fall [September] of 1993). The data for each observation well was averaged to represent conditions under pumping conditions for the calibration period. The early spring and early fall periods are considered the periods of light and heavy on-site pumping. By averaging the data from these periods, the calibration targets are representative of average conditions that would be observed under average pumping. This approach therefore, is also consistent with the approach of applying average pumping rates to the supply wells (see section 4.4. Pumpage and On-site Recharge).

Precipitation records for Long Island (obtained from the NOAA database) were also reviewed to ensure that groundwater recharge from precipitation for the period 1991 through 1993 was representative of average conditions. Precipitation data for 1991, 1992, and 1993 were 43.46, 44.29, and 40.84 inches per year, respectively. The average for the three year period is 42.83 inches per year, essentially the same rate (43.0 inches per year) reported for long-term average conditions.

The model contains a total of 129 head calibration targets. Although the targets are not evenly distributed throughout the entire model domain, they are widely distributed nonetheless, and they thoroughly cover the areas of greatest concern. Vertically, the majority of head calibration targets (106 of 129) are located within the Upper Glacial aquifer (see Figure 5-1 for locations of head calibration targets in the Upper Glacial aquifer). Note that for the purpose of this discussion, Upper Glacial targets are defined as those existing in Model Layers 1, 2, and 3. Within the Upper Glacial aquifer 59, 11, and 36 calibration targets are located in Model Layers 1, 2, and 3, respectively. Of the 106 calibration targets in the Upper Glacial aquifer, 63 of 106 are located on-site. Within the Magothy aquifer, 8, 3, 4, 6, and 2 calibration targets are located in Model Layers 4 through 8, respectively. Of the 23 calibration targets in the Magothy aquifer, 8 of 23 are located on-site (see Figure 5-2 for locations of head calibration targets in the Magothy aquifer). It should be noted that many of the target locations are observation well clusters, therefore, it may appear on Figures 5-1 and 5-2 that there are less targets than stated.

5.2.2 Calibration Results

Four criteria were considered for the steady-state calibration:

1. Simulated flow patterns will adequately reproduce the flow patterns observed in the field (i.e., groundwater flow lines inferred from groundwater level contours).

2. The average of residuals (residual mean and absolute residual mean), where a residual is defined as the difference between an observed and a simulated water level, will be within 5 percent of the range in target heads.

3. The variation of residuals (residual standard deviation) will be within 10 percent of the range in target heads.

4. The distribution of residuals within the model will not show any spatial bias.

The criteria listed above were satisfied during model calibration. Simulated flow patterns match both local groundwater flow patterns in the areas of greatest concern (on-site and in areas downgradient to the south), and regional patterns over the entire model domain. The simulated water-table configuration (Model Layer 1) and calibration residuals for the Upper Glacial aquifer are shown on Figure 5-3. The simulated regional water-table configuration reproduces the regional gradients and flow directions inferred on many of the regional maps presented by the USGS (such as, Doriski 1986). The regional maps developed by others, however, do not reflect the local scale impacts of discharge to on-site basins nor the local impacts of pumping wells. This is not an oversight but rather a function of the regional nature of the maps. The simulated groundwater flow patterns and features of the flow field at the regional and site-wide scales, as described below, are consistent with observed conditions and the conceptual model of the groundwater flow system.

A review of the simulated water-table configuration at the regional scale shows water table elevations above 80 ft msl (at the northern extent of the model) that correspond to the east-west trending groundwater divide located north of the site. To the south of this divide, groundwater flows southerly towards the Great South Bay/Atlantic Ocean. Shallow groundwater passing beneath the site generally flows to the south, eventually discharging to surface-water bodies (streams located near the south shore) or the southern shoreline discharge boundary. Mounding of the water table in the vicinity of the recharge basins is evident, with groundwater flowing radially away from these recharge areas until it becomes more a part of the regional flow system. The basin impact is clearly seen on-site in three basin areas; to the northeast, along the western boundary, and along the southern boundary. A review of the simulated potentiometric surface for the Magothy aquifer at the regional scale also indicates an east-west trending groundwater divide located to the north of the site. Generally, the regional simulated flow patterns for the Magothy are similar to those for the Upper Glacial aquifer, with groundwater flowing to the south of the divide (Figure 5-4). The differences between the maps are seen as cones of depression around pumping wells and the absence of mounding around recharge basin locations and the general increase in the elevation of the water table at the site (due to the recharge basins).

As discussed in Section 5.2.1 (Calibration Targets), the steady-state flow model calibration involved an evaluation of model-generated residuals. A residual was calculated for each head calibration target by subtracting the model-calculated water level from the observed water level (calibration target). A residual near zero signifies a close match between the model results and the observed field condition. The sign of the residual, positive or negative, is as important as the magnitude of the residual. Negative residuals occur where the model-calculated water levels are higher than observed. Conversely, positive residuals indicate that the model-generated water levels are lower than observed. Simulated heads, observed heads, and calculated residuals for each head calibration target are provided in Table 5-1. Table 5-2 summarizes the head calibration statistics by model layer for the entire model area.

The residual mean for the calibrated model was -0.18 ft, as indicated in Table 5-2, and is a negligible percent of the total change in head across the model area (more than 40 ft.) This value, which is close to zero, implies that positive residuals (areas where model-generated water levels are low) and negative residuals (areas where model-generated water levels are high) are relatively balanced within the model domain. The absolute residual mean for the calibrated model was 0.91 ft and is about two percent of the total change in head across the model area. The absolute residual mean is included as an additional measure to evaluate the quality of calibration without compensating errors from the addition of positive and negative residuals. In addition to a residual mean close to zero, the residual standard deviation should be low. The model residual standard deviation was 1.15 ft, which means that most model residuals are in error by no more than 1.15 ft. The residual standard deviation of 1.15 ft is three percent of the total change in head across the model area.

A scatterplot was also constructed for the calibrated model to evaluate patterns and relationships between various calibration targets with respect to residuals. Figure 5-5 shows the scatterplot of observed water levels versus model-calculated water levels with a 45-degree line superimposed for comparison. The scatterplot supports the acceptability of the calibration in that the majority of targets fall along or near the 45-degree line and related targets do not exhibit groupings far from the 45-degree line. The scatterplot, in conjunction with the residual ranges posted on Figure 5-3 and listed in Table 5-1, supports the indication that the distribution of positive and negative residuals does not exhibit significant spatial bias.

5.2.3 Volumetric Flow Budget

As part of the numerical solution effort, MODFLOW output includes a volumetric budget of all inflows, outflows, and changes in groundwater storage. The components must satisfy the continuity equation:

inflow = outflow +/- changes in storage.

Because steady-state conditions were simulated (i.e., no change in storage) all inflows must balance outflows to ensure model accuracy and stability. The model-calculated percent discrepancy between inflows and outflows for the Northrop Grumman flow model was 0.05 percent. This discrepancy indicates that mass was conserved and that the simulation was steady-state. Closure criteria was set at 0.0001 and the Strongly Implicit Procedure (SIP) was used as the solution package.

Inflow to the model included areal recharge (3,425,500 ft^3/d), on-site recharge through recharge basins (817,979 ft^3/d), and an influx from constant heads along the model boundaries (1,472,200 ft^3/d). Model outflows primarily were withdrawal by pumping wells (3,693,600 ft^3/d [this does not include pumpage from wells located within lateral model boundary cells]), and flow to constant head boundaries, primarily along the southern model boundary (2,019,300 ft^3/d). These flows are consistent with the conceptualization of the groundwater flow system.

5.3 SENSITIVITY ANALYSIS

A series of tests were performed to analyze the sensitivity of the simulations made with the model to key parameters input to the flow model. The sensitivity analyses were performed by changing a single parameter at a time while maintaining all other input parameters constant. The simulated aquifer response was compared to the calibrated model output to provide a quantitative estimate of the magnitude of potential error associated with changes in individual input parameters.

Sensitivity analyses focused primarily on horizontal and vertical hydraulic conductivities of the hydrogeologic units, and recharge from precipitation. In each simulation, only one of the parameters (or zone for a specific conductivity value) was varied. Horizontal and vertical hydraulic conductivities of the Upper Glacial aquifer (Model Layers 1, 2, and 3) and the Magothy aquifer were chosen because of the relative uncertainty associated with those values. In addition, sensitivity analyses were performed by others (to whom the model has been distributed) for no-flow boundary conditions as opposed to constant-head boundary conditions (results indicated insignificant changes in simulated water levels at the site). In all, 14 sensitivity runs were simulated.

The results of the sensitivity analyses are summarized in Table 5-3. For each sensitivity run, the residual mean, normalized to the calibrated model statistic, was used as a measure of the model's sensitivity to the changes in input parameters. The normalized residual mean is defined as the average value of the difference between calculated heads for the sensitivity run and heads simulated under calibrated model conditions. As such, the normalized residuals directly indicate the corresponding head difference due to the change implemented in the sensitivity run compared to the calibrated model.

Horizontal and vertical hydraulic conductivities of the Upper Glacial aquifer were increased and decreased by 100 ft/d and 30 ft/d, respectively. Horizontal hydraulic conductivity of the Magothy aquifer was increased and decreased by 20 ft/d and 10 ft/d, respectively. Vertical conductivity of the Magothy was increased and decreased by 2 and 1 ft/d, respectively. Where the Magothy aquifer exists under water-table conditions (northeast corner of the model area) horizontal conductivity was increased and decreased by 100 ft/d. The transitional zone (where reworked Magothy and Glacial material exists) was increased and decreased by 60 ft/d. Finally, groundwater recharge from precipitation was increased and decreased by two inches per year.

The sensitivity analysis indicated that the horizontal hydraulic conductivity values of the Magothy aquifer and recharge from precipitation are the most sensitive parameters. As shown in table 5-3, increases in Magothy horizontal conductivity and recharge resulted in a normalized residual mean of +0.485 and -0.380, respectively. Decreases in the same parameters yielded normalized residual means of -0.317 and +0.367, respectively.

5.4 MODEL VERIFICATION

The calibrated groundwater flow model was verified through simulation of an independent set of observed hydrologic conditions while aquifer stresses were different from those simulated in the calibrated case.

5.4.1 Verification Set-up

The groundwater model was verified to groundwater conditions observed in the Spring of 1993. Water levels measured in observations wells on or about April 1, 1993 were used as the verification target set. This target set included 125 of the 129 data point locations used in the calibrated model run, but is representative of a specific time under specific hydraulic conditions. The on-site demand for water was lowest during the March/April timeframe.

On-site groundwater pumpage data for Northrop Grumman supply wells for the month of March 1993 were applied to the model. Total on-site pumpage at this time was approximately 2.8 mgd and represents approximately 42 percent of the pumpage simulated in the calibration runs. Discharge to on-site recharge basins corresponds directly to on-site pumpage and was therefore adjusted accordingly. These conditions represent a significant change in hydraulic stresses imposed on the local aquifer system as compared to the calibration runs. Off-site pumpage (public water-supply wells) was not changed from the calibrated model.

In addition to on-site changes in pumpage and discharge to basins, groundwater recharge was increased over the entire model domain to simulate the natural increase in recharge to the groundwater system at this time of the year. Precipitation records indicate that March of 1993 was an extremely wet month with over 6 inches of precipitation measured. Because the verification run is a steady-state simulation, however, it would not be appropriate to increase the steady state recharge rate to one that is based on a monthly "event" of this magnitude (corresponding to over 72 inches per year of precipitation). Therefore, the groundwater recharge rate was increased by only 2 inches per year to be more representative of the increased seasonal recharge rate. Geraghty & Miller believes that considering the transient seasonal nature of groundwater recharge on Long Island, this increase is more representative for use in a steady-state application.

5.4.2 Verification Results

The same criteria used for model calibration (see section 5.2.2) were also used for model verification. All verification criteria were met. Simulated flow patterns match both local groundwater flow patterns in the areas of greatest concern (on-site and in areas downgradient to the south), and regional patterns over the entire model domain. In general, observed and simulated regional water levels (verification) are approximately one foot higher than those observed and simulated for the calibration run. In the immediate vicinity of the on-site recharge basins, however, observed water levels are similar in magnitude (verification and calibration). This is likely a function of the increase in the discharge to the basins under the calibration run hydraulic conditions. These trends are simulated by the model. The exceptions are near the Plant 3 basins, where simulated water levels (verification) are approximately 1 foot lower than observed, and at the lateral boundaries of the model, where water levels are influenced by constant head values (constant heads values set for this verification run were not modified from the calibration run). Minor discrepencies seen at the Plant 3 basins are likely a function of the daily fluctuations in discharge to the basins compared with the monthly average discharge rate applied in the model.

As discussed in the Calibration Targets section (section 5.2.1), the verification run also involves an evaluation of model-generated residuals. A residual was calculated for each head calibration target by subtracting the model-calculated water level from the observed water level (calibration target). A residual near zero signifies a close match between the model results and the observed field condition. Negative residuals occur where the model-calculated water levels are higher than observed. Conversely, positive residuals indicate that the model-generated water levels are lower than observed. The residual mean for the verification run was 0.42 ft, and is approximately one percent of the total change in head across the model area (more than 40 ft.) This value, which is close to zero, implies that positive residuals (areas where model-generated water levels are low) and negative residuals (areas where model-generated water levels are high) are relatively balanced within the model domain. The absolute residual mean for the verified model was 0.95 ft and is about two percent of the total change in head across the model area. The absolute residual mean is included as an additional measure to evaluate the quality of calibration without compensating errors from the addition of positive and negative residuals. In addition to a residual mean close to zero, the residual standard deviation should be low. The model residual standard deviation was 1.18 ft, which means that most model residuals are in error by no more than 1.18 ft.

6.0 SUMMARY AND CONCLUSIONS

Geraghty & Miller has completed a comprehensive modeling effort by developing a three-dimensional groundwater flow model for the Northrop Grumman site and the surrounding area. The modeling effort consisted of conceptual model development, model design and construction, model calibration, sensitivity analyses, and verification, and presentation of simulated results of the groundwater flow regime under calibrated, steady-state conditions.

The modeling effort and model design were structured to address critical groundwater issues at and around the Northrop Grumman site. A "systems approach," whereby the complexities of the groundwater system are evaluated as intricately related processes, was used in the modeling effort to allow for assessment of the effects of various potential remedial scenarios and water-supply alternatives on the groundwater resource. The modeling effort was intended to develop and construct a three-dimensional groundwater flow model that will be used as a tool for evaluation of these scenarios and alternatives at varying scales of interest.

The Upper Glacial aquifer has the highest and greatest range of estimated values for hydraulic conductivity due to the variation in deposits encountered (from lower permeability morainal deposits to outwash materials). The Magothy aquifer exhibits less variation in hydraulic characteristics than the Upper Glacial aquifer, but is less permeable and exhibits a higher degree of anisotropy due to stratification of the Magothy deposits.

Artificial stresses imposed on the aquifer system act as internal boundaries and include pumping wells and recharge basins. The horizontal direction of groundwater flow at Northrop Grumman is locally influenced by pumping supply wells and recharge basins. Pumping wells locally depress the water table, while recharge basins may produce local groundwater mounding.

The modular finite-difference groundwater flow code, known as MODFLOW, was selected for the groundwater flow model. The goal of model design and construction was to provide a consistent numerical representation of the conceptualized groundwater system. Model construction was accomplished by completing the following steps: discretization, definition of boundary conditions, parameter zonation, and representation of hydraulic stresses such as groundwater pumpage and recharge basins.

Discretization of the model domain into a finite-difference grid was conducted after careful consideration of project goals. The grid design also considered several additional factors, such as the level of detail of the data available to define the hydrogeologic framework and hydraulic characteristics, the ability to define and represent boundary conditions and stresses, and the amount and distribution of hydraulic head data for calibration. The grid design addressed all three dimensions by also including a vertical discretization scheme that resulted in eight model layers. Model Layers 1 and 2 represent the Upper Glacial aquifer; Model Layer 3 is representative of the Upper Glacial and Magothy (depending on local erosion); Model Layers 4, 5, 6, 7, and 8 represent the Magothy aquifer.

Appropriate mathematical boundary conditions, based on actual groundwater system boundaries where possible, were specified to define the lateral, upper, and lower boundaries of the flow model. In general, these boundary conditions include constant head and constant flux. Active pumping wells simulated in the calibrated model included industrial wells located on-site, and public water supply wells located off-site within the model domain. Sources of artificial recharge simulated in the calibrated model included on-site recharge basins, which return much of the supply water to the groundwater system.

The groundwater flow model was calibrated to steady-state groundwater conditions represented by average 1991 to 1993 flow conditions. Observed measurements considered as calibration targets included water levels from 129 on-site and off-site wells located within different portions of the aquifer system. In addition, specific water-level calibration criteria were considered, including reproducibility of observed flow patterns (i.e., water level contours) as well as several statistical measures (residual mean, absolute residual mean, residual standard deviation, and distribution of residuals). The residual mean for the calibrated model was -0.18 ft, which is close to zero, implying that positive residuals and negative residuals are relatively balanced within the model domain. Review of the distribution of residuals indicated that significant spatial bias was not exhibited. In addition, the model residual standard deviation was 1.15 ft, which means that most model residuals are in error by no more than 1.15 ft. The model was successfully calibrated to the specified criteria. The simulated groundwater flow patterns and features of the simulated flow field at the regional and site-wide scales are consistent with the conceptual model of the groundwater flow system. To increase the level of confidence in the models' ability to simulate the real system, a verification simulation was run. The model successfully simulated observed water levels under a set of hydraulic conditions that were different than those used in the calibration run.

In conclusion, the resultant model design provides a consistent numerical representation of the conceptualized groundwater system for evaluation of potential impacts on the aquifer system. In addition, because the model was constructed using MODFLOW, widely used transport codes can be readily implemented with additional input for evaluation of advective transport or general evaluations of solute transport.

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Table 2-1. Hydrogeologic units in the Vicinity of the Northrop Grumman Site, Groundwater Flow Model, Northrop Grumman Corporation, Bethpage, New York.

Geologic Unit	Hydrogeologic Unit	Approximate Maximum Thickness (Feet)	Character Of Deposits And Water-Bearing Properties.
Recent deposits and fill	Recent deposits	10	Sand, gravel, clay, silt, organic mud, loam, and fill. Constitutes soil zone and fill area and is hydraulically connected to underlying Upper Glacial aquifer.
Upper Pleistocene deposits	Upper Glacial aquifer	75	Sand, fine to coarse, gravel, glacial outwash deposits, commonly brown or tan but may be yellow or orange. Some thin local lenses of clay or silty zones. Outwash deposits are moderately to highly permeable.
Magothy Formation-Matawan Group, undivided	Magothy Aquifer	650	Sand, fine to medium, clayey in part; interbedded with lenses and layers of coarse sand and sandy and solid clay. Gravel is common in basal zone. Sand and gravel are quartzose. Lignite, pyrite, and iron oxide concretions are common. Colors are gray, white, red, brown, and yellow. Most layers are poorly to moderately permeable; some are highly permeable locally. Water is unconfined in uppermost parts, elsewhere confined. Principle aquifer for public supply.
Raritan Formation	Raritan confining unit	175	Clay, solid and silty; few lenses and layers of sand. Lignite and pyrite are common. Colors are gray, red, and white, commonly variegated. Low to very low permeability; constitutes confining layer above Lloyd aquifer.
	Lloyd aquifer	300	Sand, fine to coarse, and gravel, commonly with clayey matric, some lenses and layers of solid and silty clay; locally contains thin lignite layers. Sand and most of gravel are quartzose. Colors are yellow, gray, and white; clay is red locally. Permeability low to moderate. Water is confined by overlying Raritan clay.
Bedrock	Bedrock		Crystalline and metamorphic and (or) igneous rocks; muscovite-biotite schist, gneiss, and granite. Contains a soft, clayey weathered zone more than 50 ft thick locally. Poorly permeable to relatively impermeable; forms lower boundary of ground-water system.

Modified from Smolensky and Feldman, 1995

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Table 4-1. Hydrogeologic Units and Model Layering Scheme in the Vicinity of the Northrop Grumman Site, Groundwater Flow Model, Northrop Grumman Corporation, Bethpage, New York.

Model Layer	Hydrogeologic Unit	Bottom Elevation (ft msl)
1	Upper Glacial (Magothy Aquifer northeast of site)	40
2	Upper Glacial (Magothy Aquifer northeast of site)	25
3	Upper Magothy Aquifer (locally Upper Glacial northwest of site)	-50
4	Magothy Aquifer	-140
5	Magothy Aquifer	-235
6	Magothy Aquifer	-365
7	Magothy Aquifer	-530
8	Magothy Aquifer	-600

ft msl feet relative to mean sea level.

Table 4-2. Summary of On-Site Pumpage for the Calibrated Flow Model, Groundwater Flow Model, Northrop Grumman Corporation, Bethpage, New York.

Well Designation	NYSDEC Well Number	Location in Model Grid I (row)	J (col)	K (layer)	Pumping Rate (cfd)	(mgd)	(gpm)
GP-1	N8842	53	29	7	202,188	1.51	1,050
GP-2	N8154	43	30	6	14	0	0
		43	30	7	8	0	0
GP-3	N8124	48	27	7	9,479	0	49
GP-4	N1923	50	29	5	17	0	0
GP-5	N7635	37	27	5	106	0	1
GP-6	N7534	35	22	5	52,494	0	273
GP-8	N7535	26	30	5	1,755	0	9
GP-9	N7536	28	32	6	71,410	1	371
GP-10	N7636	27	35	5	121,202	1	630
GP-11	N7637	29	38	6	100,534	0.75	522
GP-13	N8454	22	34	7	113,188	0.85	588
GP-14	N8643	30	29	6	7,837	0	41
GP-15	N8816	26	40	6	58,192	0	302
GP-16	N7518	17	42	5	142,318	1.06	739
TOTALS					880,741	6.59	4,575

cfd Cubic feet per day.
mgd Million gallons per day.
gpm Gallons per minute.
NYSDEC New York State Department of Environmental Conservation.

Table 4-3. Summary of Off-Site Pumpage for the Calibrated Flow Model, Groundwater Flow Model, Northrop Grumman Corporation, Bethpage, New York.

Water District Name	Local Well Number	NYSDEC Well Number	Location in Model Grid I (row)	J (col)	K (layer)	Pumping Rate (cfd)	Total Pumping Rate (mgd)	Total Pumping Rate (gpm)
Bethpage Water District								
	5-1	N-8004	89	59	8	14,075	0.11	73
	6-1	N-3876	83	46	6	44,531	0.33	231
	6-2	N-8941	83	46	8	25,738	0.19	134
	7	N-8767	22	62	7	161,454	1.21	839
	8	N-8768	23	62	7	114,971	0.86	597
	9	N-6078	19	62	4	5	0.00	0
	10	N-6915	80	62	6	27,890	0.40	279
			80	62	7	25,745		
	11	N-6916	82	62	7	57,735	0.43	300
	BDG-1	N-09591	30	65	7	4,959	0.07	52
			30	65	8	4,959		
Hicksville Water District								
	1-4	N-7562	4	6	6	35,305	0.26	183
	1-6	N-09488	4	6	7	147,202	1.10	765
	3-2	N-8525	45	5	6	78	0.00	0
	4-2	N-8526	35	1	7	45,465	0.34	236
	7-1	N-6190	1	11	7	2,434	0.02	13
	8-1	N-6192	23	6	7	72,223	0.54	375
	8-3	N-9180	22	5	7	49,819	0.37	259
	9-1	N-8778	13	10	7	88,588	0.66	460
	9-2	N-8779	13	10	7	63,691	0.48	331
	9-3	N-10208	13	8	7	83,879	0.63	436
	10-1	N-09463	6	3	7	127,327	0.95	661
	11-1	N-10555	7	26	7	90,224	0.67	469

Table 4-3. Summary of Off-Site Pumpage for the Calibrated Flow Model, Groundwater Flow Model, Northrop Grumman Corporation, Bethpage, New York.

Water District Name	Local Well Number	NYSDEC Well Number	Location in Model Grid I (row)	J (col)	K (layer)	Pumping Rate (cfd)	Total Pumping Rate (mgd)	(gpm)
Levittown Water District								
	6A	N-3618	85	5	6	23,260	0.17	121
	5A	N-7076	85	6	7	49,411	0.74	513
			85	6	8	49,411		
	14	N-5304	102	5	7	77,112	0.58	401
	13	N-5303	99	13	7	75,685	0.57	393
	12	N-5302	99	1	7	57,175	0.43	297
	8A	N-7523	97	7	8	105,838	0.79	550
	2A	N-8321	71	1	7	36,614	0.49	340
			71	1	8	28,768		
	7A	N-8279	97	7	6	21,727	0.51	353
			97	7	7	46,169		
	9	N-4450	90	2	6	101,858	1.09	756
			90	2	7	43,653		
	10	N-4451	57	5	6	5	0.00	0
Plainview Water District								
	1-1	N-4095	5	67	6	78,305	0.59	407
	1-2	N-4096	5	68	6	62,154	0.46	323
	2-1	N-7526	3	68	6	5,926	0.15	103
			3	68	7	13,828		
	3-1	N-4097	4	47	6	8,985	0.07	47
	3-2	N-6580	5	47	6	24,401	0.79	551
			5	47	7	81,691		
	4-1	N-6076	3	59	5	13,343	0.10	69
	4-2	N-6077	3	60	6	79,735	0.60	414

Table 4-3. Summary of Off-Site Pumpage for the Calibrated Flow Model, Groundwater Flow Model, Northrop Grumman Corporation, Bethpage, New York.

