KEYSPAN

VILLAGE OF GARDEN CITY WATER SUPPLY WELLS CAPTURE ZONE ANALYSIS REPORT

Assessment of Hempstead Intersection Street Former MGP Site Related Impacts

H2M PROJECT NO.: KEYS 04-05

OCTOBER 2006

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EXECUTIVE SUMMARY

On behalf of KeySpan, Holzmacher, McLendon & Murrell, P.C. (H2M) analyzed ground water flow in the vicinity of the former Hempstead Intersection Street Manufactured Gas Plant (MGP) site and the Village of Garden City's public water supply wells which are located on 2nd Avenue approximately 200 feet west of the former MGP site. The analysis was conducted using data from the March 2006 Paulus, Sokolowski & Sartor Engineering, P.C Final Remedial Investigation Report, which describes the groundwater conditions and impacts from the former MGP site.

H2M performed computer modeling to simulate groundwater flow in the aquifer system, which is the source for the public supply water wells. The modeling results indicate that the area of the former MGP site related impacts is outside of the groundwater capture zone of the water supply wells, assuming normal pumping rates based on historical data. Under theoretical maximum pumping conditions the capture zone for the supply wells could extend into the former MGP site area if the worst-case maximum pumping scenario persisted for about 16 years. However, this scenario is very conservative in nature and the maximum pumping scenario is unlikely to occur for an extended time period (e.g. 16 years) due to the following:

- The possibility of the Village of Garden City requiring the maximum pumping rates necessary to create the worst-case scenario is very remote since the residential and commercial community served by these wells is at or near maximum growth potential and local water supply demand is therefore not expected to increase significantly over time.

- Good engineering practice and applicable guidance documents for the water supply industry call for redundancy in water supply systems which would reduce the likelihood of any one system operating at full capacity for more than a few years time.
- There is little known precedent for water purveyors in the local region to operate a given pumping system at maximum output for the timeline required to create the worst-case scenario.

In addition, the model focuses on groundwater flow instead of contaminant migration and does not account for natural contaminant attenuation factors such as dispersion, advection, and adsorption, which can significantly limit contaminant mobility through the subsurface environment.

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1.0 INTRODUCTION

1.1 PURPOSE

In order to further assess the potential impacts of the Hempstead Intersection Street former manufactured gas plant (MGP) site on the nearby Village of Garden City public supply wells, KeySpan Corporation retained Holzmacher, McLendon & Murrell, P.C. (H2M) to prepare this capture zone analysis.

Review of the Contaminant Fate Report - Hempstead Gas Plant, May 1995 as prepared by P.W. Grosser Consulting Engineer & Hydrogeologist, P.C., indicated that improvements could be made to several general assumptions in the report, regarding groundwater stratigraphy and conductivity rates. The new groundwater model includes more site-specific data and provides a more refined analysis of groundwater flow.

H2M constructed a groundwater flow model to define the potential capture zones of the Village of Garden City supply wells N-10033 and N-10034, which are located approximately 200 feet west of the former MGP site. The groundwater flow model was created using Visual ModFlow 4.0, a hydrogeologic software program developed by Waterloo Hydrogeologic, Inc.

This software program simulates steady state and transient conditions for a three-dimensional, finite difference groundwater flow model. The Visual ModFlow software solves the fundamental partial differential equation of Darcy's Law for groundwater flow, and generates output data that is used to analyze specific scenarios of interest. The modeling effort was conducted in accordance with standard and accepted scientific and engineering practices for the development of groundwater flow models including applicable ASTM standards. The groundwater model was prepared in accordance with applicable provisions of ASTM Standard D5718-95 Standard Guide for Documenting a Ground-Water Flow Model Application.

1.2 SITE BACKGROUND

The Hempstead Intersection Street former MGP site is located in Garden City, New York in Nassau County. The site was used as a gas manufacturing plant from the early 1900's until the mid-1950's, when it was retired by the Long Island Lighting Company (LILCO). In 1998, LILCO merged with Brooklyn Union Gas to form KeySpan Corporation. KeySpan now owns the site and uses it as a natural gas regulator station. According to the *February 2005 Paulus, Sokolowski & Sartor Engineering, P.C Draft Final Remedial Investigation*, on-site sampling results indicate the presence of non-aqueous phase liquids (NAPL), BTEX (benzene, toluene, ethylbenzene and total xylenes) and polycyclic aromatic hydrocarbons (PAH) in soil and groundwater.