Water District Name	Local Well Number	NYSDEC Well Number	Location in Model Grid I (row)	J (col)	K (layer)	Pumping Rate (cfd)	Total Pumping Rate (mgd)	(gpm)
South Farmingdale Water District								
	1-2	N-4043	100	66	6	56,131	0.42	292
	1-3	N-05184	99	66	6	21,701	0.16	113
	1-4	N-7377	99	66	7	42,244	0.57	399
			99	66	8	34,564		
	3-1	N-6150	101	44	7	104,979	0.79	545
	6-1	N-8664	104	41	7	53,108	0.40	276
	6-2	N-8665	104	40	7	48,749	0.36	253
New York Water Service Corporation								
	3-S	N-8480	102	27	7	171,009	1.28	888
	4-S	N-9338	102	26	7	260,946	1.95	1,356
TOTALS						3,166,781	24	16,451

cfd Cubic feet per day.
mgd Million gallons per day.
gpm Gallons per minute.
NYSDEC New York State Department of Environmental Conservation.

Table 4-4. Summary of On-Site Discharge to Basins for the Groundwater Flow Model, Northrop Grumman Corporation, Bethpage, New York.

Recharge	Location in Model Grid I (row)	J (col)	K (layer)	Cell Recharge Rate (cfd)	Total Recharge Rate (mgd)	(gpm)
Recharge Basins						
Plant 3	27	45	1	26,341	3.15	2,189
	27	46	1	26,341		
	28	41	1	26,341		
	28	42	1	26,341		
	28	45	1	26,341		
	28	46	1	26,341		
	29	41	1	26,341		
	29	42	1	26,341		
	29	43	1	26,341		
	30	43	1	26,341		
	30	44	1	26,341		
	30	45	1	26,341		
	30	46	1	26,341		
	31	45	1	26,341		
	31	46	1	26,341		
	29	44	1	26,341		
Plant 5	48	25	1	49,870	1.49	1,036
	49	26	1	49,870		
	50	26	1	49,870		
	51	27	1	49,870		
Plant 12	31	21	1	4,522	0.07	47
	31	22	1	4,522		
Southern Boundary	62	36	1	18,800	1.41	977
	63	38	1	18,800		
	63	40	1	18,800		
	64	41	1	18,800		
	64	43	1	18,800		
	62	35	1	18,800		
	63	37	1	18,800		
	63	39	1	18,800		
	64	42	1	18,800		
	64	44	1	18,800		
Total				817,979	6.12	4,249

cfd Cubic feet per day
mgd Million gallons per day.
gpm Gallons per minute.

Table 5-1. Summary of Observed and Simulated Water-Level Elevations, and Residuals, Groundwater Flow Model, Northrop Grumman Corporation, Bethpage, New York.

Well Designation	Location in Model Grid I (row)	J (col)	K (layer)	Observed Head (ft msl)	Simulated Head (ft msl)	Residual (Observed minus Simulated) (ft)
gm-1s	10	35	1	72.42	71.69	0.73
gm-1i	10	35	3	72.37	71.62	0.75
gm-2s	13	42	1	72.39	70.82	1.57
gm-2i	14	43	3	71.43	70.54	0.89
gm-3s	14	24	2	71.4	70.53	0.87
gm-3i	16	24	3	70.78	70.12	0.66
gm-4s	17	24	1	73.1	70.03	3.07
gm-4i	17	24	3	70.75	69.95	0.8
gm-5s	21	27	1	70.53	69.3	1.23
gm-5i	21	27	3	70.29	69.2	1.09
gm-6i	21	35	3	64.92	69.29	-4.37
gm-7s	23	40	1	70.95	70.38	0.57
gm-7i	23	40	3	70.72	70.12	0.6
gm-7d	23	40	4	68.72	68.87	-0.15
gm-8s	26	45	1	73.37	73.32	0.05
gm-8i	26	45	3	73.28	72.18	1.1
gm-9s	25	24	1	69.85	68.83	1.02
gm-9i	25	24	3	69.69	68.76	0.93
gm-10i	31	20	3	68.93	68.29	0.64
gm-12s	35	30	1	68.78	68.04	0.74
gm-12i	35	30	3	68.22	67.93	0.29
gm-13s	40	38	1	68.53	68.19	0.34
gm-13i	40	38	3	68.64	68.1	0.54
gm-13d	43	36	4	66.66	67.2	-0.54
gm-14s	43	41	1	67.38	67.83	-0.45
gm-14i	45	39	3	67.27	67.35	-0.08
gm-15s	52	50	1	65.46	66.11	-0.65
gm-15i	59	53	3	64.69	64.5	0.19
gm-16i	46	33	3	67.67	67.26	0.41
gm-16s	46	33	1	67.77	67.36	0.41
gm17-s	49	26	1	70.73	69.87	0.86
gm-18s	58	30	1	65.66	65.42	0.24
gm-18i	57	30	3	66.2	65.52	0.68
gm-19s	59	46	1	65.64	65.09	0.55
gm-19i	59	46	3	65.51	65.02	0.49
gm-20s	64	36	1	65.48	64.99	0.49
gm-20i	64	36	3	64.86	64.62	0.24
gm-20d	64	36	4	63.88	63.97	-0.09
gm-21s	65	41	1	65.71	65.01	0.7
gm-21i	65	41	3	64.91	64.5	0.41
gm-22s	65	46	1	66.46	63.94	2.52
gm-22i	65	46	3	65.35	63.78	1.57
gm-22d	65	46	4	63.12	63.39	-0.27
gm-23s	37	23	1	67.83	67.78	0.05
gm-23i	37	23	3	67.82	67.65	0.17
gm-32s	49	34	1	66.71	66.96	-0.25
gm-33d2	60	31	7	60.07	61.94	-1.87
gm-35d2	76	40	7	57.06	57.97	-0.91
gm-36d2	79	54	7	54.61	55.87	-1.26
gm-36d	79	54	4	56.5	56.96	-0.46
gm-38d2	84	59	7	51.37	53.24	-1.87

Well Designation	Location in Model Grid I (row)	J (col)	K (layer)	Observed Head (ft msl)	Simulated Head (ft msl)	Residual (Observed minus Simulated) (ft)
gm-37d	73	60	5	58.2	59.19	-0.99
gm-37d2	73	60	6	57.82	58.88	-1.06
gm-38d	84	59	6	52.56	53.74	-1.18
hn-8d	28	47	4	68.81	70.87	-2.06
hn-24s	32	31	1	69.49	68.26	1.23
hn-24i	32	31	3	68.12	68.11	0.01
hn-25s	28	36	1	69.91	69.36	0.55
hn-25i	28	36	3	69.51	69	0.51
hn-25d	28	36	4	67.05	66.68	0.37
hn-26s	28	40	1	73.57	72.23	1.34
hn-26i	28	40	3	71.49	71.07	0.42
hn-27i	31	41	3	71.83	71.17	0.66
hn-28s	33	41	1	70.56	70.7	-0.14
hn-28i	33	42	3	68.52	70.69	-2.17
hn-29s	35	39	1	70.51	69.32	1.19
hn-29i	35	39	3	68.88	69.18	-0.3
hn-29D	35	39	4	66.67	68.43	-1.76
hn-30s	31	46	1	71.6	74.13	-2.53
hn-30i	31	46	3	70.19	72.24	-2.05
gm-34d	81	30	6	56.59	56.17	0.42
gm-34d2	81	30	7	55.01	55.97	-0.96
hn-40s	45	48	1	66.39	67.52	-1.13
hn-40i	45	48	3	66.31	67.46	-1.15
hn-41s	54	53	1	64.47	65.6	-1.13
hn-41i	54	53	3	63.85	65.57	-1.72
hn-42s	37	49	1	68.47	69.44	-0.97
hn-42i	37	49	3	68.07	69.34	-1.27
1231	5	65	1	74.93	76.46	-1.53
1232	17	65	1	71.1	71.92	-0.82
1234	73	65	1	58.62	59.58	-0.96
1236	101	66	2	41.72	40.84	0.88
8888	1	10	1	80.29	82.92	-2.63
9079	32	15	1	67.97	68.44	-0.47
9654	92	21	2	51.99	51.6	0.39
9658	104	27	2	36	36.41	-0.41
9660	104	66	2	35.03	35.91	-0.88
9661	93	65	2	51.19	49.75	1.44
9918	52	6	2	64.13	65.88	-1.75
9919	10	3	1	72.1	74.36	-2.26
9920	7	19	1	74.48	74.13	0.35
9921	73	31	1	60.17	60.43	-0.26
9922	4	1	1	78.22	79.92	-1.7
9928	87	25	1	53.1	54.02	-0.92
9930	92	68	1	48.87	49.92	-1.05
9931	41	49	1	67.14	68.39	-1.25
9932	8	54	2	73.9	73.55	0.35
9981	4	39	2	77.8	77.03	0.77
10591	17	54	1	71.58	71.09	0.49
10592	32	64	2	68.96	69.41	-0.45
10593	24	22	1	69.84	69.04	0.8
10594	29	25	1	69.57	68.41	1.16

Table 5-1. Summary of Observed and Simulated Water-Level Elevations, and Residuals, Groundwater Flow Model, Northrop Grumman Corporation, Bethpage, New York.

Well Designation	Location in Model Grid I (row)	J (col)	K (layer)	Observed Head (ft msl)	Simulated Head (ft msl)	Residual (Observed minus Simulated) (ft)
10597	44	15	1	67.04	67.16	-0.12
10600	63	23	1	62.76	63.65	-0.89
10602	77	34	1	60.59	58.62	1.97
10603	78	23	1	57.89	58.05	-0.16
10627	71	32	5	60.86	60.8	0.06
10628	70	55	1	60.33	61.26	-0.93
10631	62	31	1	63.55	64.5	-0.95
10633	68	45	1	62.36	62.91	-0.55
10634	69	41	1	60.36	62.68	-2.32
10635	77	31	1	58.9	58.6	0.3
10636	62	13	1	63.26	63.55	-0.29
10813	70	20	1	61.21	61.36	-0.15
10814	82	50	2	56.26	55.91	0.35
10815	80	13	1	57.3	57.04	0.26
10816	90	39	1	52.5	52.57	-0.07
10818	85	41	1	54.65	54.7	-0.05
10820	81	30	3	57.44	56.7	0.74
10821	80	53	1	56.81	56.78	0.03
10822	80	13	3	57.46	57	0.46
10977	73	65	8	56.75	58.3	-1.55
10999	92	29	6	51.83	51.06	0.77
11000	92	29	3	51.92	51.61	0.31
11067	73	65	3	57.07	59.53	-2.46
11722	101	5	5	40.1	41.19	-1.09
11723	101	5	8	37.47	40.05	-2.58
11724	10	66	3	72.1	73.66	-1.56
11731	10	66	7	70.78	72.25	-1.47

ft msl Elevation in feet above mean sea level

Table 5-2. Summary of Head Calibration Statistics, Groundwater Flow Model, Northrop Grumman Corporation, Bethpage, New York.

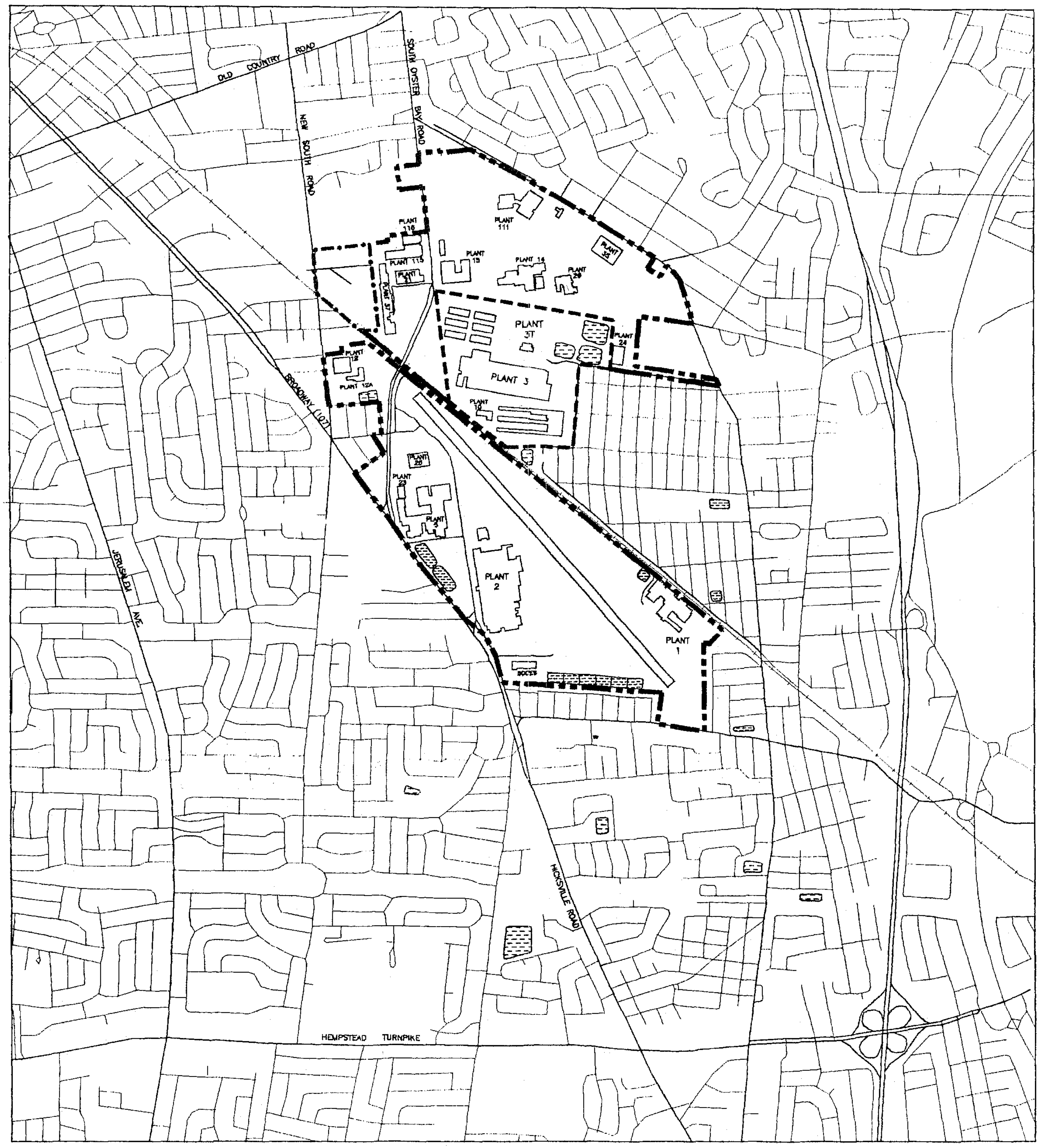
Layer	Number of Targets	Residual Mean	Residual Standard Deviation	Absolute Residual Mean
1	59	-0.047321	1.144789	0.888437
2	11	0.141799	0.883136	0.776525
3	36	-0.043084	1.230547	0.907337
4	8	-0.620859	0.790201	0.713014
5	3	-0.674157	0.519758	0.713133
6	4	-0.262039	0.868422	0.858083
7	6	-1.388095	0.388341	1.388095
8	2	-2.065014	0.511937	2.065014
Total Model	129	-0.18	1.15	0.909753

Table 5-3. Summary of Sensitivity Analysis Statistics, Groundwater Flow Model, Northrop Grumman Corporation, Bethpage, New York.

Parameter Tested	Calibrated Value	Type of Change	Parameter Changed to	Normalized Residual Mean
Upper Glacial K(h)	300 ft/d	Increase	400 ft/d	+ 0.264
		Decrease	200 ft/d	- 0.294
Shallow Magothy K(h)	200 ft/d	Increase	300 ft/d	- 0.156
		Decrease	100 ft/d	+ 0.166
Magothy K(h)	30 ft/d	Increase	50 ft/d	+ 0.485
		Decrease	20 ft/d	- 0.317
Transitional Zone K(h)	120 ft/d	Increase	180 ft/d	+ 0.017
		Decrease	60 ft/d	- 0.049
Upper Glacial K(v)	60 ft/d	Increase	90 ft/d	- 0.004
		Decrease	30 ft/d	- 0.008
Magothy K(v)	2 ft/d	Increase	4 ft/d	+ 0.23
		Decrease	1 ft/d	- 0.43
Groundwater Recharge	22.36 in/yr	Increase	24.36 in/yr	- 0.380
		Decrease	20.36 in/yr	+ 0.367

ft/d feet per day
in/yr inches per year
K(h) Horizontal hydraulic conductivity
K(v) Vertical hydraulic conductivity

DWG DATE: 08OCT97 | PRJCT NO. NY0008.068-2 | HARD FILE: GRUM | DRAWING: SITEB | CHECKED: JS | APPROVED: CSG | DRAFTER: A.WARREN



EXPLANATION

RECHARGE BASIN

PROPERTY BOUNDARY OF NORTHROP GRUMMAN CORPORATION

PROPERTY BOUNDARY OF THE U.S. NAVY SITE

PROPERTY BOUNDARY OF THE OCC/RUCO SITE

N

NOTE:

WELL INVENTORY REVISED BETWEEN AUGUST 4 AND AUGUST 23, 1995; WELL DATA OBTAINED FROM UNITED STATES GEOLOGICAL SURVEY, NASSAU COUNTY DEPARTMENT OF PUBLIC WORKS, NASSAU COUNTY DEPARTMENT OF HEALTH, AND THE NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION.

0 2000 FT

GERAGHTY & MILLER, INC.
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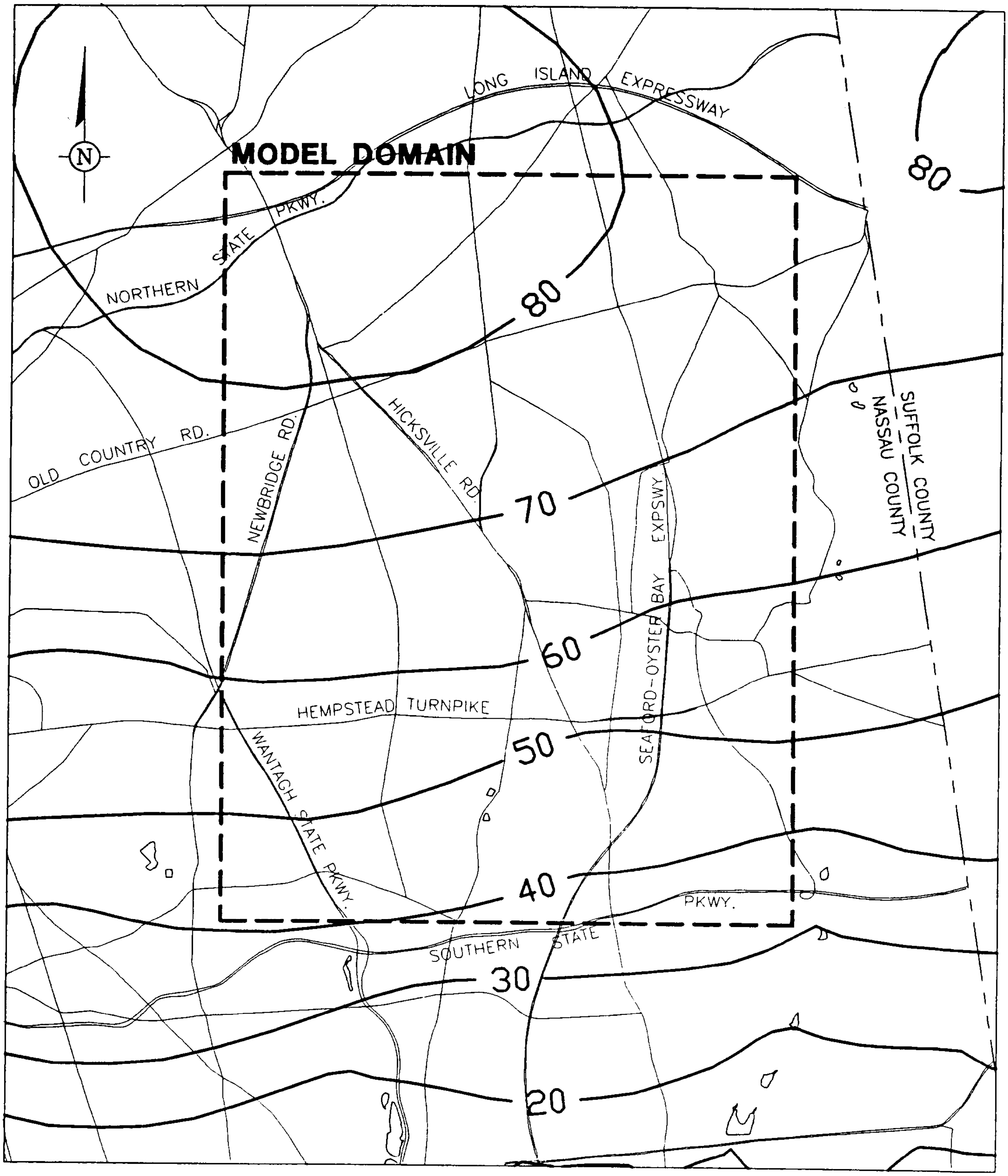
A Heidemij Company

REGIONAL SITE LOCATION

GROUNDWATER FLOW MODEL
NORTHROP GRUMMAN CORPORATION
BETHPAGE, NEW YORK

FIGURE 2-1

0109C012



— 20 — LINE OF EQUAL WATER-TABLE ELEVATION, IN FEET ABOVE MEAN SEA LEVEL

0 6000 FT

DRAFTER: W.H.CICIO | APPROVED: C.S.G. | CHECKED: R.P. | DRAWING: WT-CONFG | HARD FILE: | PRJCT NO.: NY0008.123T2 | DWG DATE: 29OCT97

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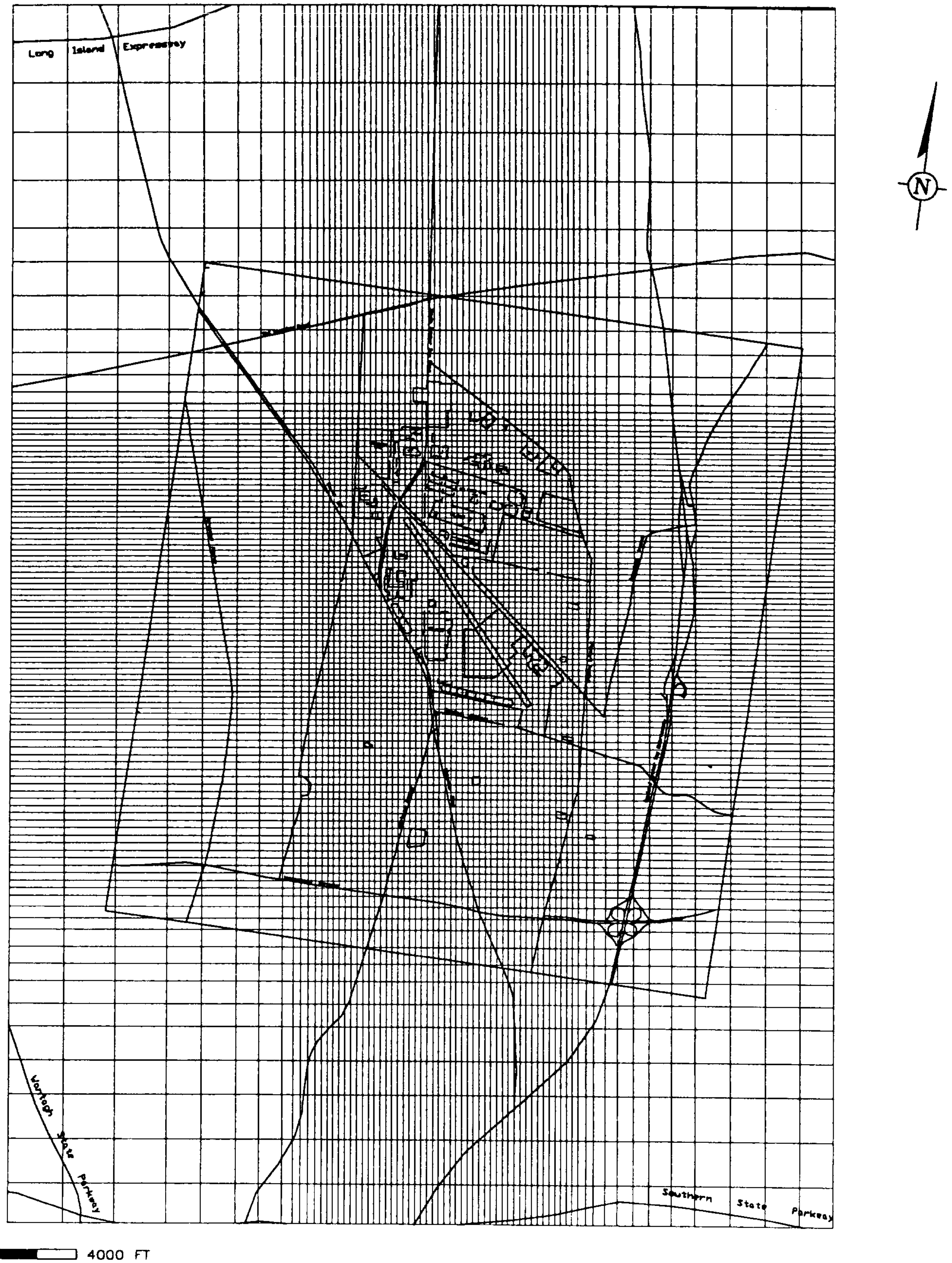
GENERALIZED WATER-TABLE CONFIGURATION AND EXTENT OF MODEL DOMAIN

GROUNDWATER FLOW MODEL
NORTHROP GRUMMAN CORPORATION
BETHPAGE, NEW YORK

FIGURE 2-2



DRAFTER: B.CICIO
APPROVED: CSG
CHECKED: RP
DRAWING: FIG4-1
PRJCT NO.: NY0008.068-2 FILE NO.:
DWG DATE: 30OCT97

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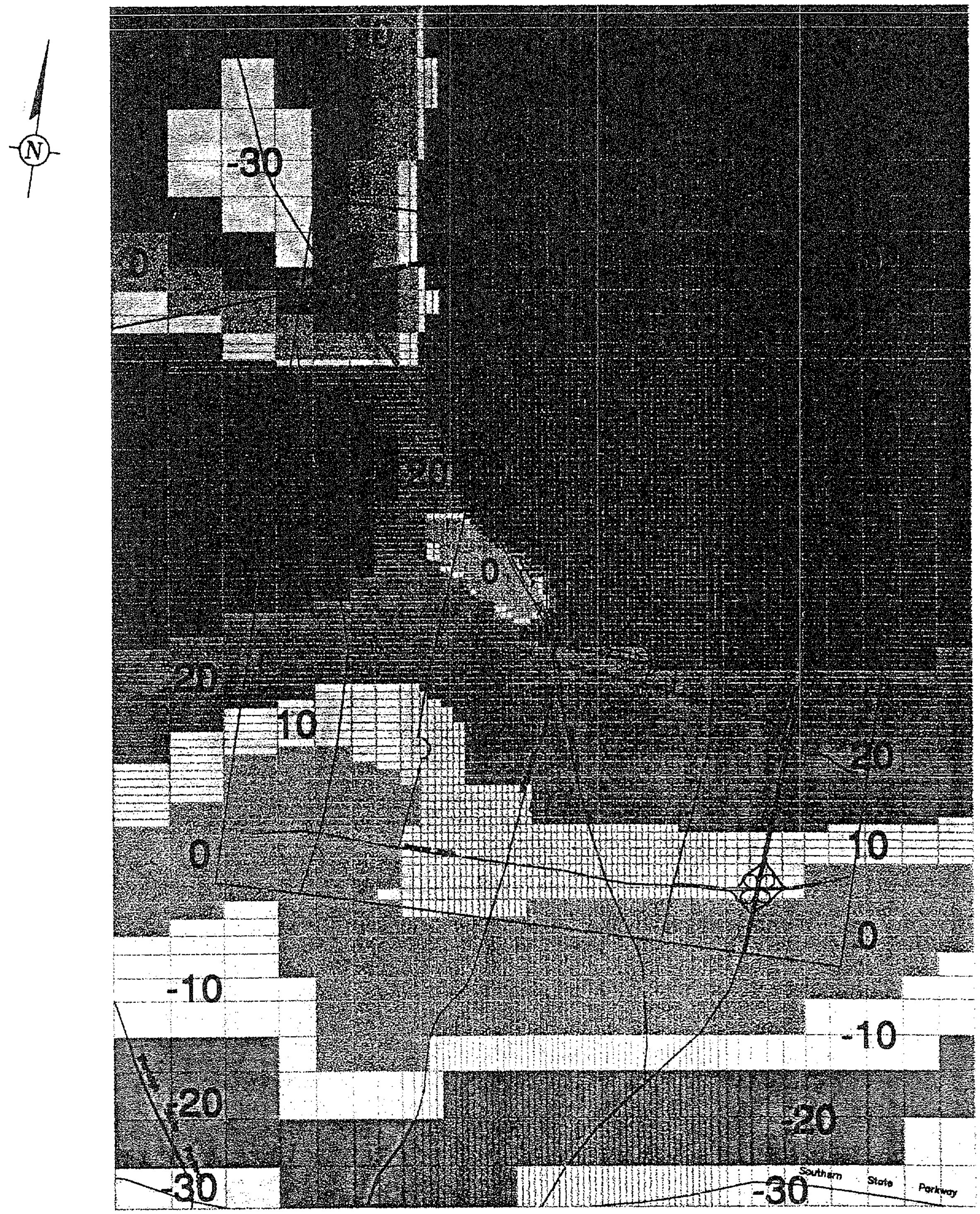
MODEL GRID

GROUNDWATER FLOW MODEL
NORTHROP GRUMMAN CORPORATION
BETHPAGE, NEW YORK

FIGURE
4-1



LEGEND

-30 BOTTOM SURFACE OF UPPER GLACIAL AQUIFER UNIT (FT MEAN SEA LEVEL)

0 4000 FT

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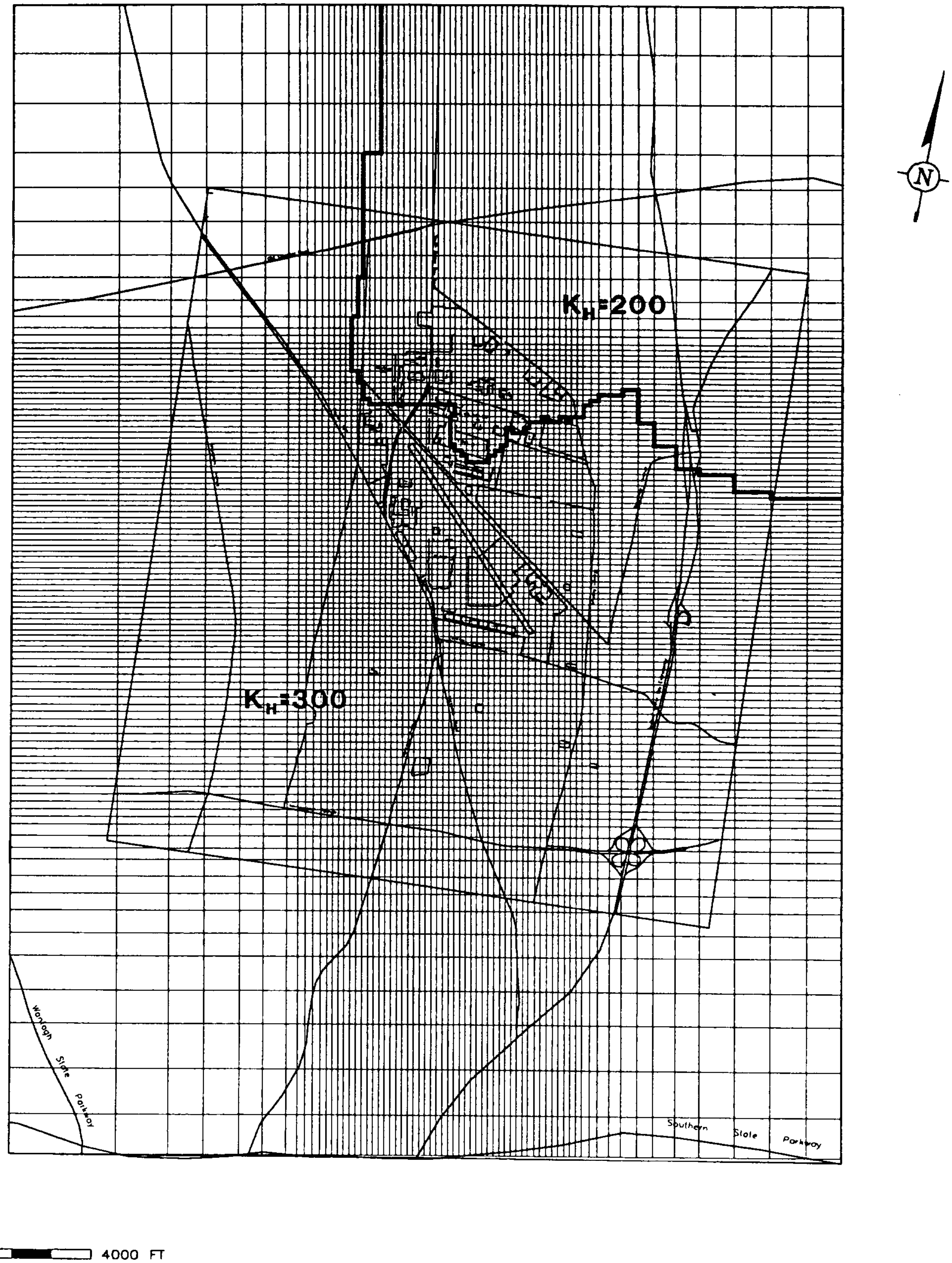
BOTTOM SURFACE OF UPPER GLACIAL AQUIFER MODEL LAYER 2 GROUNDWATER FLOW MODEL

NORTHROP GRUMMAN CORPORATION
BETHPAGE, NEW YORK

FIGURE 4-2

DWG DATE: 09OCT97 | PRJCT NO.: NY0008.068-2 FILE NO.: GRUM | DRAWING: FIG4-2 | CHECKED: JS | APPROVED: CSG | DRAFTER: -



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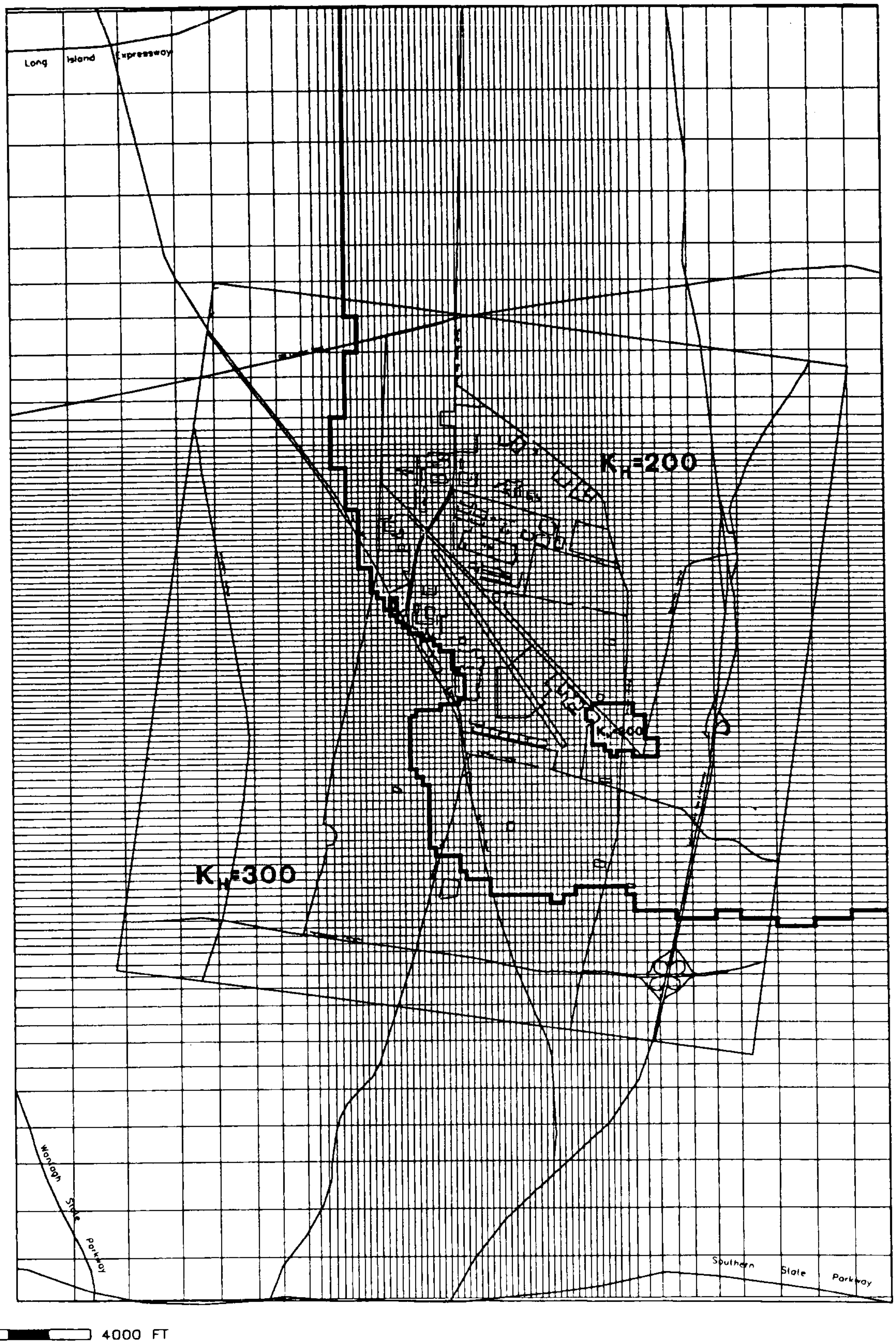
HYDRAULIC CONDUCTIVITY ZONES FOR MODEL LAYER 1

GROUNDWATER FLOW MODEL
NORTHROP GRUMMAN CORPORATION
BETHPAGE, NEW YORK

FIGURE 4-3

DWG DATE: 09OCT97 | PRJCT NO.: NY0008.068-2 | FILE NO.: GRUM | DRAWING: FIG4-4 | CHECKED: JS | APPROVED: CSG | DRAFTER: A.WARREN



DRAFTER: A.WARREN | APPROVED: CSG | CHECKED: JS | DRAWING: FIG4-5 | PRJCT NO.: NY0008.068-2 | FILE NO.: GRUM | DWG DATE: 09OCT97

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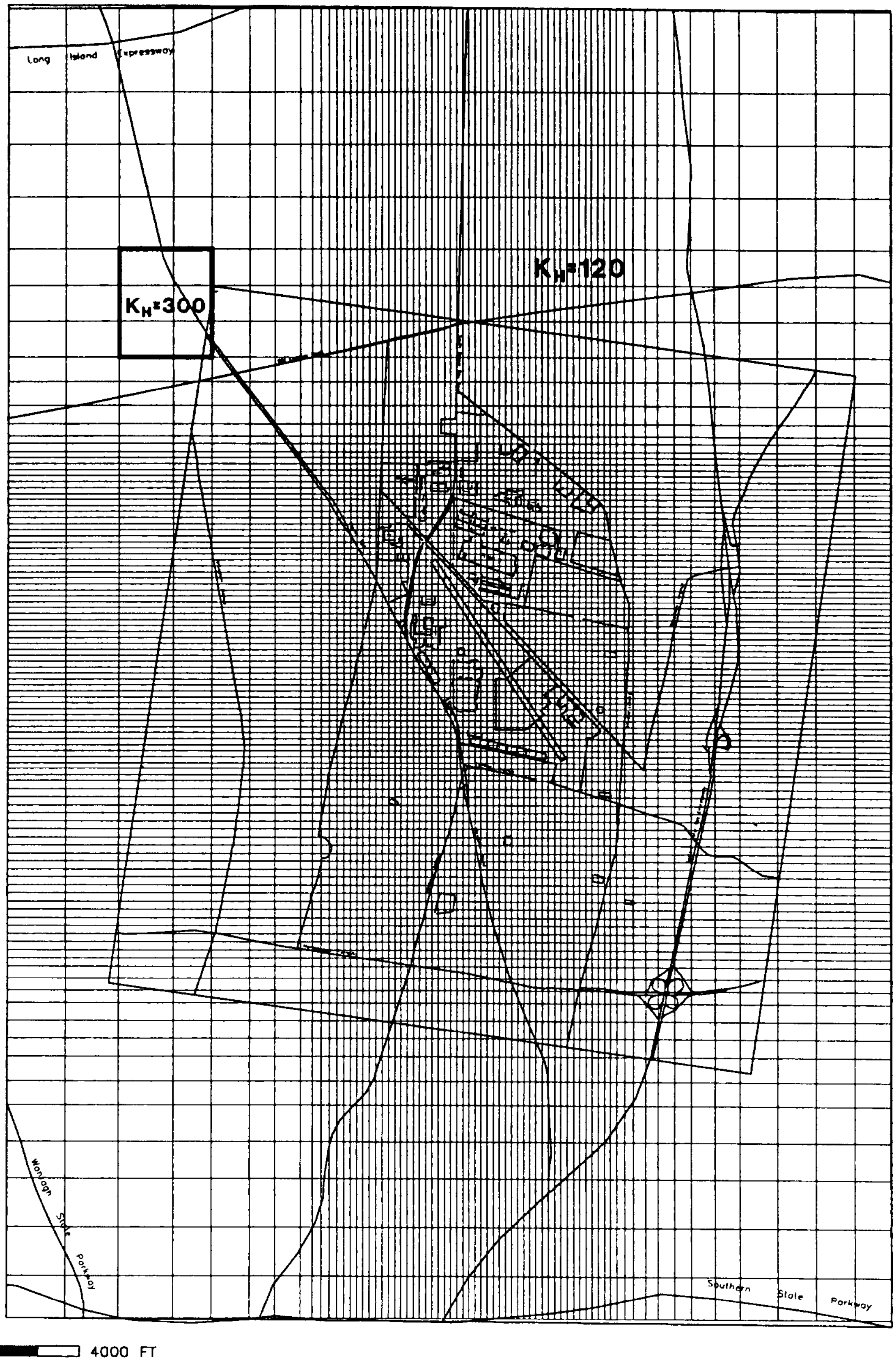
HYDRAULIC CONDUCTIVITY ZONES FOR MODEL LAYER 2

GROUNDWATER FLOW MODEL
NORTHROP GRUMMAN CORPORATION
BETHPAGE, NEW YORK

FIGURE 4-4



DRAFTER: A.WARREN | APPROVED: CSG | CHECKED: JS | DRAWING: FIG4-6 | PRJCT NO.: NY0008.068-2 FILE NO.: | DWG DATE: 29OCT97

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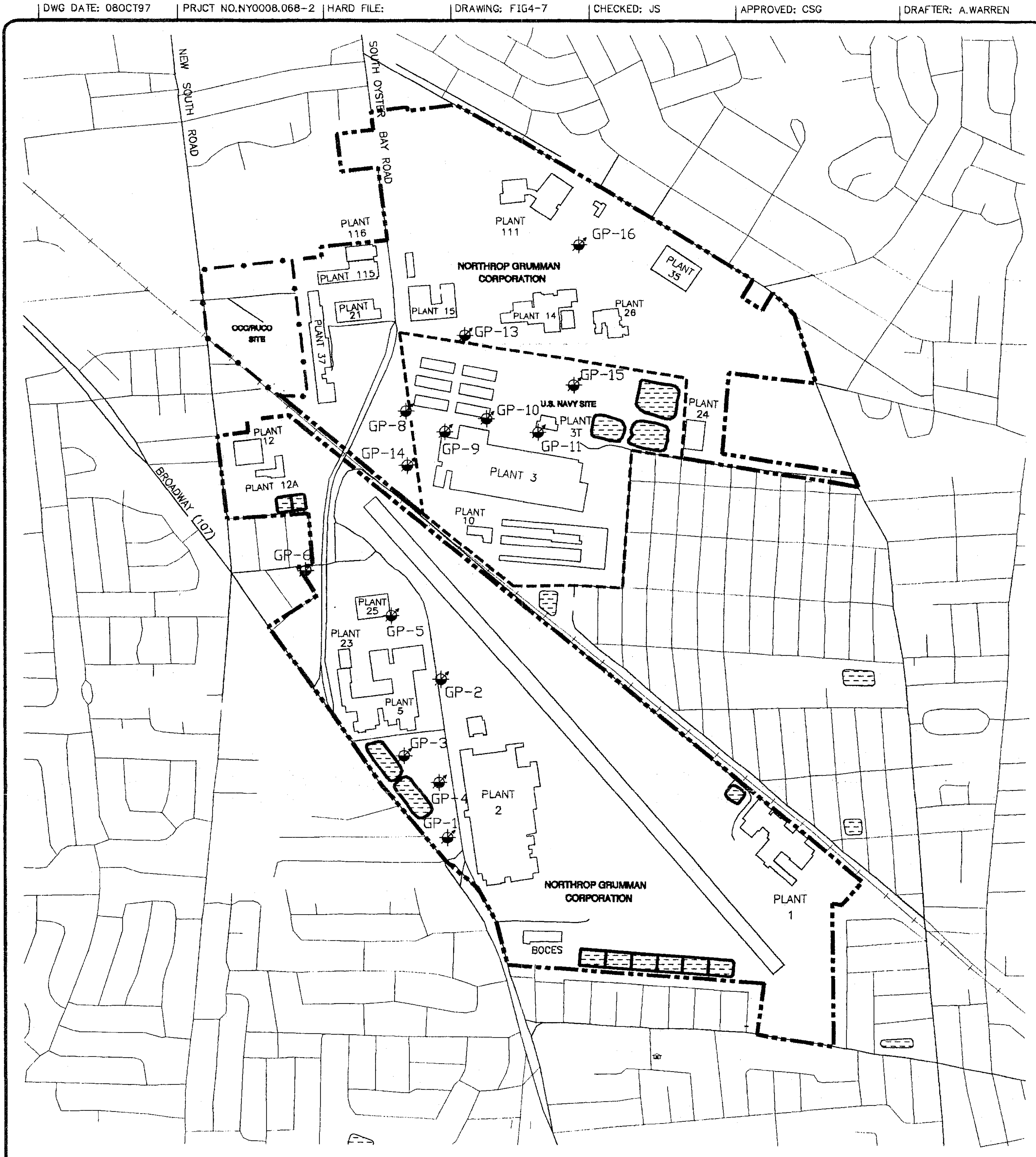
HYDRAULIC CONDUCTIVITY ZONES FOR MODEL LAYER 3

GROUNDWATER FLOW MODEL
NORTHROP GRUMMAN CORPORATION
BETHPAGE, NEW YORK

FIGURE 4-5

DWG DATE: 08OCT97	PRJCT NO.NY0008.068-2	HARD FILE:	DRAWING: FIG4-7	CHECKED: JS	APPROVED: CSG	DRAFTER: A.WARREN



EXPLANATION

- RECHARGE BASIN
- PROPERTY BOUNDARY OF NORTHROP GRUMMAN CORPORATION
- PROPERTY BOUNDARY OF THE U.S. NAVY SITE
- PROPERTY BOUNDARY OF THE OCC/RUCO SITE
- GP-16 — LOCATION AND DESIGNATION OF DEEP GRUMMAN PRODUCTION WELL

0 1000 FT

N

NOTE:
WELL INVENTORY REVISED BETWEEN AUGUST 4 AND AUGUST 23, 1995; WELL DATA OBTAINED FROM UNITED STATES GEOLOGICAL SURVEY, NASSAU COUNTY DEPARTMENT OF PUBLIC WORKS, NASSAU COUNTY DEPARTMENT OF HEALTH, AND THE NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION.