This capture zone analysis focused on the two (2) public supply wells located approximately 200 feet west of the former MGP site. These wells are identified as N-10033 and N-10034, otherwise known as Village of Garden City Well Nos. 15 and 16 respectively.

2.0 HYDROGEOLOGY

2.1 REGIONAL HYDROSTRATIGRAPHY

Three major aquifers, the Upper Glacial, the Magothy and the Lloyd, comprise the hydrogeologic layered formations that underlie the region surrounding the former MGP site. Located a short depth below the ground surface, the Upper Glacial aquifer ranges in thickness from 50 to 100 feet, and consists of medium-to-course grained Pleistocene deposits. Proceeding deeper, the Magothy aquifer is approximately 400 to 600 feet thick, and includes the Upper Magothy and Lower Magothy. The Upper Magothy typically contains fine-to-medium sand, while the Lower Magothy consists of coarser material. The Village of Garden City public water supply wells N-10033 and N-10034 withdraw water from the Lower Magothy. A 100 to 200-foot thick confining layer of clay, known as the Raritan Formation, separates the Lower Magothy from the Lloyd aquifer. The deepest layer, known as the Lloyd aquifer, ranges in thickness from 200 to 300 feet, and consists of coarse to fine sands on top of the underlying bedrock formation. The bedrock formation has a low permeability and is considered the base of the groundwater system.

The ground surface, the underlying layered aquifers, and the bedrock generally have a southeastward slope, which contributes to the horizontal groundwater flow direction. Additionally, groundwater flow is typically greater in the horizontal direction than in the vertical direction. Groundwater contours for this model were generated using data tables from the Nassau County Regional Groundwater Model (NCRGM). The regional head contours (water level) that were generated at five foot intervals are presented in Figure 2-1.

2.2 WELL CHARACTERISTICS

The two Village of Garden City public supply wells, N-10033 and N-10034, are located approximately 200 feet from the MGP site. Characteristics of each well are presented in Table 2-1 below.

	N-10033 (Village Well No. 15)	**N-10034 (Village Well No. 16)**
Depth of Well	545 ft.	575 ft.
Pump Capacity	1,380 GPM*	1,380 GPM*
Screen Interval	419'-2" to 540'-10"	488'-8" to 569'-9"
Aquifer Source	Lower Magothy	Lower Magothy

Table 2-1: Well Characteristics

* Total plant output limited by treatment capacity to 1 well at a time (1,380 GPM).

The design capacity of each well is 1,380 gallons per minute (GPM). However, the existing iron removal treatment plant that treats water from both wells limits the combined output from these wells to a maximum pumpage of 1,400 GPM. Under existing operating conditions, well N-10033 pumps at an average daily rate of 234 GPM, and well N-10034 pumps at an average rate of 476 GPM, over the course of a typical pumping year.

3.0 GROUNDWATER MODEL INPUT PARAMETERS

A groundwater model is a computer simulation representing an approximation of groundwater flow in an aquifer. The aquifer is defined by its unique hydrogeological parameters. Visual ModFlow uses the MODFLOW groundwater flow code developed by McDonald and Harbough at the United States Geological Survey (USGS). MODFLOW is capable of simulating transient or steady state three-dimensional flow in porous media.

MODFLOW uses the finite difference method to solve a partial differential equation for three-dimensional groundwater flow in porous media. Visual ModFlow uses the same partial differential equation, which is mathematically derived from Darcy's Law. The equation is:

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)+\mathrm{W}=S_s\frac{\partial h}{\partial t}$$

Where,

$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)$ =*Groundwater Flux in 3 dimensions*

K_{xx}, K_{yy}, K_{zz} = *Hydraulic Conductivity*

h = *Head*

W = *Sources/Sinks*

$S_s\frac{\partial h}{\partial t}$ = *Change in Storage (where* S_s *is Storage)*

The groundwater model was created to simulate the capture zone for the Village of Garden City public supply water wells N-10033 and N-10034. The NCRGM was the source of many of the input parameters, and it is considered the conceptual starting point for the model. The groundwater model includes input parameters to define the model boundaries, including recharge and flow boundaries. Aquifer properties including hydraulic conductivity, porosity and storage, were input for the various hydrogeologic layers of the model. Also, initial conditions and field observations for groundwater heads and well pumpages were input to the model.

3.1 THREE DIMENSIONAL PARAMETERS

Conservative assumptions were made regarding the geographic extents of the model, with consideration for the project objectives. The model boundaries were set at 5.4 miles from East to West, and 5.6 miles from North to South. The model grid was established by setting the former MGP site as the central point in the model. Boundary lines were then established to allow for influences from regional groundwater flow and pumpage from nearby public supply wells.

The groundwater model was dissected in the longitudinal and latitudinal directions, creating a grid using the mathematical optimization features of the Visual ModFlow software program. The model domain was divided into 74 rows, 65 columns and 7 layers of grid cells. Each grid cell is a three-dimensional, right-angled shape with an elemental volume that is input into the program's equation solver. A uniform grid was not used for the groundwater model. Grid sizes are approximately 2.5 acres in areas surrounding the former MGP site and the grid sizes gradually enlarge to 4.5 acres on the edges of the model space. A grid smoothing algorithm was applied to optimize discretization and to maximize numerical and computational stability. The elevation of each corner of every grid cell in the model was obtained by interpolation of geographically referenced data points from the NCRGM. The three-dimensional model grid is shown on Figure 3-1.

Public supply well coordinate locations and screen elevations were also imported from the NCRGM. These parameters were verified or refined according to topographic mapping and well completion reports.

3.2 HYDROGEOLOGIC PARAMETERS

The groundwater model design and subsequent simulation efforts incorporated conservative considerations for system geometry and hydrogeologic parameters. The key hydrogeologic parameters that were tested for accuracy and consistency of results include; recharge, hydraulic conductivity, initial head and constant head. In addition, accepted regional values for effective porosity and specific storage were imported from the NCRGM data files.

Recharge is the amount of water returned to the ground after both runoff and evapotranspiration are subtracted from the total amount of precipitation. The sole source of groundwater replenishment for Long Island aquifers is precipitation, which averages 44 inches per year. The United States Geological Survey and the New York State Department of Environmental Conservation estimate that about 50% of the average rainfall (22 inches) that falls on the land eventually percolates through the soil to the water table. The balance is returned to surface water via runoff and to the atmosphere via surface evaporation and transpiration of plants.

Hydraulic conductivity (K) is a measure of an aquifer's ability to transmit groundwater. By definition, water passes easily through the large pore spaces of a coarse material, thereby equating to a high K value. Similarly, a fine material, through which water flows slowly, has a low K value. The hydraulic conductivity of the Glacial, Magothy and Lloyd aquifers range from 10 to 100 times greater in the horizontal direction than the vertical direction. It should be noted that hydraulic conductivity values used in the model were approximated for the entire thickness of each aquifer, however the natural stratification of the deposits in these formations results in variations of conductivities at different depths. Values for hydraulic conductivity were obtained from the NCRGM data files. A listing of hydraulic conductivities used in each layer of the groundwater model, with the corresponding geologic formation, is presented on Figure 3-2 and in Table 3-1 on the following page.

Model Layer	Geologic Formation	K_x (ft/d)	K_y (ft/d)	K_z (ft/d)
1	Glacial	200	200	20
2	Upper Magothy 1	30	30	0.35
3	Upper Magothy 2	35	35	0.35
4	Lower Magothy 1	40	40	0.40
5	Lower Magothy 2	125	125	1.25
6	Raritan Clay	0.30	0.30	0.002
7	Lloyd	35	35	0.35

Table 3-1: Hydraulic Conductivities

Initial head is a measure of the pressure or head corresponding to the height to which water would rise in an observation well penetrating a specific aquifer. The initial heads for nodes within the groundwater model were imported from the NCRGM data files. Initial heads are used in the simulation process for calculation of drawdown, and the values are adjusted for each consecutive time iteration.

Constant head boundaries are assigned to the groundwater model to act as a fixed head source or sink. These groundwater system boundaries are necessary in order to completely enclose the region of interest. The northern boundary acts as an infinite source of water entering the system, and the southern boundary acts as an infinite sink for water exiting the system. For this groundwater model, constant head boundaries were assigned to their respective grid coordinates based on head values interpolated from the NCRGM data files.