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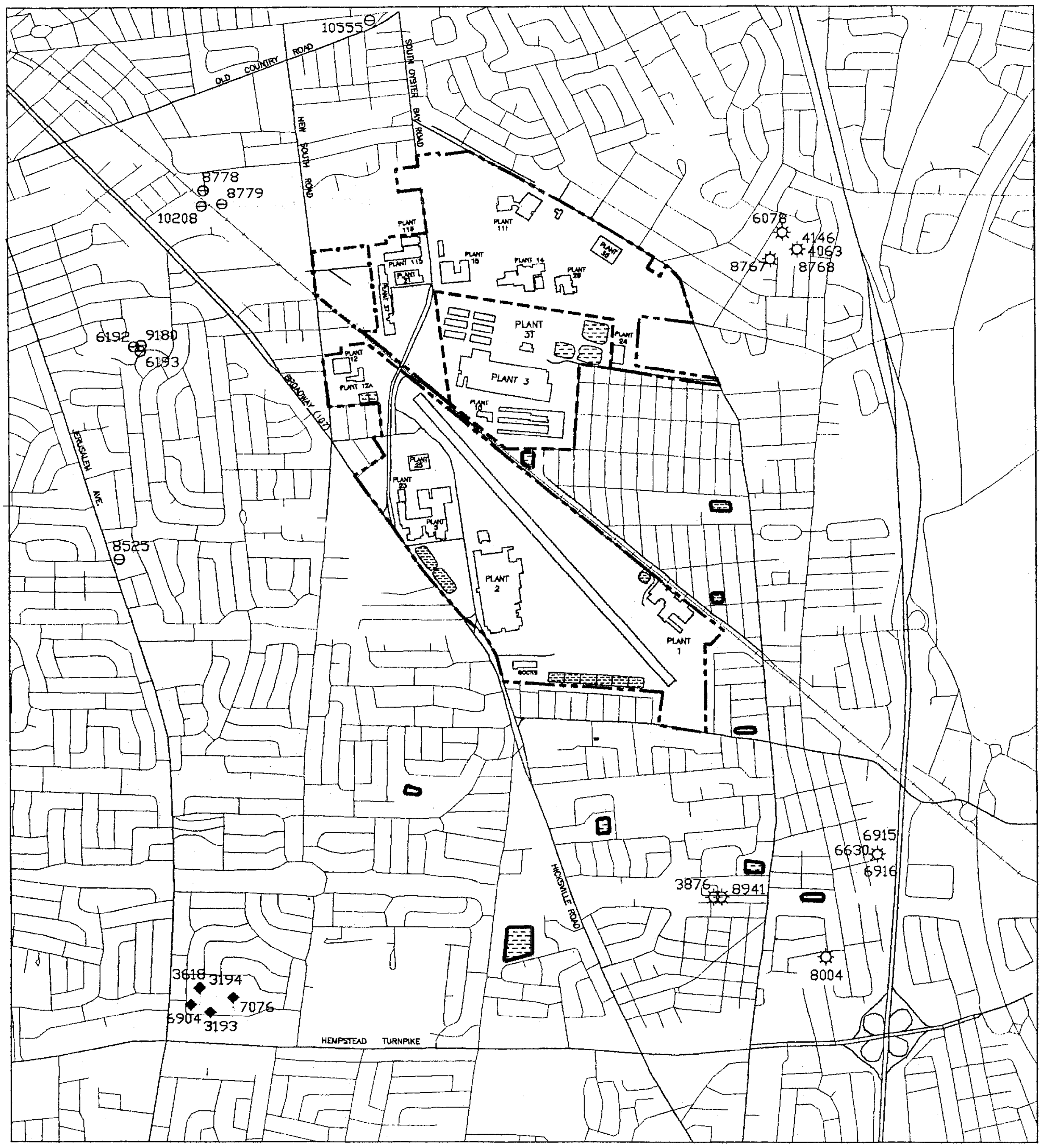
LOCATIONS OF ON-SITE SUPPLY WELLS AND RECHARGE BASINS

GROUNDWATER FLOW MODEL
NORTHROP GRUMMAN CORPORATION
BETHPAGE, NEW YORK

FIGURE 4-6

0109CB2Z

DWG DATE: 08OCT97	PRJCT NO.NY0008.068-2	HARD FILE: GRUM	DRAWING: FIG4-8	CHECKED: JS	APPROVED: CSG	DRAFTER: A.WARREN



EXPLANATION

RECHARGE BASIN

PROPERTY BOUNDARY OF NORTHROP GRUMMAN CORPORATION

PROPERTY BOUNDARY OF THE U.S. NAVY SITE

PROPERTY BOUNDARY OF THE OCC/RUCO SITE

3876 — LOCATION AND DESIGNATION OF BETHPAGE WATER DISTRICT PUBLIC SUPPLY WELL

8525 — LOCATION AND DESIGNATION OF HICKSVILLE WATER DISTRICT PUBLIC SUPPLY WELL

3193 — LOCATION AND DESIGNATION OF LEVITTOWN WATER DISTRICT PUBLIC SUPPLY WELL

NOTE 1:

IN ADDITION TO THE 24 PUBLIC SUPPLY WELLS SHOWN ABOVE, 29 ADDITIONAL SUPPLY WELLS WERE SIMULATED IN THE MODEL BUT WERE BEYOND THE EXTENT OF THE MAP.

N

NOTE 2:

WELL INVENTORY REVISED BETWEEN AUGUST 4 AND AUGUST 23, 1995; WELL DATA OBTAINED FROM UNITED STATES GEOLOGICAL SURVEY, NASSAU COUNTY DEPARTMENT OF PUBLIC WORKS, NASSAU COUNTY DEPARTMENT OF HEALTH, AND THE NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION.

0 — 2000 FT

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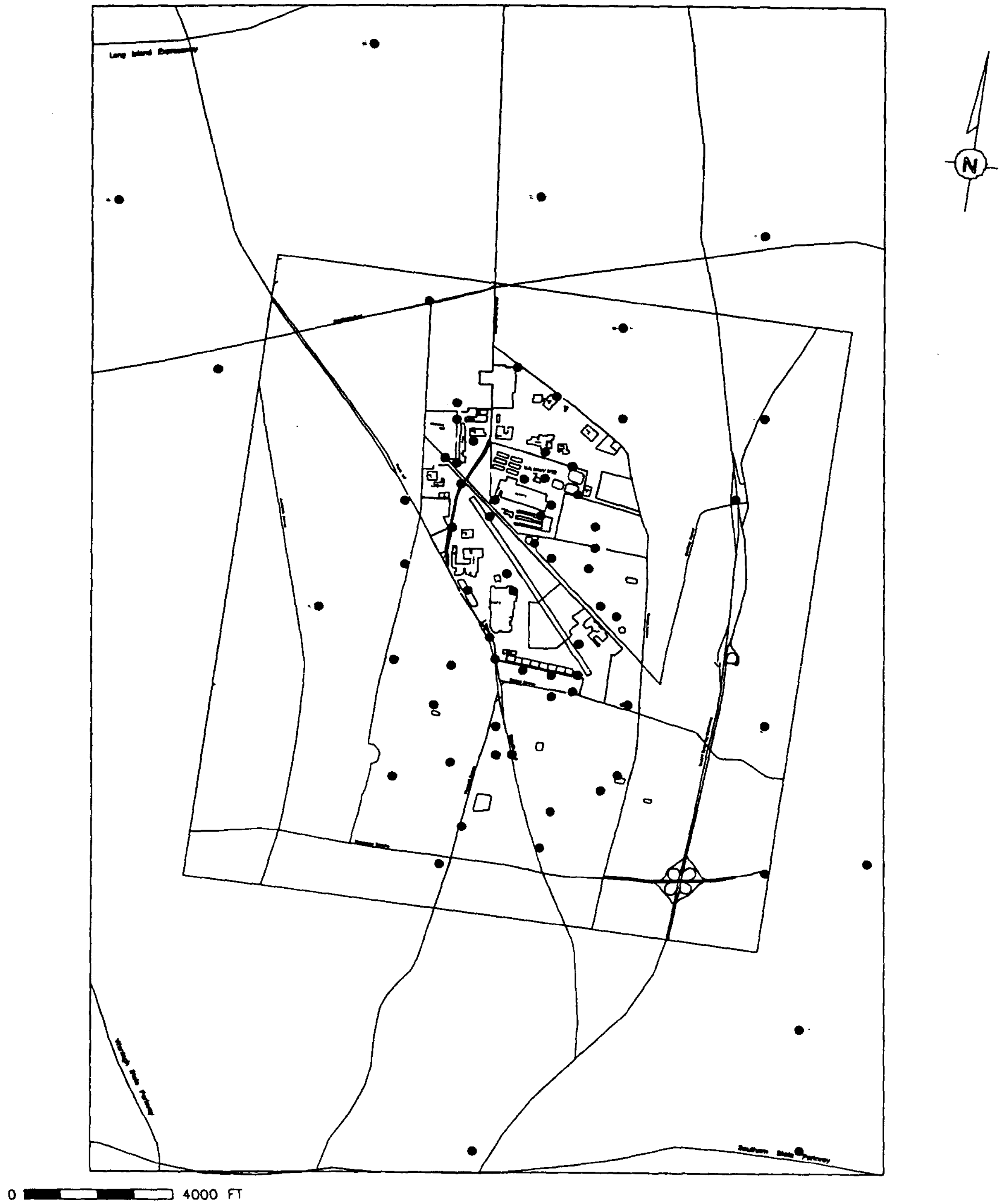
LOCATIONS OF OFF-SITE SUPPLY WELLS AND RECHARGE BASINS

GROUNDWATER FLOW MODEL
NORTHROP GRUMMAN CORPORATION
BETHPAGE, NEW YORK

FIGURE 4-7



DWG DATE: 13OCT97 | PRJCT NO.: NY0008.068-2 | FILE NO.: GRUM | DRAWING: FIG5-1 | CHECKED: JS | APPROVED: CSG | DRAFTER: -

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LOCATIONS OF HEAD CALIBRATION TARGETS IN THE UPPER GLACIAL AQUIFER GROUNDWATER FLOW MODEL

NORTHROP GRUMMAN CORPORATION
BETHPAGE, NEW YORK

FIGURE
5-1

DWG DATE: 13OCT97 | PRJCT NO.: NY0008.123-2 | FILE NO.: GRUM | DRAWING: FIG5-2 | CHECKED: JS | APPROVED: CSG | DRAFTER: -

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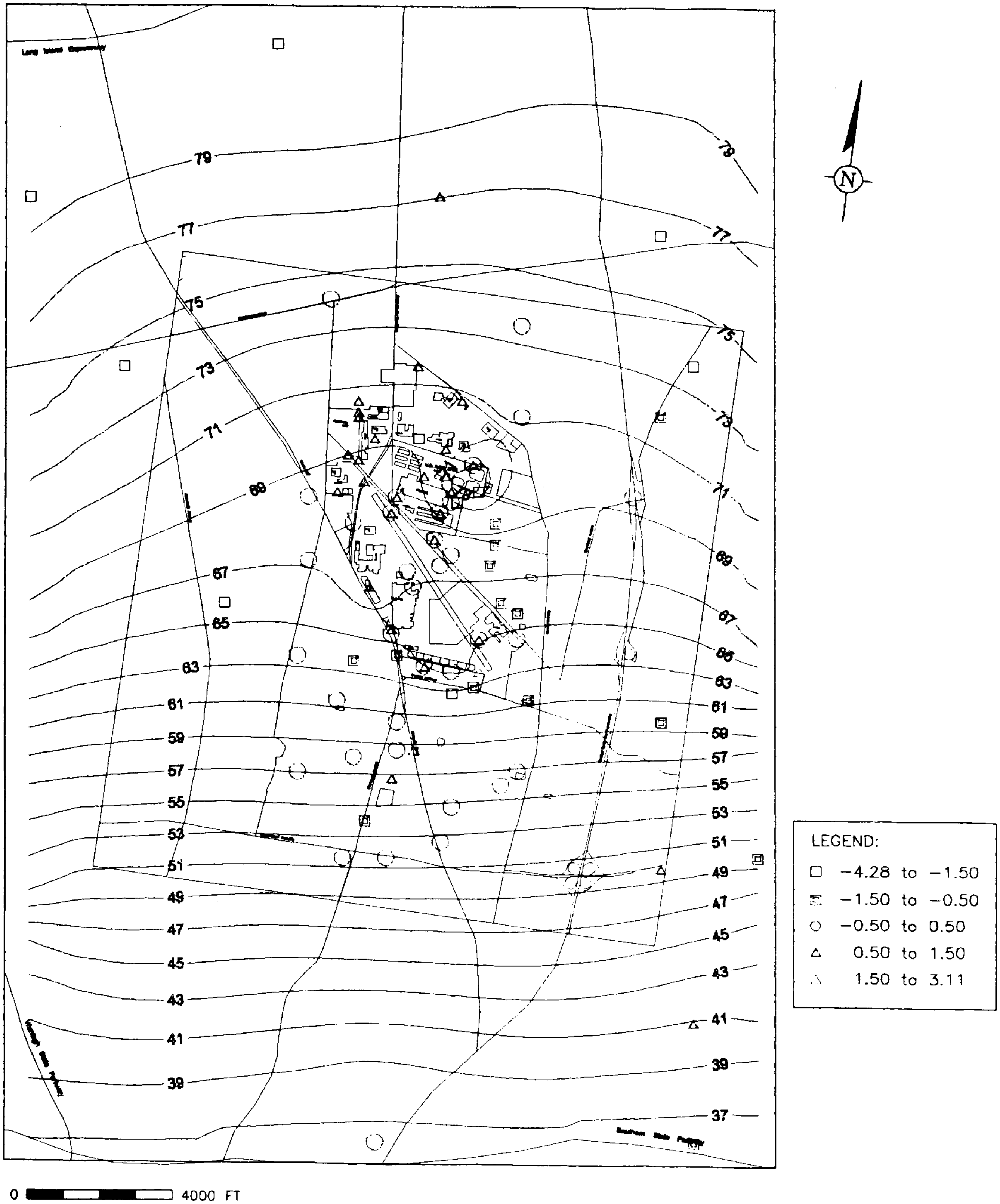
LOCATIONS OF HEAD CALIBRATION TARGETS IN THE MAGOTHY AQUIFER GROUNDWATER FLOW MODEL

NORTHROP GRUMMAN CORPORATION
BETHPAGE, NEW YORK

FIGURE 5-2



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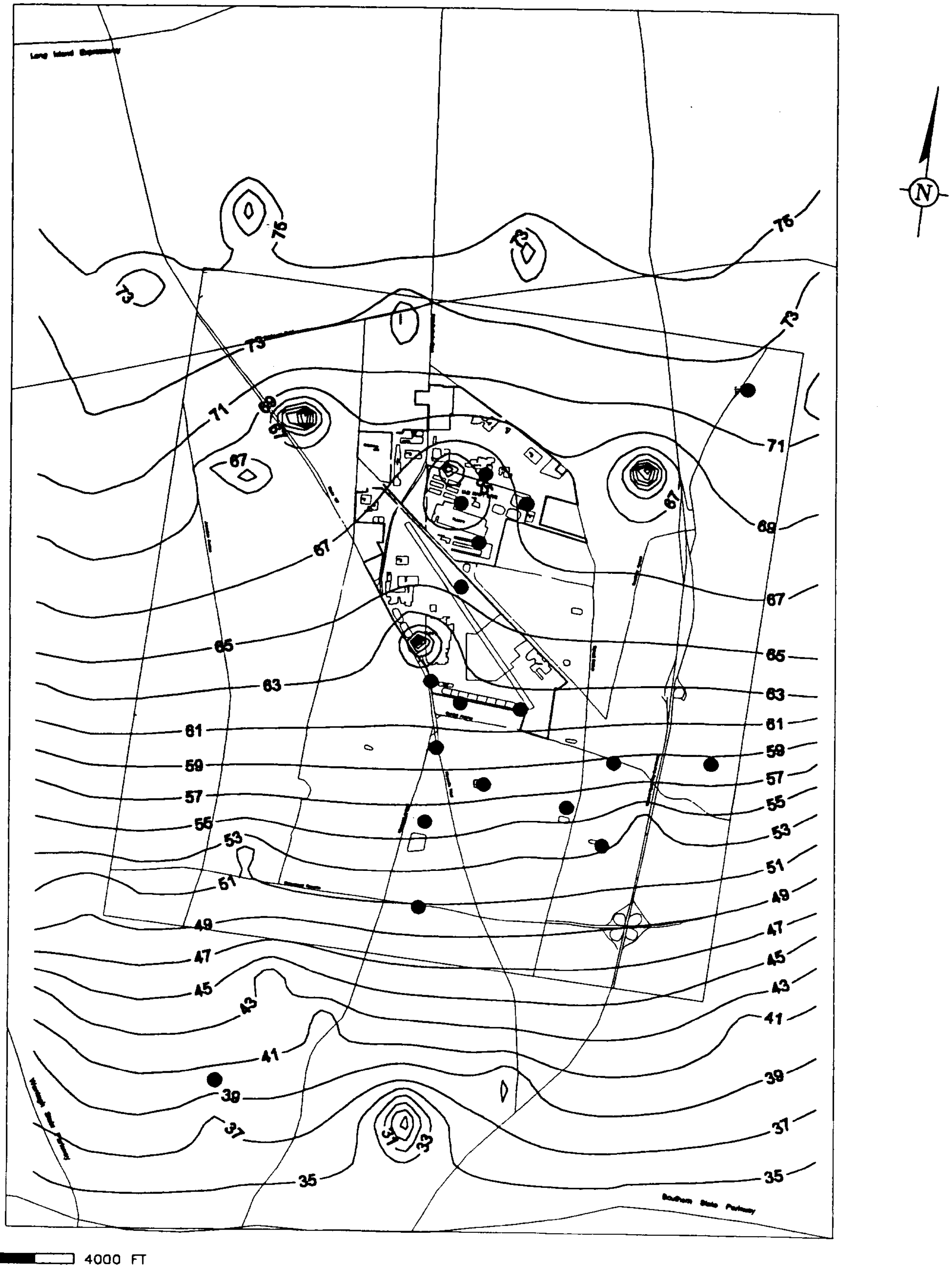
SIMULATED REGIONAL WATER-TABLE CONFIGURATION AND RESIDUALS FOR THE UPPER GLACIAL AQUIFER

GROUNDWATER FLOW MODEL
NORTHROP GRUMMAN CORPORATION
BETHPAGE, NEW YORK

FIGURE 5-3

DWG DATE: 29OCT97 | PRJCT NO.: NY0008.068-2 | FILE NO.: | DRAWING: FIG5-3 | CHECKED: JS | APPROVED: CSG | DRAFTER: W.H.CICIO



SIMULATED REGIONAL POTENTIOMETRIC SURFACE MODEL LAYER 7 AND TARGET LOCATIONS

GROUNDWATER FLOW MODEL
NORTHROP GRUMMAN CORPORATION
BETHPAGE, NEW YORK

FIGURE 5-4

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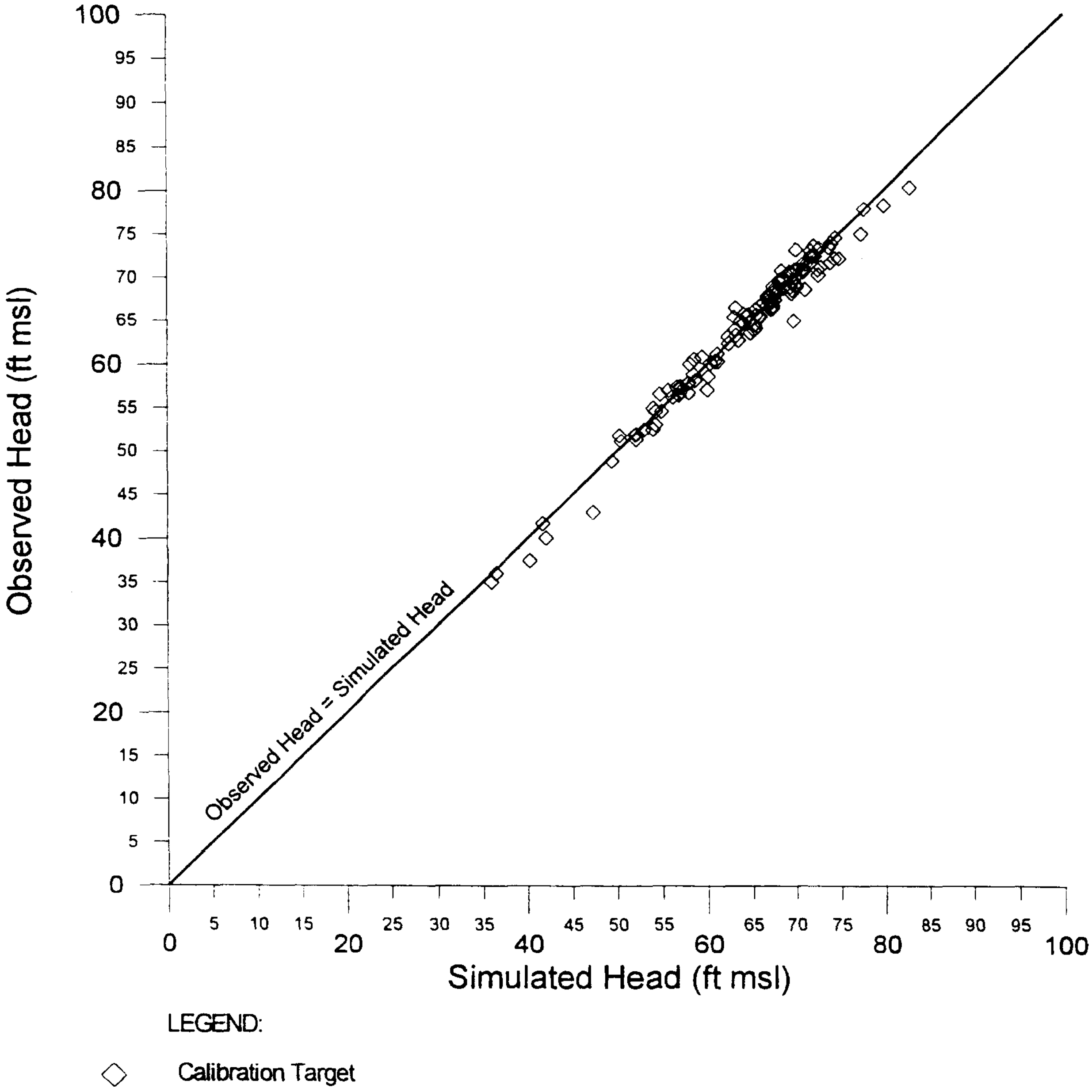
DRAFTER: B.CICIO | APPROVED: CSG | CHECKED: JS | DRAWING: FIG5-4 | PRJCT NO.: NY0008.068-2 | FILE NO.: | DWG DATE: 29OCT97

DRAFTER: W.H.CICIO | APPROVED: M.WOLFERT | CHECKED: R.PORSHE | DRAWING: NON-CAD | FILE: | PRJCT NO.: NY0008.123T2 | DWG DATE: 30OCT97



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Environment and Infrastructure
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SCATTERPLOT OF HEAD CALIBRATION TARGETS

GROUNDWATER FLOW MODEL
NORTHROP GRUMMAN CORPORATION
BETHPAGE, NEW YORK

FIGURE **5-5**

ARCADIS

Appendix B

Updated Northrop Grumman Regional Groundwater Flow and Contaminant Transport Model Report, Northrop Grumman Corporation, Bethpage, New York

ARCADIS

Infrastructure, buildings, environment, communications

ARCADIS G&M, Inc.
88 Duryea Road
Melville
New York 11747
Tel 631 249 7600
Fax 631 249 7610
www.arcadis-us.com

Mr. Larry Leskovjan
Northrop Grumman Corporation
South Oyster Bay Road
Bethpage, New York 11714

ENVIRONMENTAL

Subject:
Updated Northrop Grumman Regional Groundwater Flow and Contaminant Transport Model Report, Northrop Grumman Corporation, Bethpage, New York.

Date:
30 October 2002

Contact:
Douglas Smolensky

Phone:
631 391 5290

Email:
dsmolensky@arcadis-us.com

Our ref:
NY001321.0006.00001

Dear Larry:

ARCADIS has prepared this report to document modifications and updates to the Regional Groundwater Flow and Contaminant Transport Model developed for the Northrop Grumman Corporation Site in Bethpage, New York. The updated model is based on the previously constructed flow model that was documented in the October 1997 report entitled, "Groundwater Flow Model, Northrop Grumman Corporation, Bethpage, New York" (hereinafter referred to as the 1997 flow model). The 1997 flow model (technically the flow model was completed prior to 1997 but is referred to as the 1997 model because that is the year the model was documented in a report) was the basis for contaminant transport simulations conducted to evaluate Feasibility Study alternatives, which are documented in the October 2000 Groundwater Feasibility StudyGrumman Aerospace-Bethpage, NY Site #130003A and Naval Weapons Industrial Reserve Plant Bethpage, NY Site #130003B as Appendix B, "Simulation of Groundwater Flow and Contaminant Transport" (hereinafter referred to as the 2000 transport model).

Introduction

This letter report describes the differences between the updated model and the 1997 flow model, the basis and intended purpose of the updated model, and the information used to develop the updated model.

Conceptual Groundwater Model

The conceptual model for the updated model is consistent with the conceptual model upon which the 1997 flow model is based. Please refer to the October 1997 report for a detailed description of the conceptual groundwater model.

Modeling Strategy

The technical objectives defined in the 1997 flow model report are consistent with the objectives of the model update effort on the regional scale. On the site-specific scale, the updated model represents a significant improvement with respect to model discretization, as described below under the heading "Model Construction".

Uses of the Model

The updated model will be used to conduct steady state groundwater flow and contaminant transport simulations for the following purposes:

- To assess the migration of the off-site portion of the TVOC plume associated with the Northrop Grumman and Navy NWIRP sites.
- To support the selection of outpost monitoring well locations and screen settings.
- To support off-site remedial system design via determination of the number, locations, screen settings, and extraction rates of remedial wells, locations of treated water discharge points, and approximate influent concentrations over time at the treatment facility, all in the context of achieving specific remedial goals.

Model Code Description

Simulations of groundwater flow will be conducted using the modular finite-difference groundwater flow code (MODFLOW) developed by the United States Geological Survey (1988).

Contaminant transport simulations will be conducted using MT3D, a modular three-dimensional transport model developed for the U.S. Environmental Protection Agency in 1990. MT3D was developed to use MODFLOW simulation output as the basis for advective transport.

Model Construction

Details such as model discretization and calibration of the updated model, and how it differs from the 1997 model are provided below.