4.0 MODEL SIMULATIONS

The three-dimensional groundwater flow model was used as a tool for evaluation of the following scenarios. Firstly, two steady state scenarios were developed to determine capture zones for wells N-10033 and N-10034. Secondly, a transient scenario was developed to track the path line of groundwater flow downstream of the monitoring wells located on the former MGP site. Following development of a steady state model, it was deemed appropriate to estimate the time frame associated with the capture zone transformation from the average scenario to the maximum scenario. Accordingly, a transient model was developed to estimate the time frame associated with the relocation of the capture zone path lines. The transient model was also used to determine whether there could be sufficient time for a contingency plan to be implemented should the Village significantly increase the supply well pumping rates.

All groundwater modeling scenarios were run using the WHS Solver in Visual ModFlow. The WHS Solver uses a bi-conjugate gradient stabilized acceleration routine implemented with incomplete decomposition for preconditioning of the groundwater flow partial differential equations.

4.1 CAPTURE ZONE SCENARIOS

A capture zone is an estimated area that contributes water to a pumping well. Capture zone analysis is a technique used to predict the horizontal and vertical extent of groundwater that could be drawn into a well under specified pumping conditions for which the capture zone was defined. The use of capture zones is a conservative tool for predicting contaminant impacts, because the calculation of a capture zone does not take into account natural attenuation of contamination known to exist in the real world, such as dispersion, adsorption and advection.

Visual ModFlow can generate capture zones using particle path lines. By running the numerical model in reverse and placing particles at the well screen, the resultant particle path lines provide a graphical representation of the area contributing to the respective pumping well. This process outlines the capture zone for a specific well.

To generate the capture zones for wells N-10033 and N-10034, an average and maximum condition were simulated in order to delineate a probable capture zone and a worst-case capture zone. The simulations were run with steady state conditions, whereby Visual Modflow runs numerous iterations until convergence occurs and calculated results are repeatable within an acceptable margin. The capture zone scenarios that were run are; Baseline Pumpage, which simulates average pumping rates for all public supply wells; and Maximum Pumpage, which simulates maximum pumping rates at the two adjacent public supply wells (1,380 GPM total from both, limited by treatment capacity), and average pumping rates for all other wells.

The use of the maximum pumpage scenario is very conservative. The circumstances that would occur to cause the maximum pumping condition are extreme and not probable. However, rather than try and determine the possible combinations and permutations of scenarios that could occur, (these being infinite), and associate a probability of occurrence, the maximum possible pumpage was utilized. Any conclusions derived from this scenario would represent a worst case scenario and from a planning perspective could be used as a starting point for planning an appropriate response.

4.1.1 Baseline Pumpage Scenario

The Baseline Pumpage Scenario was developed using actual Village well pumpage records from the last three years. The pumpage values were converted to average pumping rates by assuming the wells are in continuous operation for the purposes of the steady state simulation. The Baseline Pumpage Scenario simulates average pumping rates for all of the Village of Garden City public supply wells N-10033 and N-10034. Based on actual pumping data from 2002 supplied by the Village of Garden City, Well N-10033 was simulated to pump 234 GPM and Well N-10034 was simulated to pump 476 GPM. It should be noted that the baseline scenario represents current public water supply withdrawal rates for a residential and commercial community at or near maximum growth potential. Therefore, local water supply demand should not increase significantly over time.

4.1.2 Maximum Pumpage Scenario

This steady state maximum pumping scenario simulates the two adjacent public supply wells operated at their maximum pumpage. An existing iron removal treatment system for these two Village of Garden City public supply wells limits the amount of water that can be pumped to approximately 50% of the total maximum pump rate. The iron removal treatment system treats raw water from each well (N-10033 and N-10034), and can treat a maximum combined pumpage of 1,400 GPM from the two wells. Therefore, each well was simulated to have a pumping rate of 700 GPM. In this scenario all other public supply wells in the model are held to their average pumping rates. The pumping conditions simulated in this maximum scenario are conservative, as they assume a combined pumpage of 1,400 GPM from wells N-10033 and N-10034 for 24 hours per day, 7 days per week, 365 days per year. Such a pumping condition is not in line with recent or past pumping rates for the Village of Garden City wells. Furthermore, such a pumping condition is not reflective of how public supply wells are typically operated on Long Island, which depends on daily and seasonal water demand fluctuations. Hence, this maximum pumpage scenario is a worst case condition for modeling purposes.

4.2 TRANSIENT SCENARIO

The results of the maximum pumpage scenario (as will be discussed in Section 5.0) indicated that the capture zone did not correspond to locations of known MGP contamination at the ground surface. However, the path lines used to generate the capture zone did intersect several monitoring well screen zones that are known to have groundwater impacts. Although the Village will most likely not need this maximum level of pumpage from the wells, a model was developed to address the potential timetable for impact using the change from baseline to maximum pumpage as the critical event.

Baseline conditions were used as a starting point, and all wells were set to run at average pumping rates for a period of 25 years to further stabilize baseline conditions. Following the stabilization period, the pumping rates for N-10033 and N-10034 were increased to the maximum level as described in the maximum pumpage scenario above, with other public supply well pumpages held at average rates. Maximum conditions were applied for a period of 175 years in order to simulate the worst-case situation over a sufficient period of time to allow for thorough evaluation of particle path lines.

The time step when pumpage at wells N-10033 and N-10034 is changed from average to maximum is defined as 'Time Zero'. Every year prior to time zero has baseline pumpage conditions, and every year following time zero has maximum pumpage conditions. Particles were modeled from the existing monitoring wells at the former MGP site, and the flow paths of the particles were tracked forward in time. The particles at the monitoring wells were set at depths where groundwater impacts have been detected, ranging between 100 to 150 feet below ground surface. The particles were modeled from the monitoring wells at various times, including prior to time zero, at time zero, and following time zero, in order to determine the critical path lines and travel times for the particles that could potentially end up in the screened zone of wells N-10033 or N-10034.

5.0 MODELING RESULTS AND ANALYSIS

Calibration of a groundwater flow model involves the process of obtaining a reasonable match between observed and simulated conditions. Regional groundwater elevations were used as a calibration tool since hydraulic head values at the water supply wells were unavailable. Model calibration was achieved by adjusting hydraulic parameters within reasonable ranges to obtain a match between accepted and simulated head potentials and groundwater contours. Accepted data was obtained from the NCRGM, the *March 2006, Paulus, Sokolowski & Sartor Engineering, P.C, Draft Final Remedial Investigation Report*, and the Village of Garden City. The model was found to have an acceptable match between calculated groundwater elevation contours and observed groundwater elevation contours presented in the *March 2006, Paulus, Sokolowski & Sartor Engineering, P.C, Draft Final Remedial Investigation Report*. The results of simulations were evaluated for their close agreement to the accepted data sources, and adjustments to the model parameters were made to calibrate the model.

5.1 CAPTURE ZONE SCENARIOS

Under steady state conditions, capture zones that are generated are the result of numerous modeling iterations run by the software program, until convergence occurs and calculation results are repeatable within an acceptable margin.

5.1.1 Baseline Pumpage Scenario

Figure 5-1 shows the estimated baseline pumpage capture zone area for the Village of Garden City public supply wells N-10033 and N-10034. The area of this capture zone is approximately 130 acres at ground surface. The approximate bounds of the oval shaped baseline pumpage capture zone are; a southern limit at 1,500 feet north of 11th Street; a northern limit at 375 feet south of Old Country Road; a western limit at 1,100 feet east of Rockaway Avenue; and an eastern limit at 200 feet east of Washington Avenue.

5.1.2 Maximum Pumpage Scenario

Water particle tracking was performed in an identical procedure as described above. Figure 5-2 shows the estimated capture zone area for the Village of Garden City public supply wells N-10033 and N-10034 under maximum pumpage conditions. The area of this capture zone is approximately 350 acres at ground surface. The approximate bounds of the horseshoe shaped maximum pumpage capture zone are; a northern limit at Old Country Road; a southern limit at 3rd Street; an eastern limit at Wetherill Road; and a western limit at Rockaway Avenue.