Discretization

Consistent with the development of the 1997 model, project goals, available data, and other factors affecting the model design were considered in the model update. The updated model was expanded to cover a larger area and consists of 146 rows, 180 columns, and 11 layers. The 1997 and updated models have 56,576 and 289,080 model cells, respectively. The model has been designed to simulate groundwater flow in three dimensions over an area approximately 42,800 feet (north to south) by 29,000 feet (east to west). The original and updated model boundaries are shown on Figure 1. Dimensions of cells along row (east-west) and column (north-south) directions range from 100 to 1,200 feet. The finest grid resolution is generally used downgradient of the site with lateral grid cell dimensions of 100 by 100 feet to enhance computational accuracy and produce results at the desired level of detail. Fine-scale discretization downgradient of the site corresponds to critical areas with respect to model uses. A general rule-of-thumb was followed when systematically increasing grid spacing from areas of finer resolution to areas of coarser resolution, to minimize numerical dispersion. Generally, the variation in grid spacing progressed such that the maximum change in spacing did not exceed 1.5 times the adjacent cell.

The increase in vertical discretization in the updated model (i.e., 8 layers in the 1997 model vs. 11 layers in the updated model) is based upon data collected from a series of vertical profile borings and monitoring wells installed downgradient of the site (since development of the 1997 model). Figure 2 provides a comparison between the layering scheme used in the 1997 model and that of the updated model. The hydrogeologic data collected from these wells/borings supports the definition of additional model layers, as wells as changes to hydraulic conductivity zonation as discussed below.

Boundary Conditions

In general, the top and bottom model boundaries (water table and Raritan Clay, respectively) are unchanged from the 1997 model; however, the elevation of the

Raritan clay has been lowered based upon data gathered from recently drilled vertical profile borings. The lateral model boundaries have been expanded primarily to the east and south of the site (in the direction of regional groundwater flow). The original model covered an area of approximately 25.2 sq miles, the updated model represents an area of approximately 44.5 square miles.

Parameter Zonation

Hydraulic conductivity zonation was updated to reflect the presence of several low permeability zones not represented in the 1997 model. Specifically, data collected from the vertical profile borings drilled near BWD Plants 4 and 5 was used to update hydraulic conductivities in the vicinity of GM38.

Areal Recharge

The areal recharge rate was updated after reviewing precipitation records from January 1984 through November 2001 for the precipitation station at MacArthur Airport located in the Town of Islip, Long Island. A long-term average annual rate was established based on these data. The areal recharge rate in the updated model is 0.00588 feet per day (25.75 inches per year), consisting of fifty percent of the average annual precipitation, and 10% of the modeled municipal pumpage (representing leakage from both municipal supply systems and sewers).

Groundwater Pumpage and On-Site Recharge

Regional groundwater pumping (from both on-site remedial wells and off-site supply wells) and recharge to on-site basins (Plant 5 and South Basins) were updated as follows. Quarterly monitoring of the on-site Northrop Grumman OU2 Groundwater Remediation system provides extraction well pumping rates. These data along with discussions with Northrop Grumman personnel regarding future development of the site were used as the basis for the on-site pumping and recharge rates used for the calibration and predictive simulation. Off-site pumping rates were developed based on monthly pumping rates (on a well by well basis) provided by the water districts represented in the model. Average production rates for each of the municipal supply wells based on reported pumpage from January 1998 through June 2001 were developed and used in the model to represent the long-term steady state pumping stress (see Table 1).

Model Calibration

Procedures used for the steady state calibration of the updated model are unchanged from those used in 1997. Eighty one calibration targets (water levels) were used in the updated model. The specific calibration criteria were as follows:

- Simulated flow patterns will adequately reproduce observed flow patterns.
- The average of residuals will be within 5 percent of the range in target heads.
- The residual standard deviation will be within 10 percent of the range in target heads.
- The distribution of residuals will not show any spatial bias.

All criteria for assessing if model calibration is acceptable were satisfied. Simulated flow patterns reproduced observed flow patterns; average residuals were less than 2.4 ft; the residual standard deviation was 3.05 ft; and the distribution of residuals did not show any spatial bias.

As described in the 1997 model report, model inflows must equal model outflows to ensure model accuracy and stability. The model calculated discrepancy between inflows and outflows (volumetric flow budget) for the updated model was 0.00 percent. Inflow to the model included areal recharge, on-site recharge through recharge basins, and an influx from constant heads along the model boundaries. Model outflows primarily were withdrawal by pumping wells, seepage to streams, and flow to constant head cells at the models southern boundary. These flows are consistent with the conceptualization of the groundwater flow system.

Conclusions and Recommendations

Updates and modifications to the 1997 groundwater model have been successfully completed. The changes enable the model to be used for advective and solute transport analysis in key off-site (downgradient) areas. Specifically, the model is appropriately designed to address both remedial issues in the "GM-38 area", and outpost monitoring well issues related to public water supply wells located downgradient of the site.

Please call if you have any questions.

Sincerely,

ARCADIS G&M, Inc.

Douglas A. Smolensky
Senior Modeler

Carlo San Giovanni
Project Manager

Michael F. Wolfert
Project Director

copies:
David Brayack – Tetratech NS, Inc.
Rob Burns – Dvirka & Bartilucci
John Cofman – Northrop Grumman Corporation
James Colter – U.S. Navy Northern Division
Frank Flood – Massapequa Water Service
William Gilday – NYSDOH
Ron Krumholz – Bethpage Water District
Larry Leskovjan – Northrop Grumman Corporation
Edoardo Licci – South Farmingdale Water District
Gary Loesch – H2M Group
Tom Maher - Dvirka & Bartilucci
John Molloy – H2M Group
Arnold Palleschi – Town of Hempstead Water District
Anthony J. Sabino – Office of the Town Attorney
Steven M. Scharf – NYSDEC
Bruce Smith - NCDOHS
Matt Snyder – New York Water Service

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Table 1. Public Supply Well Average Pumping Rate, Northrop Grumman Corporation, Bethpage, New York

Owner/ User	NYSDEC Well ID#	Local Well ID#	Elevation, Top of Screen (ft msl)	Elevation, Bottom of Screen (ft msl)	Average (1) Pumping Rate (mgd)
Bethpage Water District	3876	6-1	-238	-291	533,300
Bethpage Water District	6078	9			
Bethpage Water District	6915	4-1 (10)	-450	-513	492,500
Bethpage Water District	6916	4-2 (11)	-466	-516	659,933
Bethpage Water District	8004	5-1	-594	-655	177,800
Bethpage Water District	8767	7A	-459	-520	1,333,800
Bethpage Water District	8768	8A	-485	-558	285,233
Bethpage Water District	8941	6-2	-620	-680	109,900
Bethpage Water District	9591	BDG-1	-496	-562	114,467
Hicksville Water District	5336	2-2			
Hicksville Water District	6190	7-1	-375	-425	39,871
Hicksville Water District	6192	8-1	-444	-494	545,485
Hicksville Water District	7561	5-2			
Hicksville Water District	7562	1-4	-330	-380	-
Hicksville Water District	7562	1-4	-289	-310	120,602
Hicksville Water District	8193	8-2			
Hicksville Water District	8249	1-5			
Hicksville Water District	8525	3-2			
Hicksville Water District	8778	9-1	-389	-450	499,647
Hicksville Water District	8779	9-2	-385	-445	533,876
Hicksville Water District	9180	8-3	-470	-502	-
Hicksville Water District	9180	8-3	-417	-448	1,000,189
Hicksville Water District	9212	5-3			
Hicksville Water District	9463	10-1	-416	-452	176,400
Hicksville Water District	9463	10-1	-460	-496	
Hicksville Water District	9488	1-6	-355	-408	1,240,590
Hicksville Water District	10208	9-3	-432	-509	711,389
Hicksville Water District	10320	6-1R	-405	-415	743,767
Hicksville Water District	10320	6-1R	-435	-465	
Hicksville Water District	10555	11-1	-458	-543	337,146

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Table 1. Public Supply Well Average Pumping Rate, Northrop Grumman Corporation, Bethpage, New York

Owner/ User	NYSDEC Well ID#	Local Well ID#	Elevation, Top of Screen (ft msl)	Elevation, Bottom of Screen (ft msl)	Average (1) Pumping Rate (mgd)
Massapequa Water District	4602	1	-344	-408	686,200
Massapequa Water District	5703	3	-345.5	-376	1,167,933
Massapequa Water District	5703	3	-390	-420.6	
Massapequa Water District	6442	4	-542.9	-569	-
Massapequa Water District	6442	4	-481	-522.8	879,833
Massapequa Water District	6443	5	-727	-807	208,233
Massapequa Water District	6866	6			
Massapequa Water District	6867	7			
Massapequa Water District	6867	7			
Massapequa Water District	6867	7			
Massapequa Water District	8214	8	-569	-649	414,267
Massapequa Water District	9173	2R	-727	-808	293,500
New York Water Service	3463	-			
New York Water Service	3780	1			
New York Water Service	3893	2S			
New York Water Service	8480	3S	-509	-594	1,602,533
New York Water Service	9338	4S	-527	-588	1,241,867
New York Water Service	9514	4J	-534.5	-625.5	1,533,433
New York Water Service	9878	4N	-521	-623	
New York Water Service	10195	5J	-477.5	-545.5	1,143,267
Plainview Water District	4095	1-1	-270	-320	306,666
Plainview Water District	4096	1-2	-274	-324	526,333
Plainview Water District	4097	3-1			
Plainview Water District	6077	4-2	-240	-300	242,097
Plainview Water District	6580	3-2	-376	-436	219,582
Plainview Water District	7526	2-1	-370	-380	-
Plainview Water District	7526	2-1	-390	-410	-
Plainview Water District	7526	2-1	-430	-455	-
Plainview Water District	7526	2-1	-340	-355	245,187
Plainview Water District	12535	4-3	-398	-458	641,709

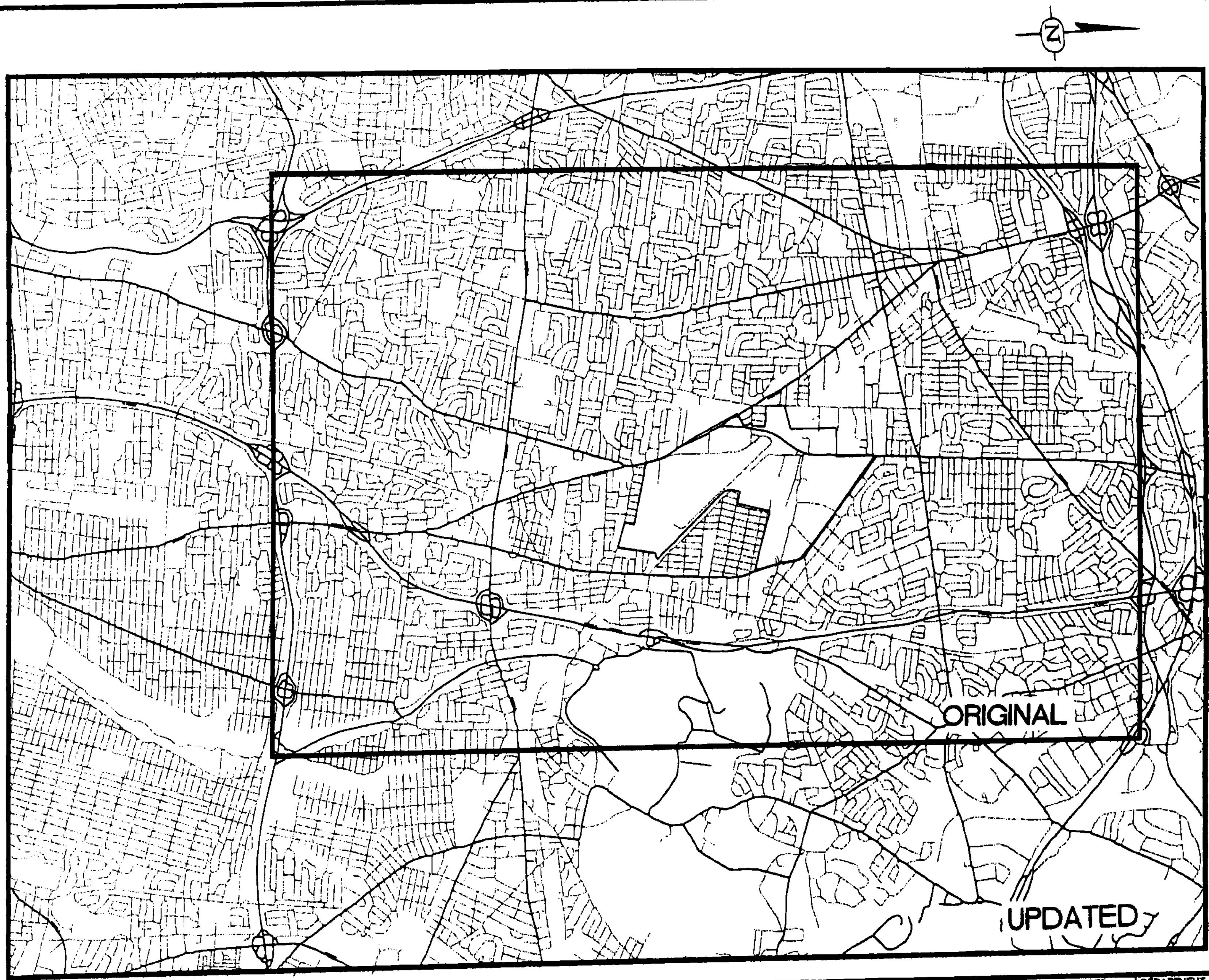
Table 1. Public Supply Well Average Pumping Rate, Northrop Grumman Corporation, Bethpage, New York

Owner/ User	NYSDEC Well ID#	Local Well ID#	Elevation, Top of Screen (ft msl)	Elevation, Bottom of Screen (ft msl)	Average [(1)] Pumping Rate (mgd)
S. Farmingdale Water District	4042	1-1			
S. Farmingdale Water District	4043	1-2	-247	-304	374,457
S. Farmingdale Water District	5147	2-1	-122	-177	15,365
S. Farmingdale Water District	5148	1-3	-284	-299	-
S. Farmingdale Water District	5148	1-3	-228	-262	590,824
S. Farmingdale Water District	6148	4-1	-483	-511	-
S. Farmingdale Water District	6148	4-1	-412	-439	503,358
S. Farmingdale Water District	6149	2-2	-548	-598	519,049
S. Farmingdale Water District	6150	3-1	-487	-547	558,241
S. Farmingdale Water District	7377	1-4	-568	-583	-
S. Farmingdale Water District	7377	1-4	-594	-604	-
S. Farmingdale Water District	7377	1-4	-657	-683	-
S. Farmingdale Water District	7377	1-4	-533	-553	222,150
S. Farmingdale Water District	7515	5-1	-220	-277	420,158
S. Farmingdale Water District	7516	5-2	-460	-513	-
S. Farmingdale Water District	7516	5-2	-423	-443	677,202
S. Farmingdale Water District	8664	6-1	-525	-550	-
S. Farmingdale Water District	8664	6-1	-475	-515	851,607
S. Farmingdale Water District	8665	6-2	-451	-521	354,764
TOH Water District(East Meadow)	5321	9			
TOH Water District(East Meadow)	5322	10	-400	-440	754,704
TOH Water District(Levittown)	2580	3			
TOH Water District(Levittown)	3193	5			
TOH Water District(Levittown)	3194	6			
TOH Water District(Levittown)	3618	6A			
TOH Water District(Levittown)	4450	9	-332	-389	1,060,433
TOH Water District(Levittown)	4451	10			
TOH Water District(Levittown)	5301	11			
TOH Water District(Levittown)	5302	12	-365	-418	874,710
TOH Water District(Levittown)	5303	13	-559	-675	881,391
TOH Water District(Levittown)	5304	14	-360	-417	142,753

Table 1. Public Supply Well Average Pumping Rate, Northrop Grumman Corporation, Bethpage, New York

Owner/ User	NYSDEC Well ID#	Local Well ID#	Elevation, Top of Screen (ft msl)	Elevation, Bottom of Screen (ft msl)	Average (1) Pumping Rate (mgd)
TOH Water District(Levittown)	7076	5A	-527	-543	951,305
TOH Water District(Levittown)	7523	8A	-555	-607	-
TOH Water District(Levittown)	7523	8A	-512	-537	699,117
TOH Water District(Levittown)	8279	7A	-394	-470	785,586
TOH Water District(Levittown)	8321	2A	-528	-576	-
TOH Water District(Levittown)	8321	2A	-476	-514	697,845
TOH Water District(Levittown)	12560	6B	-519	-544	-
TOH Water District(Levittown)	12560	6B	-444	-464	1,040
Village of Farmingdale	1937	2-1			
Village of Farmingdale	6644	2-2	-75	-127	1,400,000
Village of Farmingdale	7752	1-3	-333	-391	1,600,000
Village of Farmingdale	11004	2-3	-160	-247	1,900,000

NYSDEC: New York State Departement of Environmental Conservation.
(1) Average pumping rate based on pumpage from January 1998 through June 2001.
ft msl: feet relative to mean sea level.
mgd: Millons of gallons per day.
TOH: Town of Hempstead.
S. Farmingdale: South Farmingdale.



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SCALE: 1" = 5000'

NO.	DATE	REVISION DESCRIPTION	BY	CKD

ARCADIS G&M

DRAWN	DATE	PROJECT MANAGER	DEPARTMENT MANAGER
LMC	8/5/02	R. PORSCHE	D. SMOLLENSKY
		LEAD DESIGN PROF.	CHECKED R. PORSCHE
		PROJECT NUMBER NY001321.0006	DRAWING NUMBER 1

COMPARISON OF ORIGINAL MODEL AND UPDATED MODEL AREAL EXTENT

REGIONAL GROUNDWATER FLOW AND TRANSPORT MODEL
NORTHROP GRUMMAN CORPORATION
BETHPAGE, NEW YORK

MODEL LAYER HORIZONS
IN THE VICINITY OF GM-38D/D2

ORIGINAL MODEL	ELEVATION (1)	UPDATED MODEL
∇	55 (WT)	∇
1	30	1
2	15	
3	-50	2
4	-140	3 4
5	-235	5
6	-365	6
7	-580	7 8 9 10
8	-680	
////// (Raritan clay)		11
		////// (Raritan clay)

LEGEND

∇ AND WT WATER TABLE

////// RARITAN CLAY

(1) – FEET MEAN SEA LEVEL

DEPARTMENT MANAGER	D. SMOLENSKY
CHECKED	R. PORSCHE
DRAWING NUMBER	2
PROJECT MANAGER	R. PORSCHE
LEAD DESIGN PROF.	
PROJECT NUMBER	NY001321.0006
DRAWN	LMC
DATE	6/5/02

COMPARISON OF MODEL LAYERING

REGIONAL GROUNDWATER FLOW AND TRANSPORT MODEL
NORTHROP GRUMMAN CORPORATION
BETHPAGE, NEW YORK

ARCADIS G&M

NO.	DATE	REVISION DESCRIPTION	BY	CKD

ARCADIS

Appendix C

GM38 Area Remedial Design Modeling Results, Northrop Grumman Regional Groundwater Model, Northrop Grumman Corporation

ARCADIS

Infrastructure, buildings, environment, communications

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MEMO

To:
Mike Wolfert
Carlo San Giovanni

Copies:

From:
Robert Porsche/Doug Smolensky

Date:
4 December 2002

ARCADIS Project No.:
NY001321.0006.00003

Subject:
GM38 Area Remedial Design Modeling Results, Northrop Grumman Regional Groundwater Model, Northrop Grumman Corporation.

Purpose of GM38 Area Remedial Design Modeling

The purpose of this memo is to document the work performed and results of groundwater modeling conducted in support of the GM38 Area Remedial System Design. The so-called GM38 Area is an area of elevated volatile organic compound (VOC) concentrations in groundwater in the vicinity of Monitoring Well cluster GM38. Monitoring Well cluster GM38 is located southeast of the Northrop Grumman facility in Bethpage, New York, between Bethpage Water District (BWD) Plant 4 (supply wells 6915 and 6916), and BWD Plant 5 (supply well 8004), as shown on Figure 1.

GM38 Area Remedial System Goal

The goals of the GM38 Area Remedial System (the System) are to provide capture, contaminent mass removal, and treatment of VOCs in groundwater from the area of elevated concentrations in the vicinity of GM38. Specifically, this modeling effort focused on the capture and removal of groundwater with total VOC (TVOC) concentrations in excess of 1,000 micrograms per liter (μg/L), as is required under the Record of Decision (ROD). During this modeling effort, it was determined that the System could capture and remove groundwater with TVOCs down to the 500 μg/L level if the operational timeframe of the System was minimally extended. Therefore, the System described herein can focus on either the 1,000 μg/L or 500 μg/L TVOC level with a slightly longer period of operation required to remove TVOCs at and above 500 μg/L. The groundwater modeling effort documented in this memo was conducted to develop the remedial details (number of wells, their locations, depths, and pumping rates) necessary to achieve the System goals of capture and mass removal.

The updated Northrop Grumman groundwater model (documented in the ARCADIS October 30, 2002 letter report) was used in this evaluation to help develop the remedial design in the context of the aforementioned goals.

Design of System

The design of the proposed remedial system summarized in this memo was based on the results of both groundwater flow, and solute transport modeling. Previously conducted solute transport modeling had predicted that without any remedial effort in the GM38 Area, supply wells of the BWD to the northeast and south would extract groundwater with VOC concentrations of up to 250 μg/L. The model also predicted that the area of elevated VOC concentrations was likely to disperse and impact several downgradient supply wells in the future. Based on this information, the following modeling effort was undertaken to develop a remedial system. The following sections describe the methods used to conduct the modeling and how the results of flow and transport modeling were evaluated. The results of the groundwater modeling summarized below are based on the assumption that the groundwater system stresses (i.e., public supply well pumpage) that produce the steady state conditions simulated in the model remain constant through time. Therefore, if significant changes to pumping rates are made in the supply wells in the vicinity of the GM38 Area, the effectiveness of the proposed remedial system design should be reevaluated.

Groundwater Flow Modeling

As previously stated, the model related goals of the proposed remedial system are to provide capture and mass removal of VOC-impacted groundwater, at concentrations in excess of 1,000/500 μg/L TVOC, from the aquifer. Various configurations of pumping well locations, depths, and pumping rates were simulated to optimize the proposed system, as discussed in the following sections.

Remedial Well Locations and Pumping Rates

The groundwater flow model was used to track particles representing the leading edge of the 1,000 μg/L portion of the TVOC plume in model layers 5, 6, and 7 (the model layers that correspond to the depths where elevated concentrations have been locally observed) under steady state conditions. The particles were tracked (forward tracking) until they were either intercepted by nearby supply wells or remedial wells, or reached the end of the model domain. Simulated remedial well pumping rates and screen zone locations were optimized to capture (prevent downgradient migration) the TVOC plume at and above 1,000 μg/L.

Capture Zone Assessment

Reverse particle tracking of particles started in the proposed remedial well screen zones were as used to assess the capture zone resulting from the pumping of the simulated remedial wells. An evaluation of the particle paths indicate the source area of water to the proposed remedial wells under the simulated conditions. Additionally, the evaluation provides verification that the proposed well screen locations are appropriate to capture the 1,000/500 μg/L portion of the plume (based on the current pumping by nearby supply wells, and our understanding of contaminant distribution in the aquifer).

Modeling Results

The following sections summarize model results following a series of particle tracking and solute transport simulations. The particle tracking and solute transport modeling was conducted in an iterative manner, ultimately leading to the proposed design described below. Although several proposed remedial well designs were simulated, they did not achieve the previously stated goals of plume containment and removal and are therefore not discussed here.

Particle tracking model results

Based on the forward and reverse particle tracking described above, a 2-well remedial system was developed. The locations of the proposed remedial wells are shown on Figure 2 as RW-1 and RW-2. The proposed screen zones and pumping rates for the remedial wells are summarized below:

Well ID	Model Layer Screened	Pumping Rate (Gallons per minute)
RW-1	6	800
RW-2	7	300

Under steady state conditions, particle-tracking results indicate that the proposed remedial system will prevent the downgradient migration of groundwater containing TVOC concentrations in excess of 1,000/500 μg/L (see Figures 3, 4, and 5).

It is significant to note that the particle tracking evaluation only indicates the potential for groundwater at the plumes leading edge to reach a downgradient receptor, and does not quantify the concentration of TVOCs in the groundwater predicted to impact the well. Solute transport modeling is used to quantify the remedial systems effectiveness with regard to the removal of contaminants from the aquifer, and potential impacts of the VOC plume on nearby supply wells. The proposed systems effectiveness with regard to contaminant extraction was evaluated through a series of solute transport simulations as discussed below.

Solute transport model results

The proposed system is anticipated to operate for a limited time, as it is designed for the removal of the elevated contaminant mass resident in the aquifer near GM38, and not full plume remediation. As such, three thirty-year simulations were conducted to evaluate remedial well pumping periods of 5, 15, and 30 years. Two part simulations were used to evaluate the 5 and 15-year pumping periods; that is, the remedial wells were simulated to operate only during the first 5 or 15 years of the 30-year simulation. After the appropriate pumping period, the remedial wells were turned off, and the contaminant mass remaining in the aquifer was tracked for the remainder of the 30-year simulation.