5.2 TRANSIENT SCENARIOS

A three-dimensional isometric view of forward water particle path lines modeled from a known impacted monitoring well screen location at the MGP site and subject to average pumping conditions for a period of 25 years (transient scenario 1) is presented on Figure 5-3. In this scenario, water particles are not drawn back into wells N-10033 and N-10034. Instead, they flow southerly through the layered geologic formation.

Several modeling iterations were conducted to determine the timeline, under average pumping conditions, for an impacted water particle to flow to a point where it could no longer be captured by wells N-10033 and N10034 should the pumping rate be increased to a maximum condition. This timeline was determined to be over six years. Given this timeline, a second transient scenario was modeled to allow for average pumping conditions for 6 years followed by maximum pumping conditions for all following years. A cross sectional view for transient scenario 2 showing water particle path lines from the impacted monitoring well screen is presented on Figure 5-4. The first water particle would arrive at the screen zone for wells N-10033 and N-10034 after a travel time of 19 years (six years under average pumping conditions plus 13 years at maximum pumping condition).

As a worst case scenario, theoretical water particles were modeled from the area of impacted groundwater and subject to maximum pumping conditions at all times (transient scenario 3). Under this scenario, the first water particle would arrive at the screen zone of wells N-10033 and N-10034 in 16 years as shown in cross section figure 5-5.

6.0 CONCLUSIONS

In conclusion, the capture zones for current average pumping and theoretical maximum pumping conditions from public supply wells N-10033 and N-10034 are located in regions to the northwest of the former MGP site. Under theoretical maximum pumping conditions, the capture zone becomes wider and shifts closer to the former MGP site. For the maximum scenario, the groundwater flow model showed some groundwater particle path lines crossing underneath the former MGP site at depths between 100 and 200 feet below ground surface. The depth of these maximum pumpage path lines is within the same geologic zone as impacted groundwater from the former MGP site.

Under maximum pumping conditions, transient simulations (Scenario 3) identified a travel time of approximately 16 years for water particles modeled from the area of impacted groundwater to wells N-10033 and N-10034. A maximum pumping condition of less than 16 years was not shown to impact the Village of Garden City wells.

The baseline scenario indicates groundwater originating from the former MGP site will not flow to the Village of Garden City wells N-10033 and N-10034. If the Village changes their operation to the maximum pumpage levels described, wells N-10033 and N-10034 have the potential to receive groundwater from the MGP site assuming that the maximum pumping condition persisted for 16 years. However, this scenario is very conservative in nature and the maximum pumping scenario is unlikely to occur for an extended time period due to the following:

- The possibility of the Village of Garden City requiring the maximum pumping rates for the long time frames necessary to create the worst-case scenario is very remote since the residential and commercial community served by these wells is at or near maximum growth potential and local water supply demand is therefore not expected to increase significantly over time.
- Good engineering practice and applicable guidance[1] documents (Recommended Standards for Water Works) for the water supply industry call for redundancy in water supply systems which would reduce the likelihood of any one system operating at full capacity for more than a few years time.
- There is little known precedent for water purveyors in the local region to operate a given pumping system at maximum output for the timeline required to create the worst-case scenario.
- In addition, the model conservatively focuses on groundwater flow instead of contaminant migration and does not account for natural contaminant attenuation factors such as dispersion, advection, and adsorption, which can significantly limit contaminant mobility through the subsurface environment.

[1] Great Lakes-Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers, *Reccomended Standards for Water Works*, 2003 Edition.

7.0 REFERENCES

Historical information related to the Hempstead Intersection Street former MGP site was obtained from the following sources:

1. *Contaminant Fate Report – Hempstead Gas Plant*, May 1995, P.W. Grosser Consulting Engineer & Hydrogeologist, P.C.

2. *Final Remedial Investigation Report - Hempstead Intersection Street Former MGP Site*, February 2005, Paulus, Sokolowski & Sartor Engineering, P.C.

Both the Village of Garden City and the Village of Hempstead provided historical information on the pumpage rates and screen settings of their public supply wells. Water pumpage data for other public supply wells included in the model simulations was obtained from well completion reports for public supply wells in the West Hempstead Water District, Uniondale Water District, Garden City Park Water District, Carle Place Water District, Roosevelt Field Water District, East Meadow Water District, and the Village of Mineola.