A comparison of model predicted TVOC concentrations in remedial wells RW-1 and RW-2 under the 5, 15, and 30-year pumping periods are shown on Figures 6 and 7, respectively. Each line shows the model predicted TVOC concentration in the remedial well with time. In RW-1 (Figure 6) the model predicted TVOC concentrations in years 0-5 are identical under the 5, 15, and 30-year pumping simulations; the same is true for well RW-2 (Figure 7). As such, only the line showing TVOC concentrations in groundwater for the 30-year pumping period is visible. However, if after 5 years the remedial system is turned off, the model predicts a spike in concentration to approximately 140 μg/L in remedial well RW-1, after which concentrations are predicted to decline with time. Likewise, the model predicted TVOC concentrations in years 0-15 is identical under the 15 and 30-year pumping simulations. If, after 15 years the remedial system is turned off, the model predicts a slight increase in TVOC concentrations in RW-1, after which concentrations are predicted to decline. Model predicted changes in concentration with pumping period are similar for RW-2.

At both RW-1 and RW-2, the model predicts that TVOC concentrations will fall below 100 μg/L after approximately 5 years of remedial system operation. However, following the cessation of pumping, concentrations are predicted to rebound to approximately 140 μg/L and 200μg/L at RW-1 and 2, respectively. Approximately 9 years later the model predicts that TVOC concentrations will fall below 100 μg/L in RW-1; at RW-2, TVOC concentrations fall below 100 μg/L in less than 3.5 years after the system is turned off.

Assessment of system loading rates.

In support of remedial system design efforts, peak TVOC influent concentrations were determined. Modeling results indicate that TVOC concentrations in groundwater will peak at system startup, with concentrations at RW-1 and 2 of approximately 950 and 1,000 μg/L, respectively. The model predicts influent concentrations will steadily decline, as shown on Figures 6 and 7.

Impact to nearby supply wells.

At Bethpage Water District (BWD) Wells 4-1 and 4-2 (NYSDEC Well ID No. 6915 and 6916, respectively), the model predicts peak TVOC concentrations to occur within a half-year of the start of the simulations, as shown on Figures 8 and 9. As previously described, model predicted TVOC concentrations are identical (the lines are coincident) for the periods simulating remedial system operation, with only the line representing the 30-year pumping period visible. At BWD 4-1, the model predicts a peak TVOC concentration of 97 μg/L, with concentrations subsequently declining and then remaining below 20 μg/L after approximately 2.5 years of remedial system operation. At BWD 4-2, the model predicted peak concentration was 182 μg/L, with concentrations then declining and remaining below 65 μg/L after 5 years of remedial system operation.

At BWD Plant 5 (NYSDEC Well No. 8004), model predicted TVOC concentrations remain below 3 μg/L throughout the 30 years simulated regardless of the remedial system pumping period.

Effect of recharge

Although the effect of recharge on the performance of the currently proposed remedial system has not been evaluated, it was assumed that the recharge (to recharge basins or sumps) of treated groundwater would not adversely affect the performance of the proposed remedial system (as long as the recharge occurred at an appropriate distance from the remedial wells). This assumption is supported by previously conducted modeling, in which groundwater from the GM38 area was pumped, treated, and discharged (as recharge) to New York State Department of Transportation Basin No. 109, located adjacent to Route 135, approximately 2,700 ft south of the remedial system. In comparing the proposed system (as simulated and presented in this memo) and this earlier model simulation, no difference in capture zone, peak influent concentration, or rate of mass removal was noted at either of the remedial wells; impacts to downgradient receptors also did not vary with the addition of recharge. The model simulation described in this memo did not include the direct recharge of treated groundwater, but rather, assumed that treated water recharge would occur at an appreciable distance from the remedial wells such that it had no impact on the performance of the remedial wells.

Recommended System Design

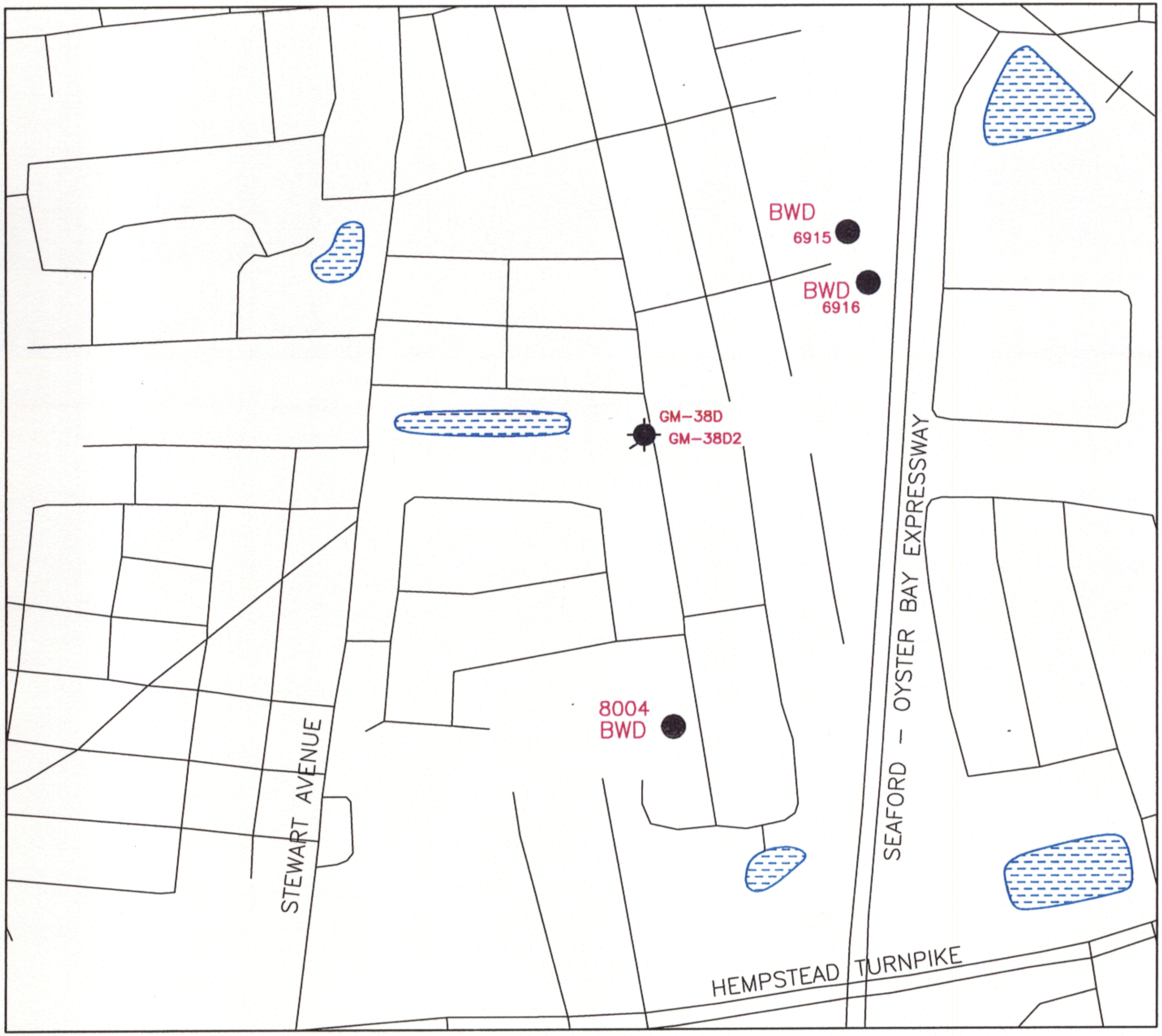
The following section describes the recommended locations for extraction and recharge of groundwater, appropriate screen zones, and extraction and recharge rates.

Well locations, screen zones, and pumping rates

Based on the results of the solute transport and particle tracking simulations described above, ARCADIS recommends that remedial well RW-1 be drilled approximately 100 ft east and 200 ft south of the northern end of South Hermann Avenue and RW-2 be drilled at the southern end of North Windhorst Avenue, as shown on Figure 2. While the modeling simulations indicated that screen zones for RW-1 and RW-2 of -260 to -330 ft msl (feet relative to mean sea level), and -350 to -430 ft msl, respectively (approximately 313-388 and 400-480 ft below land surface) were appropriate, ARCADIS recommends that vertical profiling of groundwater quality be conducted while drilling the proposed remedial wells, and the results be used in conjunction with the model results to select screen zones. The rates of groundwater extraction specified in this memo assume that the regional groundwater flow direction, as modified by local pumping stresses, will remain constant through time. A pumping test following installation and development of the remedial wells will be conducted to quantify specific capacity and well performance.

Conclusion and Recommendation

The proposed remedial system described above achieves the goals of capture and removal of groundwater with TVOC concentrations in excess of 1,000 µg/L or 500 µg/L. However, additional design simulations should be conducted to assess what impact (if any) the local recharge of treated groundwater at select locations may have on the systems capture zone.



LEGEND

- BASINS
- PUBLIC SUPPLY WELL
- OBSERVATION, MONITORING WELL

0 — 600
SCALE IN FEET

NO.	DATE	REVISION DESCRIPTION	BY / CKD

ARCADIS G&M

SUPPLY WELLS IN THE VICINITY
OF THE GM38 AREA
NORTHROP GRUMMAN CORPORATION

DRAWN LMC	DATE 11/26/02
PROJECT MANAGER R. PORSCHE	DEPARTMENT MANAGER N. VALKENBURG
LEAD DESIGN PROF.	CHECKED R. PORSCHE
PROJECT NUMBER NY001321.0006.00003	DRAWING NUMBER 1

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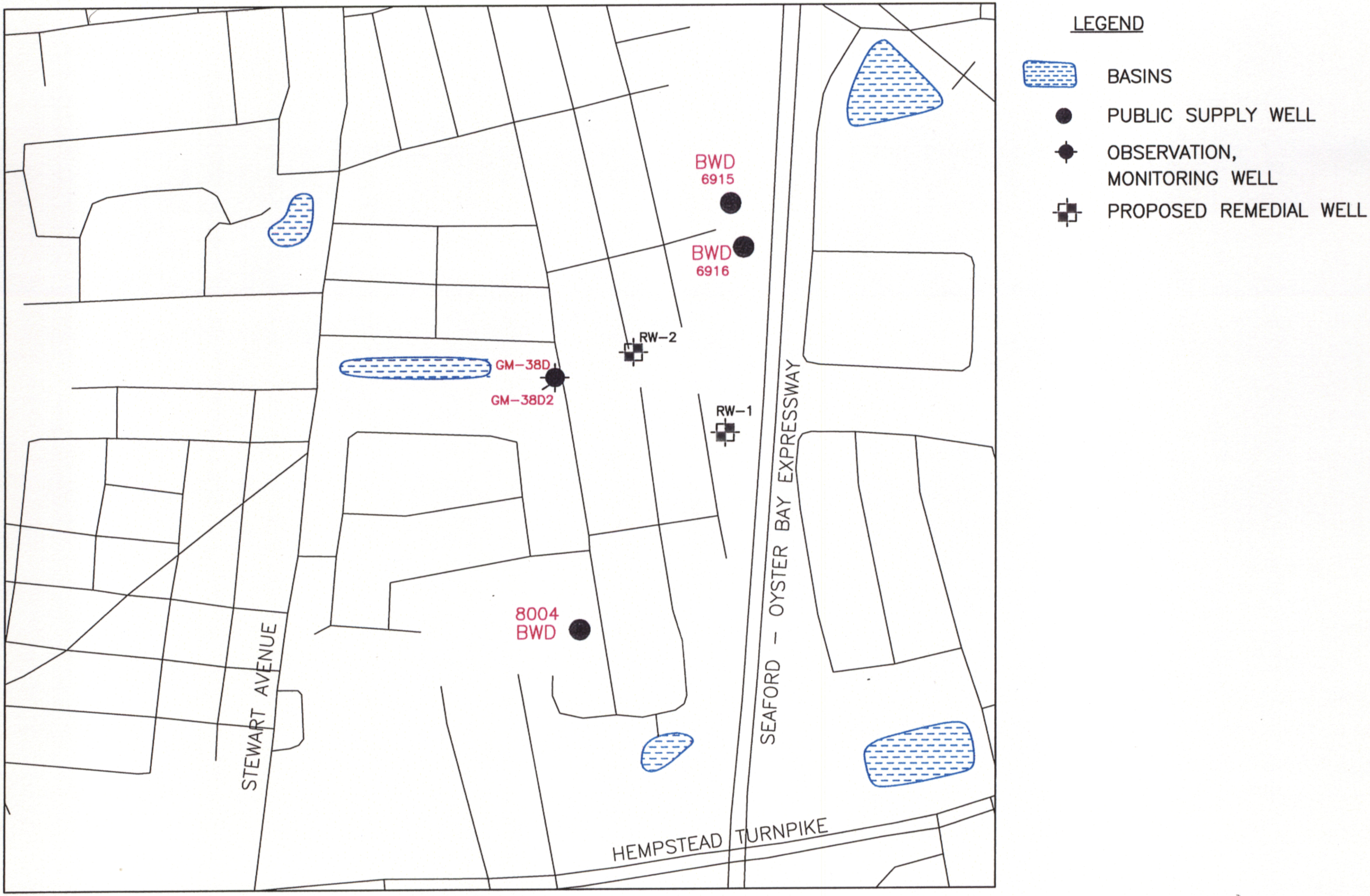

NO.	DATE	REVISION DESCRIPTION	BY	CKD

ARCADIS G&M

DRAWN LMC	DATE 11/26/02	PROJECT MANAGER R. PORSCHE	DEPARTMENT MANAGER N. VALKENBURG
LOCATIONS OF PROPOSED REMEDIAL WELLS GM38 AREA NORTHROP GRUMMAN CORPORATION		LEAD DESIGN PROF.	CHECKED R. PORSCHE
		PROJECT NUMBER NY001321.0006.00003	DRAWING NUMBER 2

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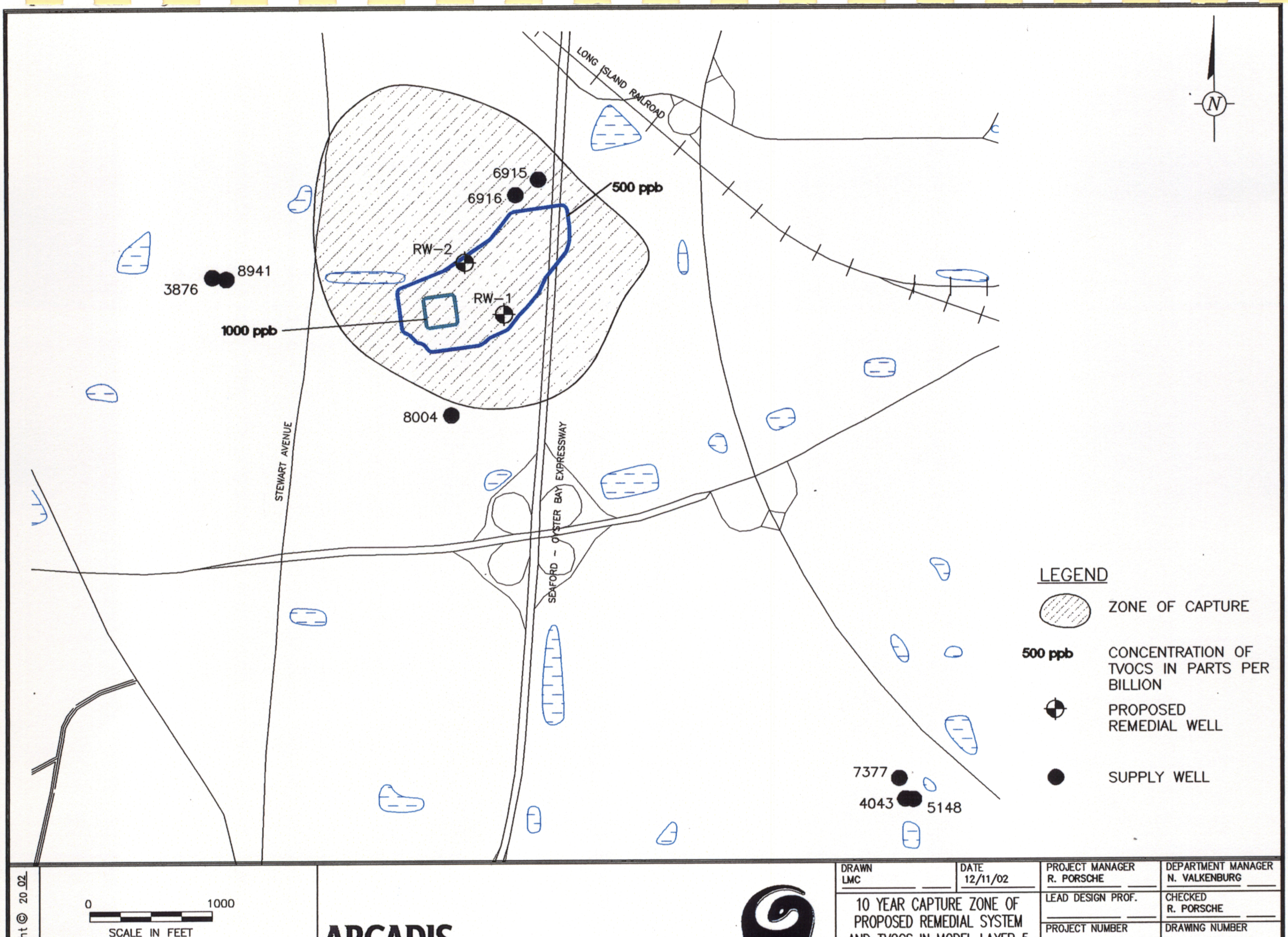

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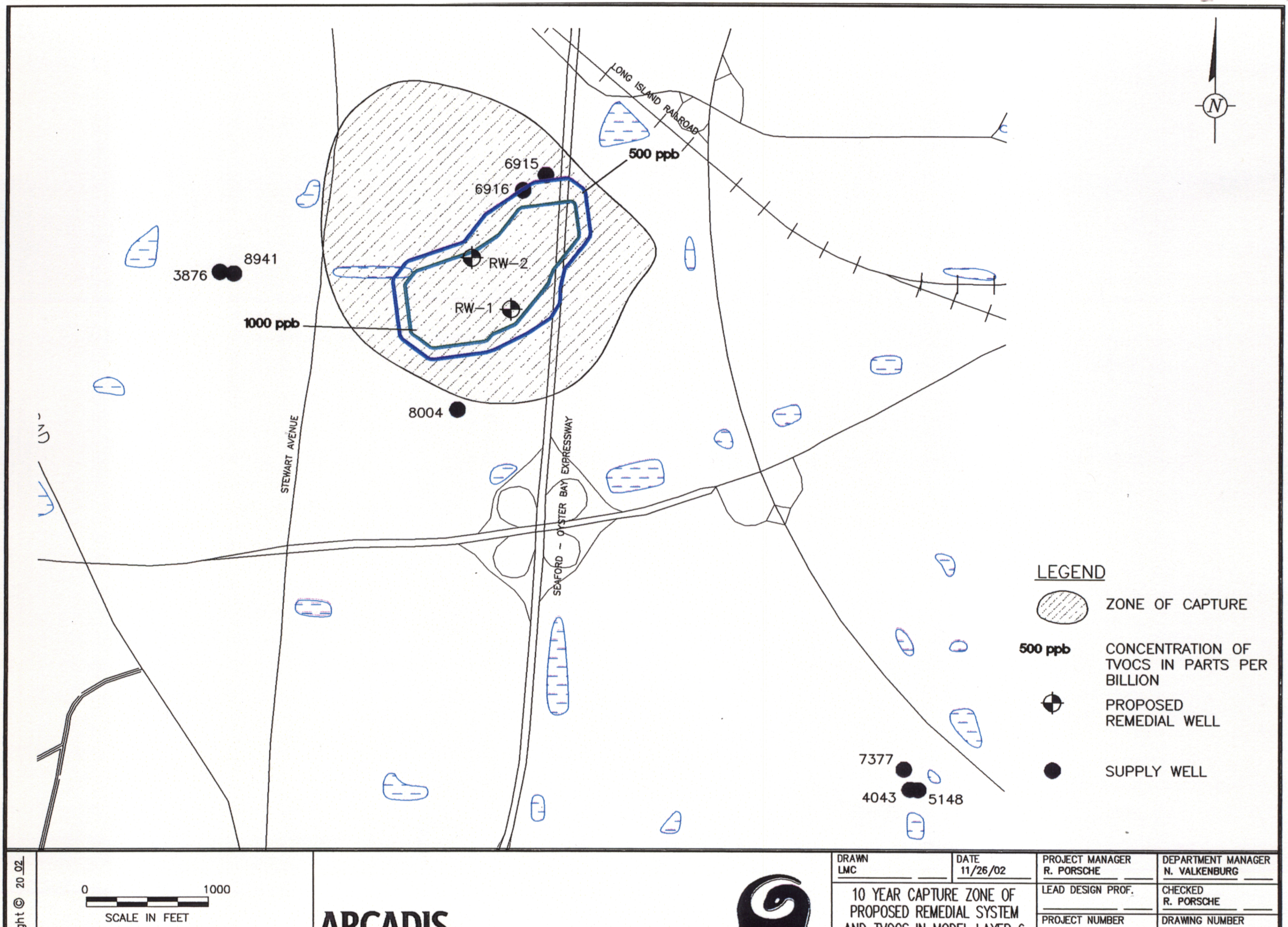
ARCADIS

DRAWN LMC	DATE 12/11/02	PROJECT MANAGER R. PORSCHE	DEPARTMENT MANAGER N. VALKENBURG
10 YEAR CAPTURE ZONE OF PROPOSED REMEDIAL SYSTEM AND TVOCS IN MODEL LAYER 5		LEAD DESIGN PROF.	CHECKED R. PORSCHE
NORTHROP GRUMMAN CORPORATION		PROJECT NUMBER NY001321.0006.00003	DRAWING NUMBER 3



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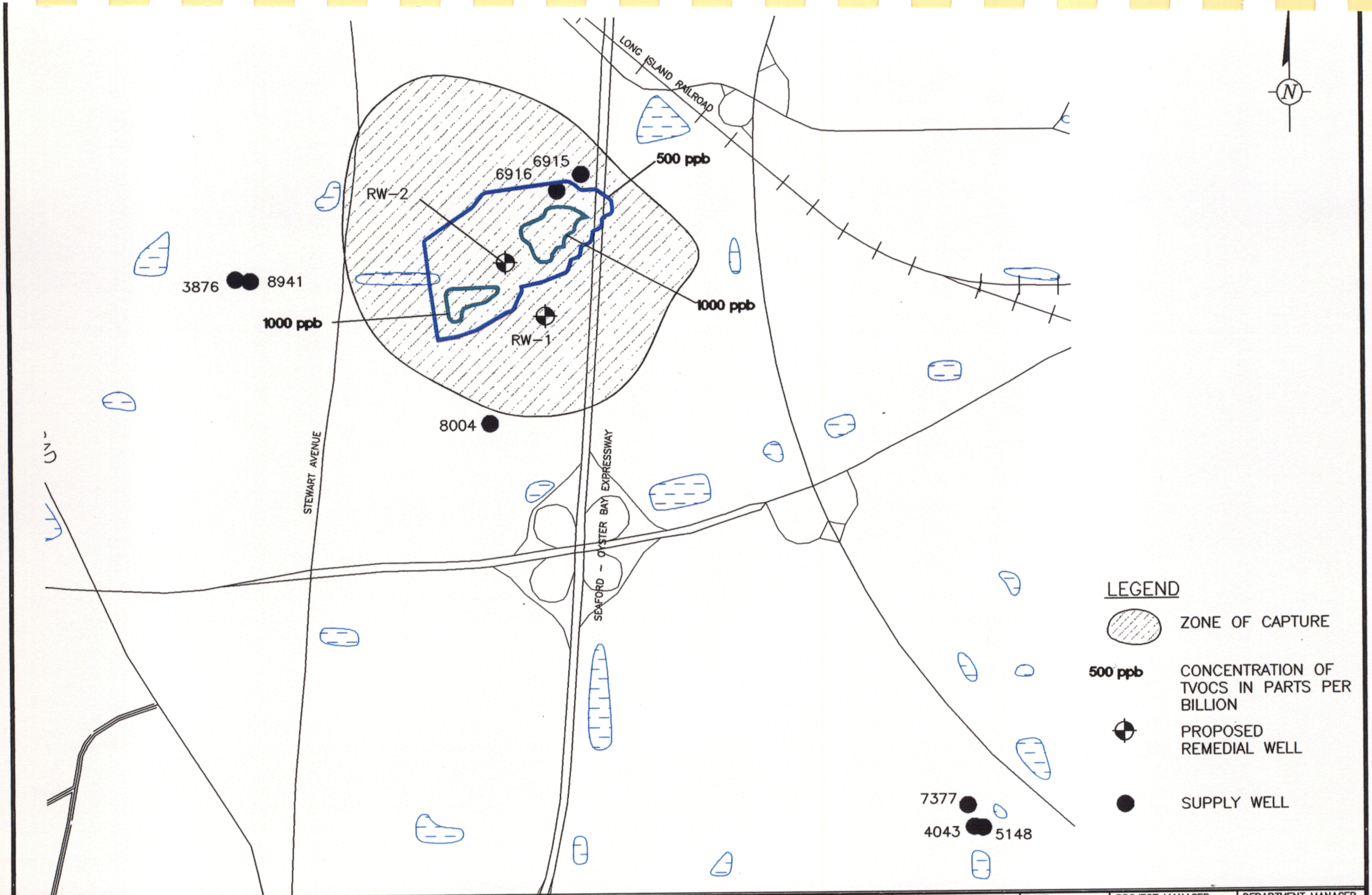
ARCADIS

DRAWN	DATE	PROJECT MANAGER	DEPARTMENT MANAGER
LMC	11/26/02	R. PORSCHE	N. VALKENBURG
10 YEAR CAPTURE ZONE OF PROPOSED REMEDIAL SYSTEM AND TVOCS IN MODEL LAYER 6		LEAD DESIGN PROF.	CHECKED R. PORSCHE
NORTHROP GRUMMAN CORPORATION		PROJECT NUMBER NY001321.0006.00003	DRAWING NUMBER 4



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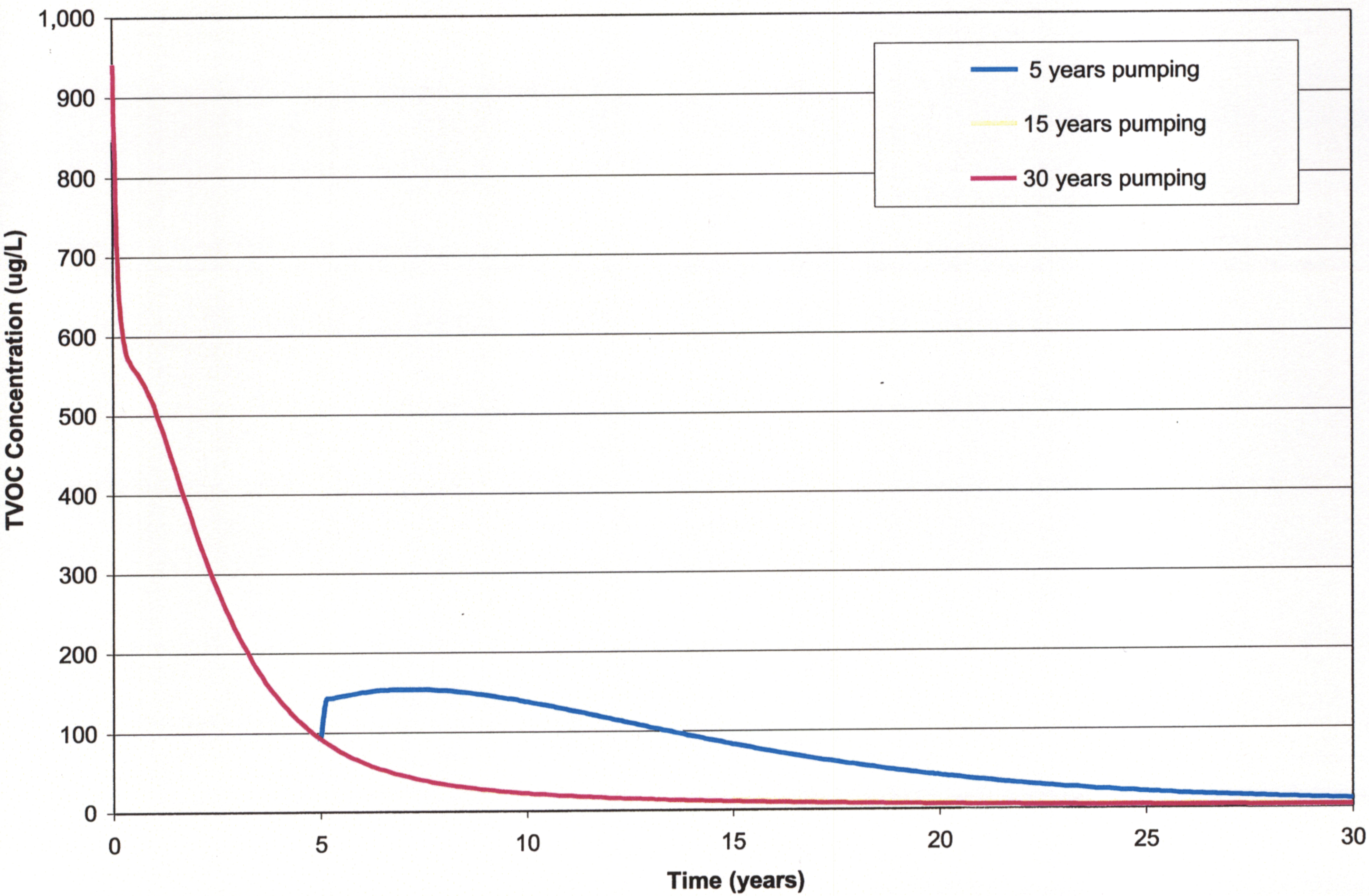
DRAWN LMC	DATE 11/26/02	PROJECT MANAGER R. PORSCHE	DEPARTMENT MANAGER N. VALKENBURG
10 YEAR CAPTURE ZONE OF PROPOSED REMEDIAL SYSTEM AND TVOCS IN MODEL LAYER 7 NORTHROP GRUMMAN CORPORATION		LEAD DESIGN PROF.	CHECKED R. PORSCHE
		PROJECT NUMBER NY001321.0006.00003	DRAWING NUMBER 5



NO.	DATE	REVISION DESCRIPTION	BY / CKD

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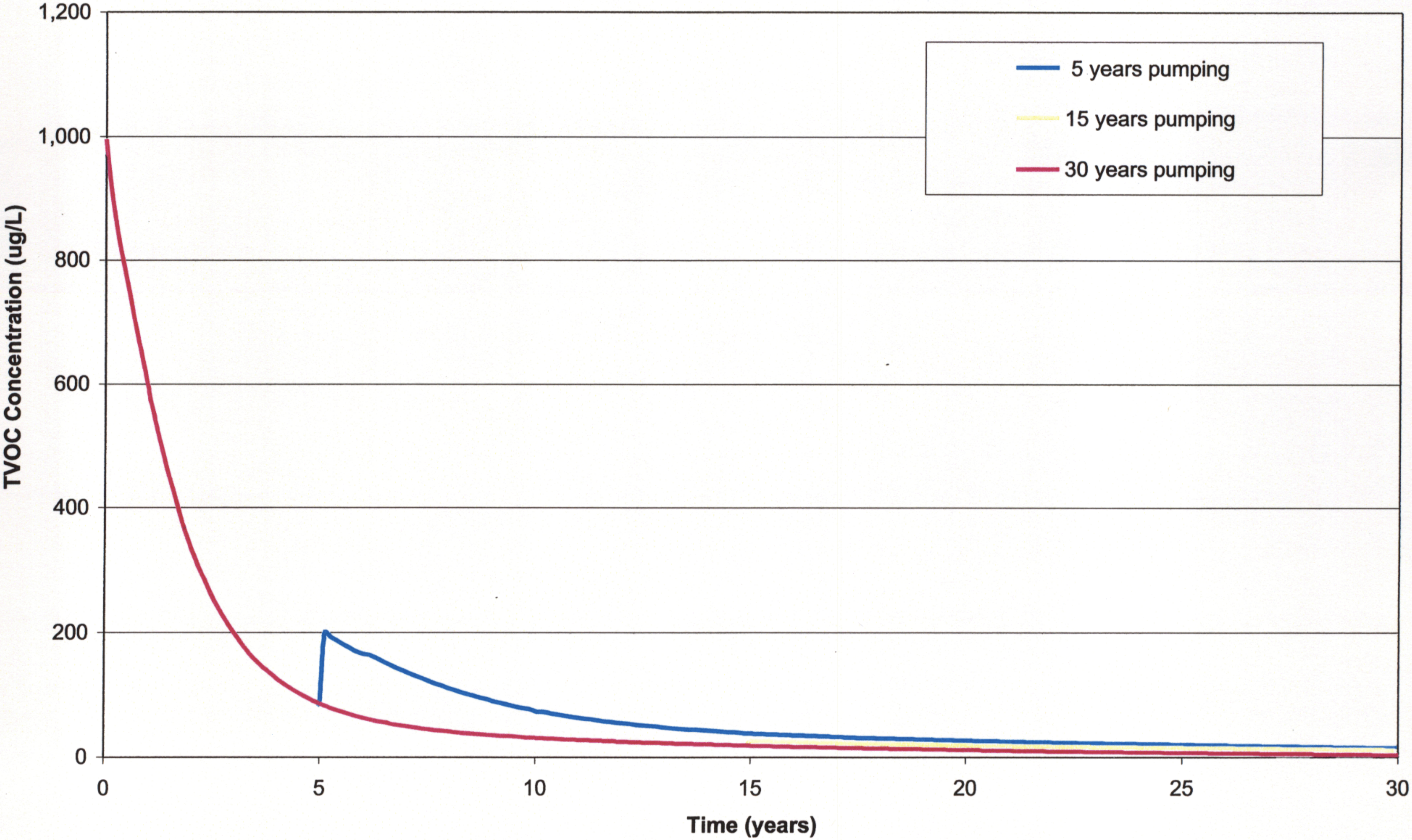
DRAWN LMC	DATE 11/26/02	PROJECT MANAGER R. PORSCHE	DEPARTMENT MANAGER N. VALKENBURG
MODEL PREDICTED TVOC CONCENTRATIONS IN PROPOSED REMEDIAL WELL 1 GM38 AREA NORTHROP GRUMMAN CORPORATION		LEAD DESIGN PROF.	CHECKED R. PORSCHE
		PROJECT NUMBER NY001321.0006.00003	DRAWING NUMBER 6



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NO.	DATE	REVISION DESCRIPTION	BY / CKD

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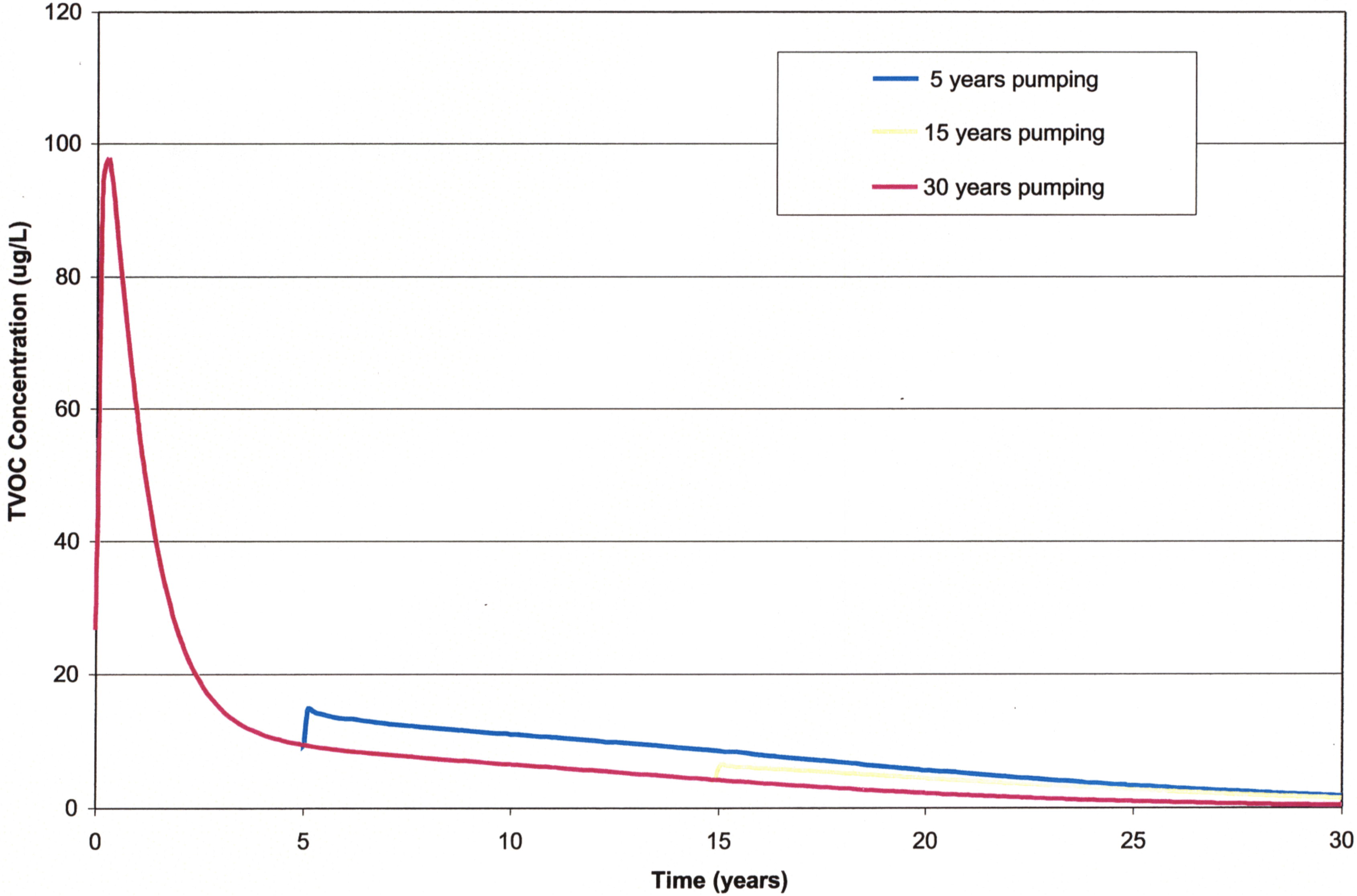
MODEL PREDICTED TVOC CONCENTRATIONS IN PROPOSED REMEDIAL WELL 2 GM38 AREA NORTHROP GRUMMAN CORPORATION	DRAWN LMC / DATE 11/26/02	PROJECT MANAGER R. PORSCHE	DEPARTMENT MANAGER N. VALKENBURG
		LEAD DESIGN PROF.	CHECKED R. PORSCHE
		PROJECT NUMBER NY001321.0006.00003	DRAWING NUMBER 7



DRAWN LMC	DATE 11/26/02	PROJECT MANAGER R. PORSCHE	DEPARTMENT MANAGER N. VALKENBURG
MODEL PREDICTED TVOC CONCENTRATION IN BWD WELL 4-1 GM38 AREA NORTHROP GRUMMAN CORPORATION		LEAD DESIGN PROF.	CHECKED R. PORSCHE
		PROJECT NUMBER NY001321.0006.00003	DRAWING NUMBER 8

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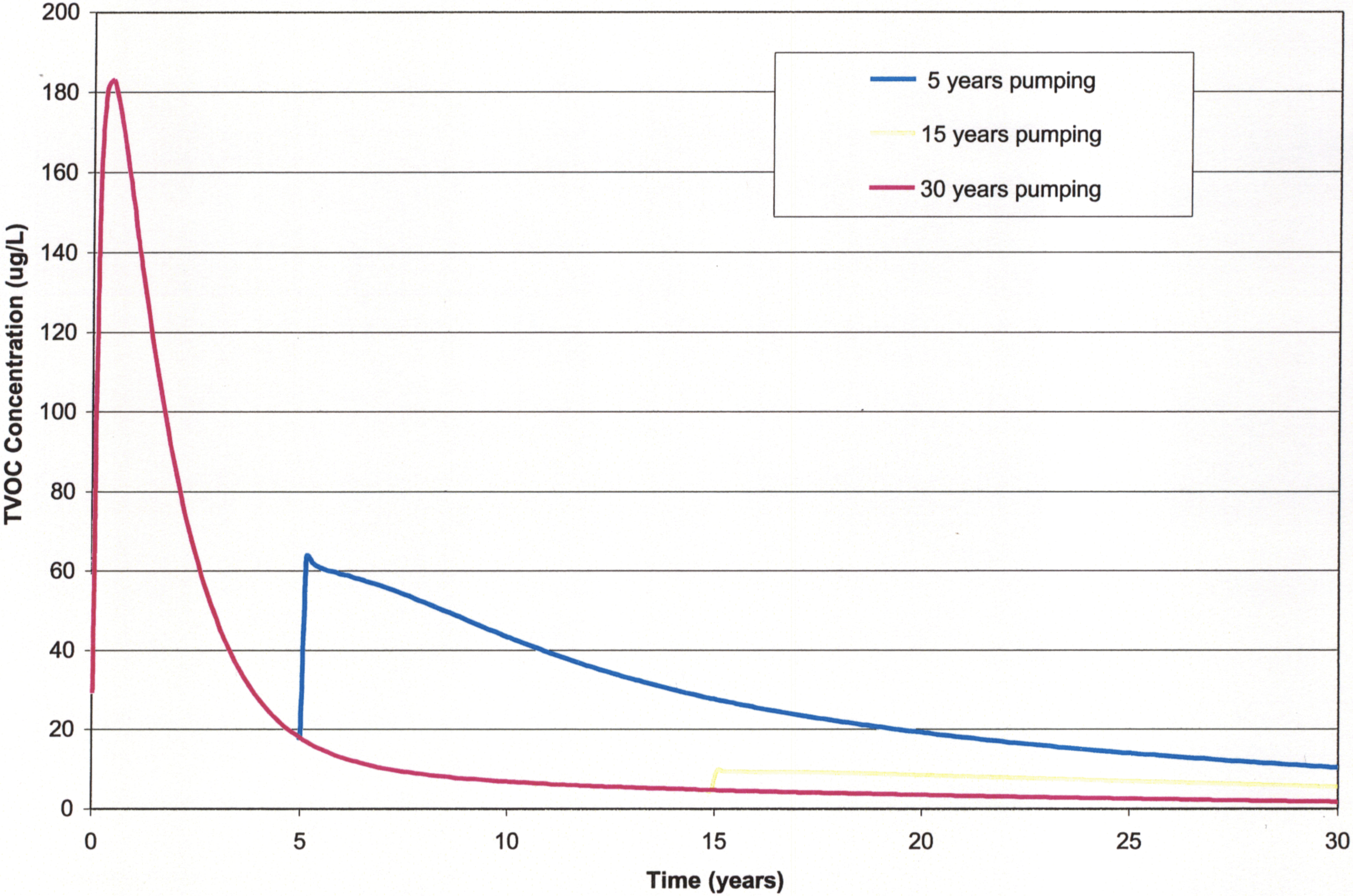
NO.	DATE	REVISION DESCRIPTION	BY / CKD



NO.	DATE	REVISION DESCRIPTION	BY / CKD

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DRAWN LMC	DATE 11/26/02	PROJECT MANAGER R. PORSCHE	DEPARTMENT MANAGER N. VALKENBURG
MODEL PREDICTED TVOC CONCENTRATION IN BWD WELL 4-2 GM38 AREA NORTHROP GRUMMAN CORPORATION		LEAD DESIGN PROF.	CHECKED R. PORSCHE
		PROJECT NUMBER NY001321.0006.00003	DRAWING NUMBER 9

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Appendix D

Groundwater Modeling in Support of Determining Locations and Screen Zones for Outpost Monitoring Wells, Northrop Grumman Corporation

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Infrastructure, buildings, environment, communications

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To:
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From:
Robert Porsche/ Doug Smolensky

Date:
13 December 2002

ARCADIS Project No.:
NY001321.0006.00003

Subject:
Groundwater Modeling in Support of Determining Locations and Screen Zones for Outpost Monitoring Wells, Northrop Grumman Corporation.

Purpose of Outpost Monitoring Wells

The purpose of this memo is to outline the process followed to select potential outpost monitoring well locations for several public water supply wells located south of the Northrop Grumman Corporation/Naval Weapons Industrial Reserve Plant (NWIRP) sites in Bethpage, New York. The outpost monitoring wells will be used to monitor groundwater quality between the leading edge of the volatile organic compound (VOC) plume and the supply wells potentially in the path of the plume. Well locations have been chosen to provide approximately 5 years notice to the water districts, specifically, the outpost monitoring well locations developed with this effort will enable detection of the groundwater plume at least 5 years before the supply wells have detections of VOCs.

The updated Northrop Grumman groundwater model (documented in the ARCADIS October 2002 letter report) was used in this evaluation to help identify the outpost monitoring well screen locations in the context of the aforementioned goals.

Determination of Municipal Wells that may have VOC Detections

Groundwater flow modeling with forward particle tracking was used to determine that the following supply wells downgradient of the leading edge of the plume have the potential to have VOC detections related to the plume: N5303 (Town of Hempstead [Levittown] Water District), N8480 and N9338 (New

York Water Service), N6150, N4043, and N5148 (South Farmingdale Water District). Travel time from the plumes leading edge to these wells is summarized in Table 1. Well locations are shown on Figure 1.

The model predicted time to VOC detections in supply wells resulting from the evaluation summarized in this memo is based on the assumption that the steady state groundwater flow conditions simulated by the model remain constant through time. Therefore, if significant changes to pumping rates are made in the supply wells downgradient of the plume, the flow field would change and the potential for VOC detections would require re-evaluation. Recall that the particle tracking evaluation only indicates the potential for groundwater at the plumes leading edge to reach a downgradient receptor. It does not quantify the concentration of VOCs in the groundwater predicted to reach the well. However, solute transport modeling (conducted by ARCADIS) has predicted that the following supply wells would have influent concentrations above 0.5 μg/L within 30 years as a result of the VOC plume; time to VOC detection is shown in parenthesis: N4043 (11 years), N6150 (4 years), N8480 (18 years), and N9338 (24 years).

Although groundwater flow modeling with forward particle tracking indicated that municipal supply wells N5303 and N5148 were potential receptors of the groundwater plume, solute transport modeling indicates that when the plume reaches these wells, influent concentrations will remain below 0.5 μg/L for the 30 year evaluation period. Nevertheless, to be conservative, ARCADIS has developed an outpost monitoring well cluster location and screen zones for supply well N5303. An outpost monitoring well location was not developed for supply well N5148 because it is located in the same well field as supply well N4043 and model results predict a VOC detection in N4043 approximately 15 years before a detection in N5148 (see Table 1). For well fields with multiple supply wells (South Farmingdale Well Field 1 and New York Water Service Wells 3S and 4S), locations for outpost monitoring wells were developed for the supply well in the field where the model predicted the first VOC detection to occur.

Selection of Outpost Monitoring Well Locations

Following the identification of supply wells with the potential to have VOC detections from the groundwater plume, and after determining the timing of the VOC detections with the model, the locations for placement of the outpost monitoring wells were defined both horizontally and vertically. In addition to being sufficiently distant from the supply well to provide a 5-year notification period, the wells were screened to detect that portion of the plume that, based on model predictions, had the potential to cause VOC detections in the supply well. In the case of supply well N5303, an outpost monitoring well location was selected in spite of the uncertainty associated with the limit of the plumes western extent. The following sections describe the procedure used to select the location and screen zone for each of the outpost monitoring wells.

Distance from municipal supply wells

Groundwater flow modeling with reverse particle tracking was used to define the appropriate distance upgradient of each supply well for the installation of the outpost monitoring well. Reverse particle tracking was used to define the capture zone resulting from the operation of each supply well, and to determine the distance from the supply well beyond which a particle of groundwater would travel for at least 5 years before reaching the supply well. As stated above, this evaluation and its results are based on the assumption that the conditions modeled will remain constant through time. If the rate of groundwater production at the supply well in question, or the rate at nearby supply wells is significantly varied from the simulated production rate for extended periods, groundwater velocities near the supply wells will vary and the selected outpost monitoring well location may not provide a 5-year notification period.

Selection of Screen Zones

The results of the groundwater flow modeling with forward particle tracking discussed earlier were used to evaluate which portion of the plume moved fastest as it approached the municipal supply wells. The layer through which the fastest moving portion of the plume traveled as it approached the well was selected as the primary horizon to be monitored for advanced warning of the approaching plume. In the case of N5303, the outpost monitoring well screen zones were selected to correspond to the screen zones of the supply well.

Modeling Results

The supply well capture zones were evaluated along with the results of forward particle tracking of the plumes leading edge, to define both the horizontal and vertical location to be monitored to detect the advancing TVOC plume at least five years before VOC detections occur in the supply well. Based on the evaluation of the groundwater modeling described above, ARCADIS recommends the installation of four clusters of outpost monitoring wells. The clusters will consist of two or three monitoring wells, each targeting a specific portion of the aquifer. ARCADIS recommends the installation of a three-well cluster to monitor groundwater upgradient of South Farmingdale's Well Field No. 1 (N4043, N5148, and N7377). Two-well clusters are recommended to monitor groundwater quality upgradient of South Farmingdale's Well Field No. 3 (N6150), the New York Water Service Well Field (N8480, and N9338), and the Town of Hempstead (Levittown) Well Field (N5303). Locations for the outpost monitoring well clusters are shown on Figure 2 through 5; screen zones for the proposed outpost monitoring wells are summarized in Table 2. The distance from the outpost monitoring well clusters to the supply wells, the model predicted trigger values, time to trigger value at the outpost wells, and time to VOC detection at the supply wells are given in Table 3, along with the nearest street intersection to the recommended outpost well location. Any differences between Tables 1 and 3 (regarding time of travel) are a function of the transport mechanisms simulated. Table 1 is based on particle tracking (advective transport modeling), while Table 3 is based on solute transport modeling. When differences are significant, the recommendations are conservative as the shortest time was always used in the decision making process.

Table 1. Groundwater travel time (in years) from the plumes leading edge in each model layer to municipal supply wells, Northrop Grumman Corporation - Bethpage, New York.

	Model Layer									
Well ID	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
South Farmingdale Well Field 1										
4043	21	22	12	12	12	--	--	--	--	--
5148	27	--	--	--	--	--	--	--	--	--
7377	--	--	--	--	--	--	--	--	--	--
South Farmingdale Well Field 3										
6150	--	--	--	12	8	>30	>30	>30	>30	--
New York Water Service Wells 3S and 4S										
8480	23	25	17	24	24	>30	>30	>30	>30	>30
9338	--	30	23	27	24	>30	>30	>30	>30	>30
Town of Hempstead (Levittown) Well 13										
5303	--	--	--	--	>30	--	>30	--	--	--

-- No model predicted detection of TVOCs.
>30 Model predicts detection of TVOCs after 30 years.

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Table 2. Screen Zones of Proposed Outpost Monitoring Well Clusters , Northrop Grumman Corporation - Bethpage, New York.

Outpost Wells ID	Model Layer Number	Model Layer Top Elevation	Model Layer Bottom Elevation	Model Layer Middle Elevation	Proposed Outpost Wells Screen Zones Top Elevation	Proposed Outpost Wells Screen Zones Bottom Elevation	Length Feet	Municipal Well Field Monitored	Municipal Supply Well Nos.
OW1-1	4	-114	-170	**-142**	-122	-162	**40**	South Farmingdale Well Field 1	4043, 5148, 7377
OW1-2	5	-170	-270	**-220**	-200	-240	**40**	South Farmingdale Well Field 1	4043, 5148, 7377
OW1-3	6	-270	-360	**-315**	-295	-335	**40**	South Farmingdale Well Field 1	4043, 5148, 7377
OW2-1	6	-265	-355	**-310**	-290	-330	**40**	South Farmingdale Well Field 3	6150
OW2-2	7	-355	-437	**-396**	-376	-416	**40**	South Farmingdale Well Field 3	6150
OW3-1	7	-354	-435	**-394.5**	-374.5	-414.5	**40**	New York Water Service 3S and 4S	8480, 9338
OW3-2	9	-524	-601	**-562.5**	-542.5	-582.5	**40**	New York Water Service 3S and 4S	8480, 9338
OW4-1	10	-583	-630	**-606.5**	-586.5	-626.5	**40**	TOH Water District (Levittown) 13	5303
OW4-2	11	-630	-740	**-685**	-665	-705	**40**	TOH Water District (Levittown) 13	5303

Elevations are given in feet relative to mean sea level.

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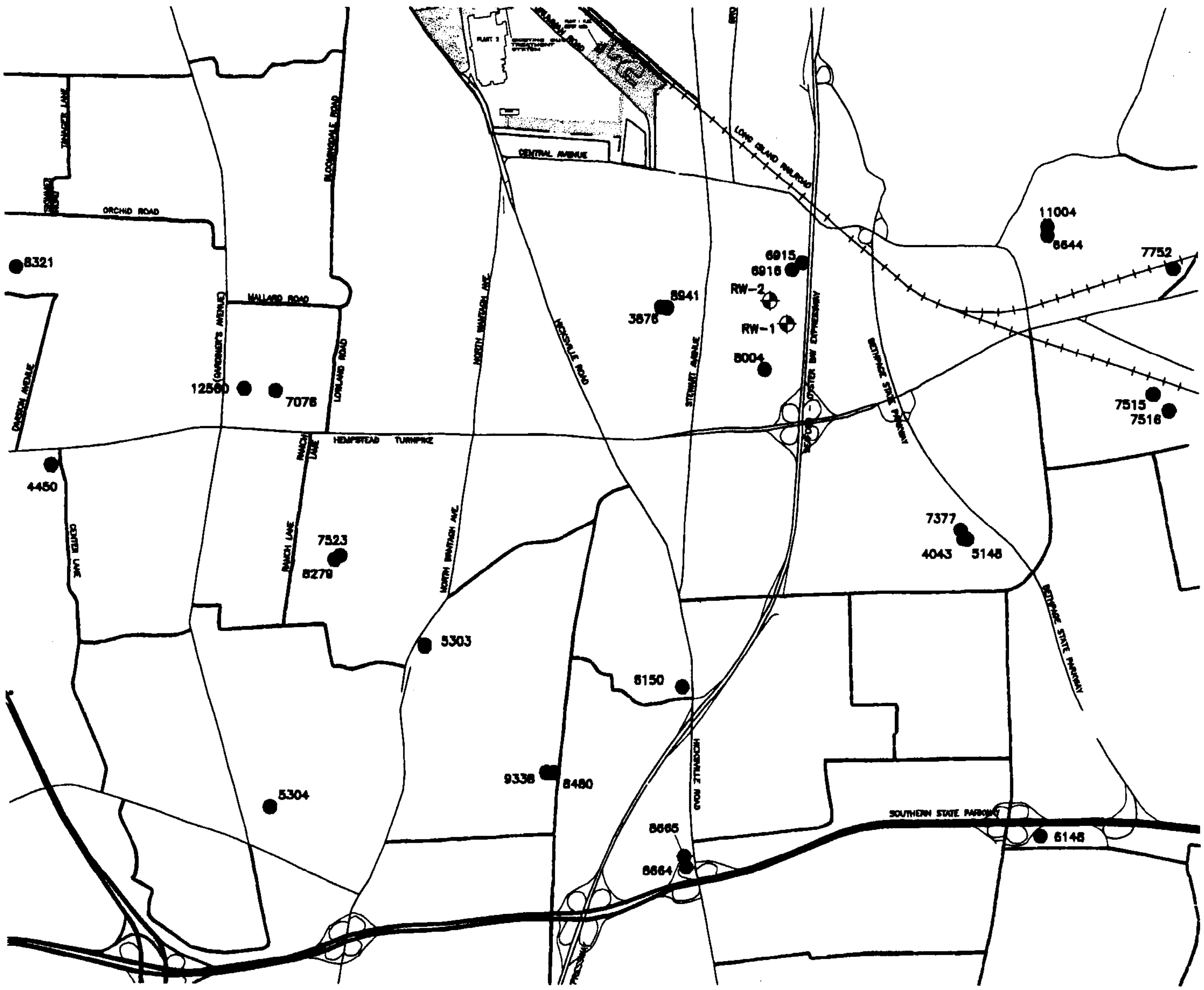
Table 3. Outpost Monitoring Well Trigger Values, Northrop Grumman Corporation - Bethpage, New York.

Outpost Well ID	Nearest Street Intersection of Outpost Well Location	Distance from Outpost Well to Municipal Supply Well (feet)	Municipal Supply Well ID	Outpost Well Trigger Value (ppb)	Time to Reach Trigger Value in Outpost Well (years)	Time to Detection in Municipal Supply Well (years)
OW1-1, OW1-2, OW1-3	Lawrence Street & Pine Tree Drive.	625	4043	0.638	6	11
OW-2-1, OW-2-2	Harriet Road & Gloria Road	320	6150	--	--	4
OW3-1, OW3-2	Red Maple Drive East & Red Maple Drive North	975	8480	1.45	13	18
OW4-1, OW4-2	Elm Drive West & Elm Drive North	850	5303	--	--	--

Time to detection is number of years before detection of 0.5 ppb total volatile organic compounds (TVOC) in municipal supply well.
Trigger Value is TVOC concentration at outpost well 5 years before model predicted detection of 0.5 ppb at municipal supply well.
For well 6150, travel time is too brief to determine trigger value, detection will occur in less than 5 years.
For well 5303 trigger value and time to detection cannot be determined because model does not predict detection to occur based on current plume delineation.

G:\TECHNICL\Porsche\NGModel\outpost wells\outpost location memo table 3.xls- summary



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LEGEND

PROPOSED REMEDIAL WELL

SUPPLY WELL

DRAWN LMC	DATE 11/26/02	PROJECT MANAGER R. PORSCHE	DEPARTMENT MANAGER N. VALKENBURG
LOCATIONS OF SELECT MUNICIPAL SUPPLY WELLS AND PROPOSED REMEDIAL WELLS		LEAD DESIGN PROF.	CHECKED R. PORSCHE
NORTHROP GRUMMAN CORPORATION		PROJECT NUMBER NY001321.0006.00003	DRAWING NUMBER 1

0 3000
SCALE IN FEET

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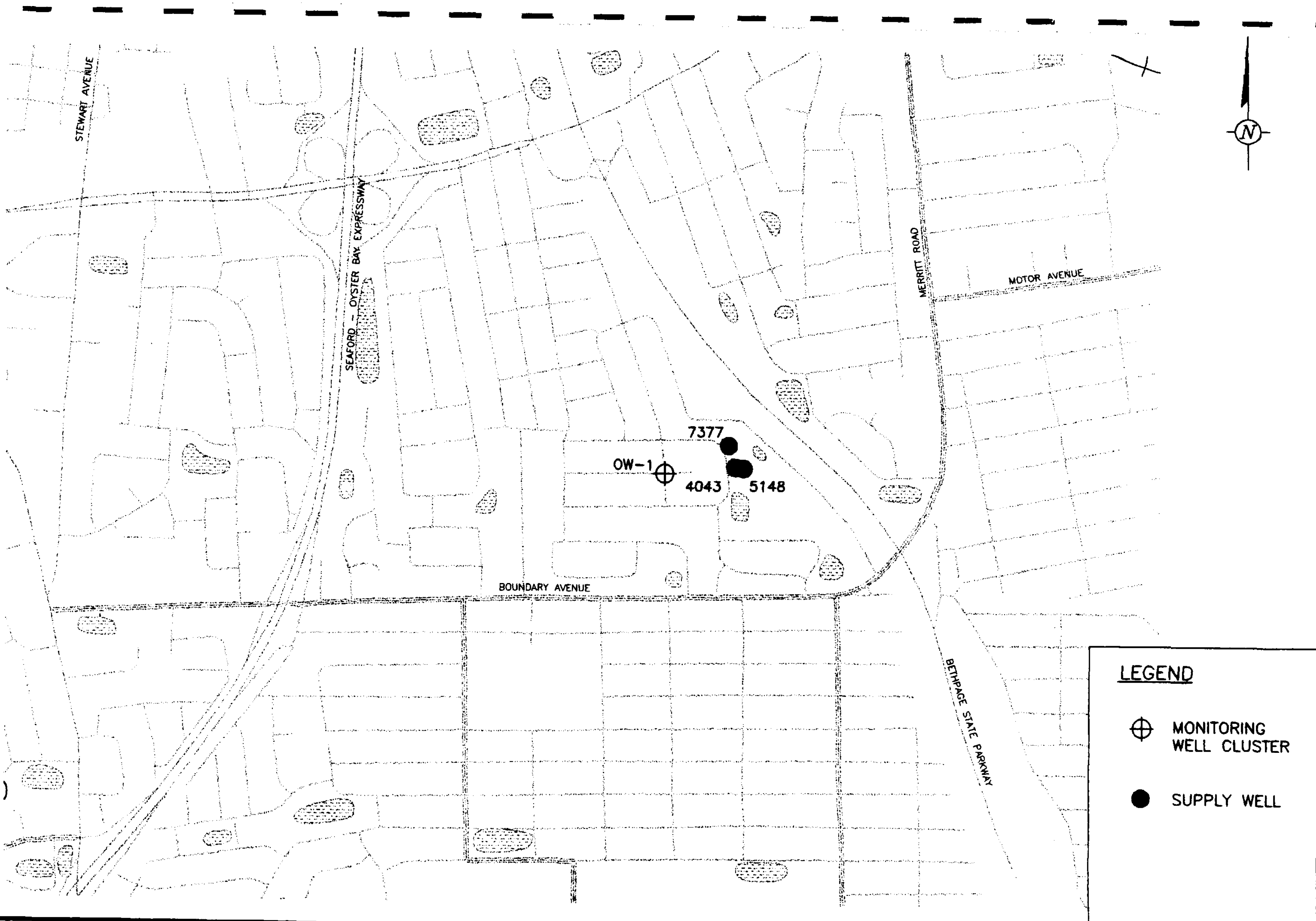

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DRAWN LMC	DATE 11/26/02	PROJECT MANAGER R. PORSCHE	DEPARTMENT MANAGER N. VALKENBURG
OUTPOST MONITORING WELL CLUSTER LOCATION FOR SOUTH FARMINGDALE'S WELL FIELD NO. 1		LEAD DESIGN PROF.	CHECKED R. PORSCHE
NORTHROP GRUMMAN CORPORATION		PROJECT NUMBER NY001321.0006.00003	DRAWING NUMBER 2

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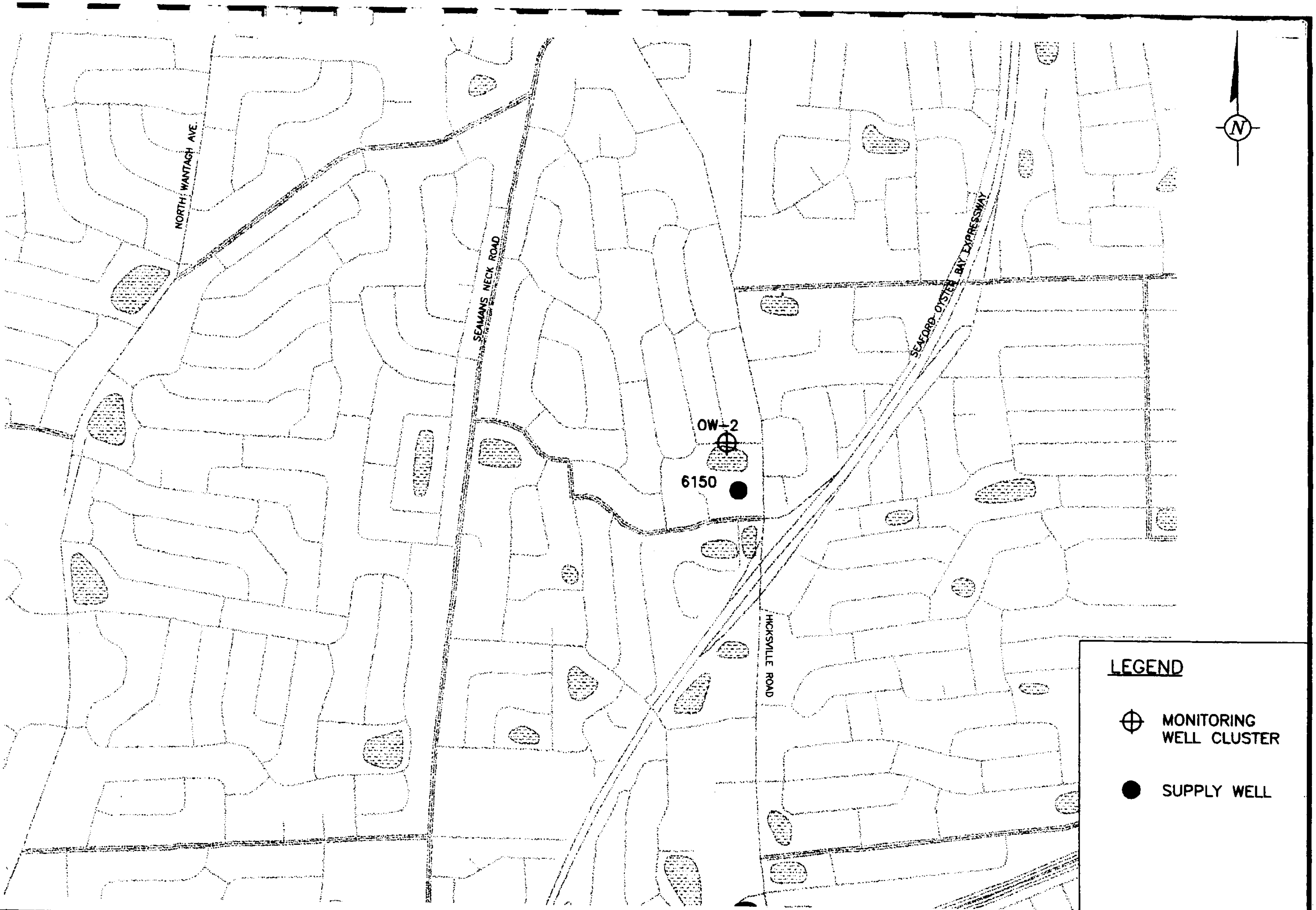

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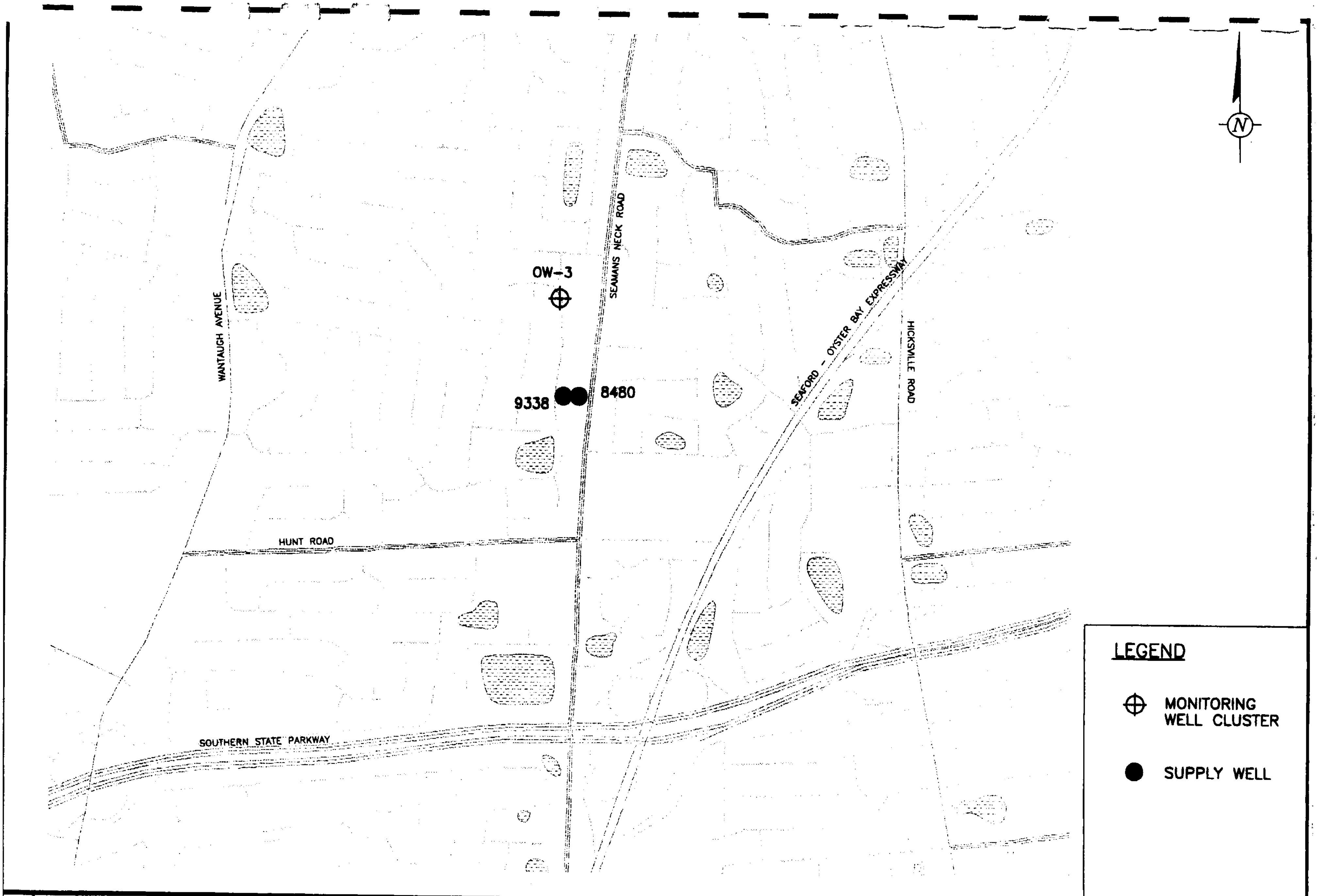
DRAWN LMC	DATE 11/26/02	PROJECT MANAGER R. PORSCHE	DEPARTMENT MANAGER N. VALKENBURG
OUTPOST MONITORING WELL CLUSTER LOCATION FOR SOUTH FARMINGDALE WELL FIELD NO. 3		LEAD DESIGN PROF.	CHECKED R. PORSCHE
NORTHROP GRUMMAN CORPORATION		PROJECT NUMBER NY001321.0006.00003	DRAWING NUMBER 3



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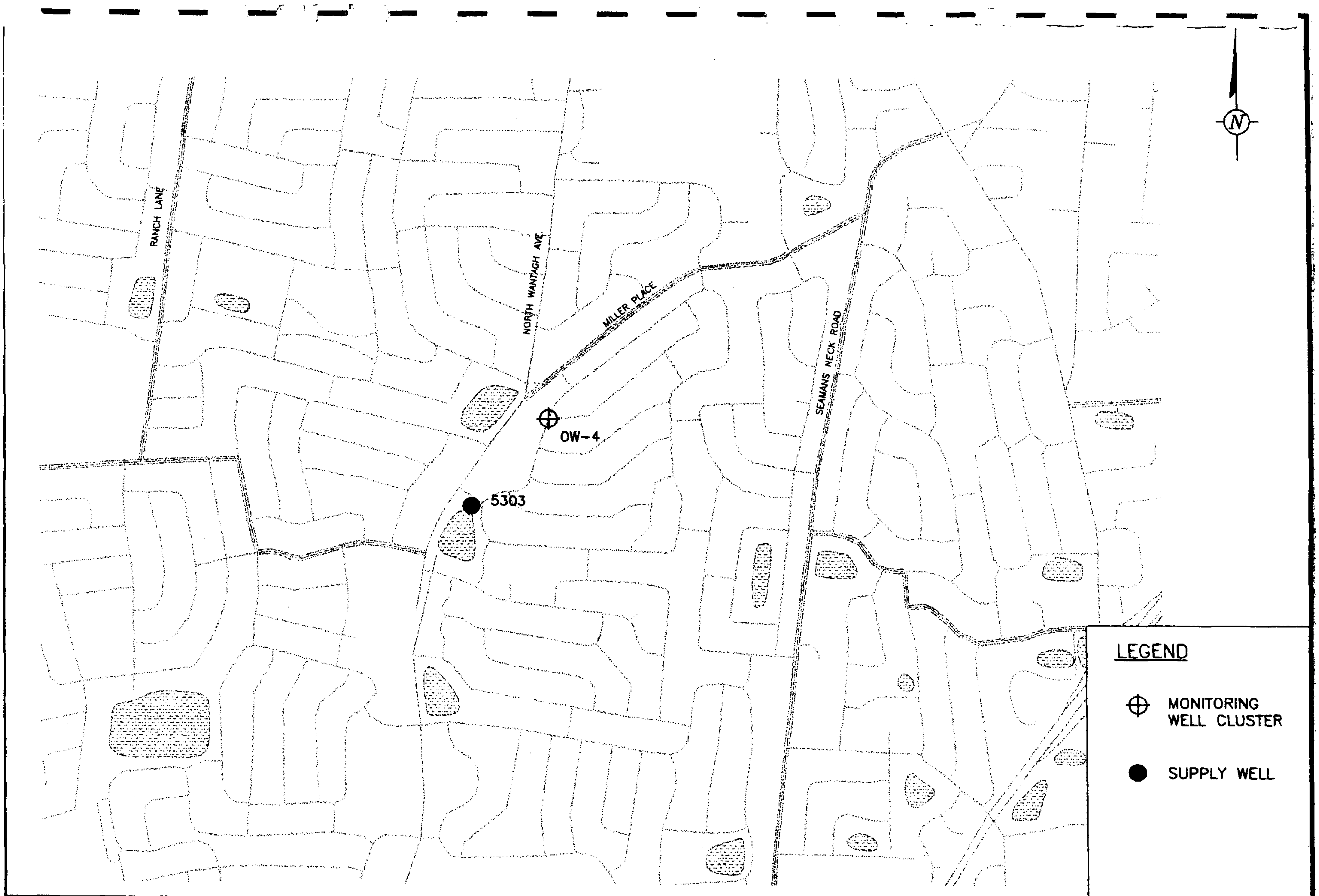
DRAWN LMC	DATE 11/26/02	PROJECT MANAGER R. PORSCHE	DEPARTMENT MANAGER N. VALKENBURG
OUTPOST MONITORING WELL CLUSTER LOCATION FOR THE NEW NEW YORK WATER SERVICE WELL FIELD (WELLS 8480 AND 9338)		LEAD DESIGN PROF.	CHECKED R. PORSCHE
NORTHROP GRUMMAN CORPORATION		PROJECT NUMBER NY001321.0006.00003	DRAWING NUMBER 4



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DRAWN LMC	DATE 11/26/02	PROJECT MANAGER R. PORSCHE	DEPARTMENT MANAGER N. VALKENBURG
OUTPOST MONITORING WELL CLUSTER LOCATION FOR THE TOWN OF HEMPSTEAD WATER DISTRICT (LEVITTOWN) WELL FIELD NO. 13		LEAD DESIGN PROF.	CHECKED R. PORSCHE
NORTHROP GRUMMAN CORPORATION		PROJECT NUMBER NY001321.0006.00003	DRAWING NUMBER 5