Regional groundwater data, including topographic and stratigraphy data, and aquifer characteristics were taken from the Nassau County Regional Groundwater Model (NCRGM). The NCRGM was developed by the New York State Department of Health, the Nassau County Department of Health, the Suffolk County Department of Health Services, and the Suffolk

County Water Authority, and was prepared by the engineering consultant Camp Dresser & McKee (CDM). The NCRGM was based on a group of existing three-dimensional finite-element groundwater model codes developed by CDM. Each of the existing groundwater models had previously been calibrated and their accuracy has been documented in earlier studies.

The full color regional aerial mapping was obtained in a geographically referenced format from the New York State Statewide Digital Orthoimagery Program, circa 1999.

Background information on MODFLOW and mathematical equations used by Visual ModFlow were obtained from *Applied Groundwater Flow & Contaminant Transport Modeling*, June 2004, Waterloow Hydrogeologic, Inc.

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FIGURES

FIGURE 2-1

GROUNDWATER CONTOURS (5 FT. INTERVALS)

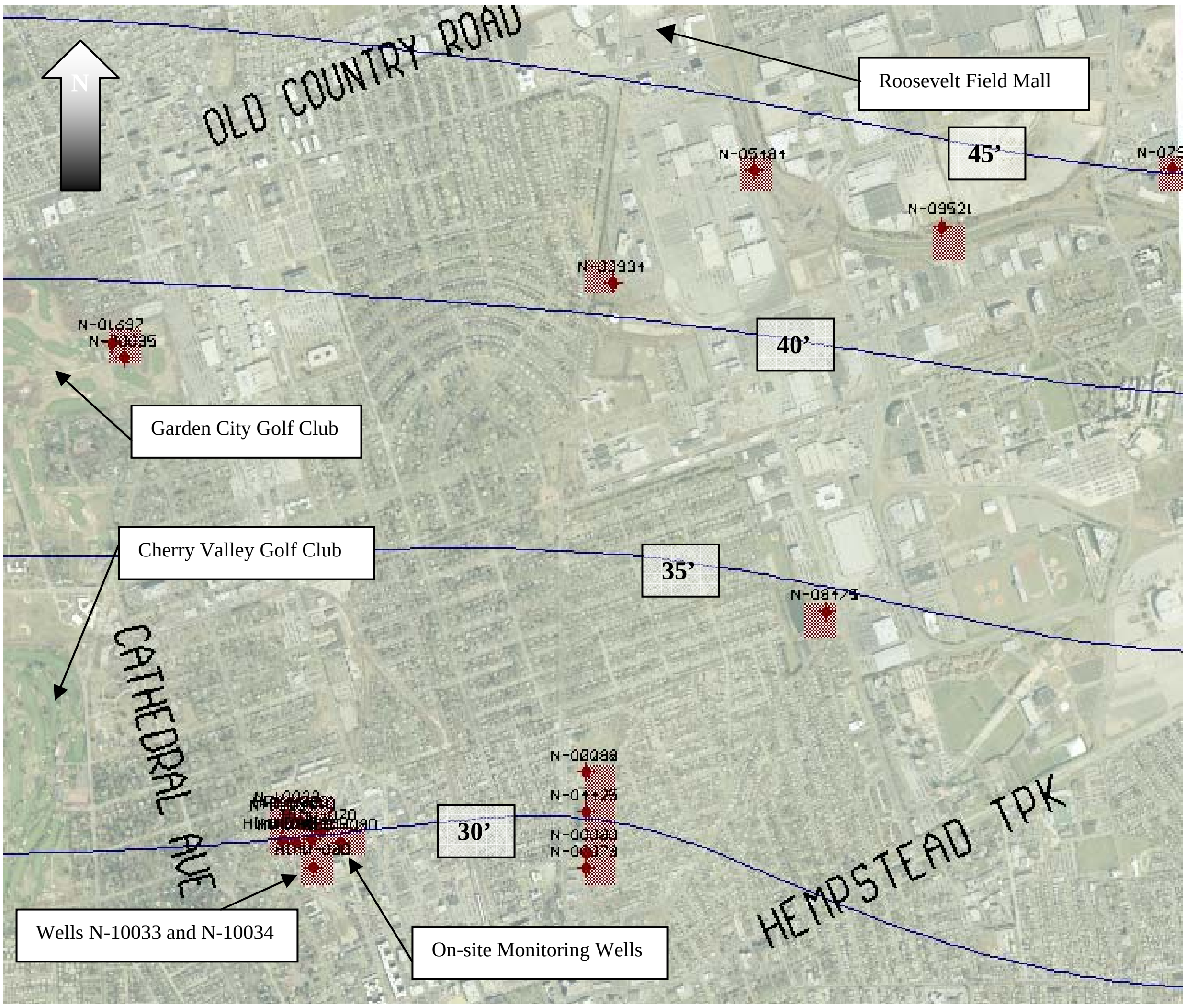

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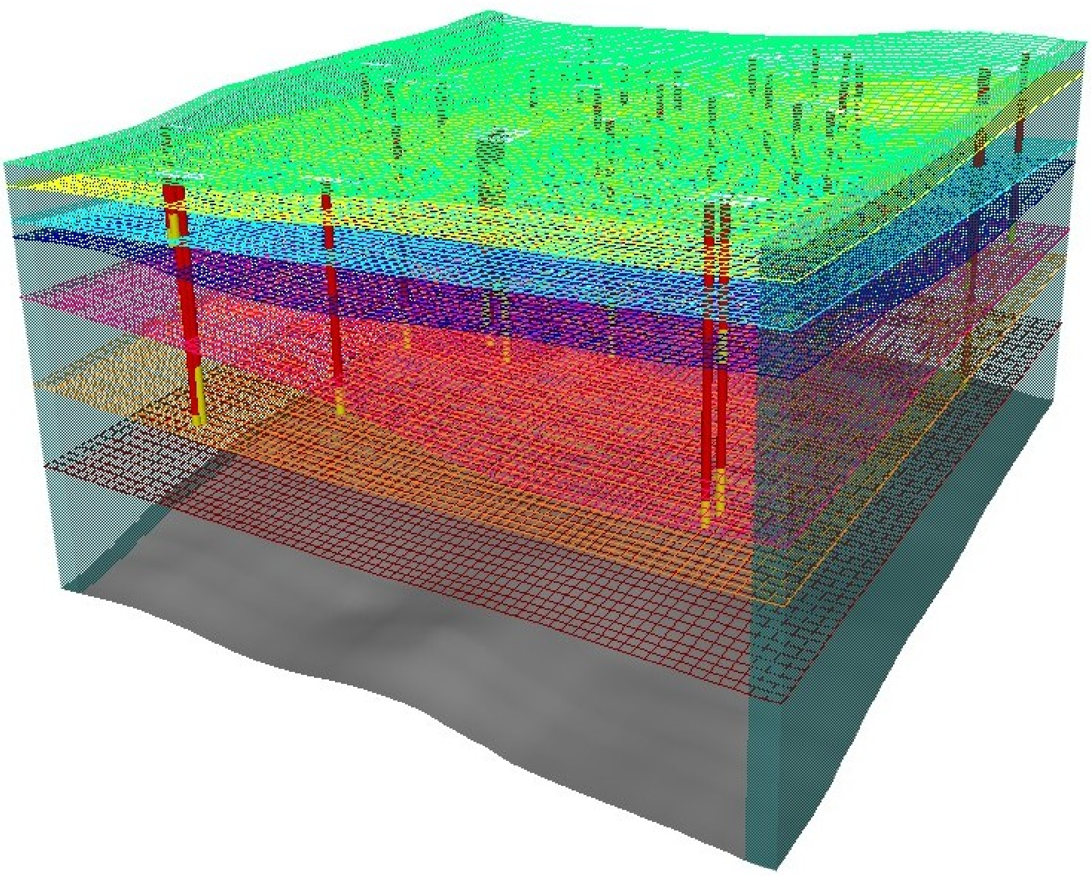
FIGURE 3-1

ISOMETRIC VIEW OF MODEL GRID



- Color shadings differentiate hydrogeologic formations.
- The top layer represents ground surface and the bottom later represents bedrock.
- Public supply wells and monitoring wells are represented as vertical red cylinders, with screen intake sections shown in yellow.

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FIGURE 3-2

HYDRAULIC CONDUCTIVITY LAYERS

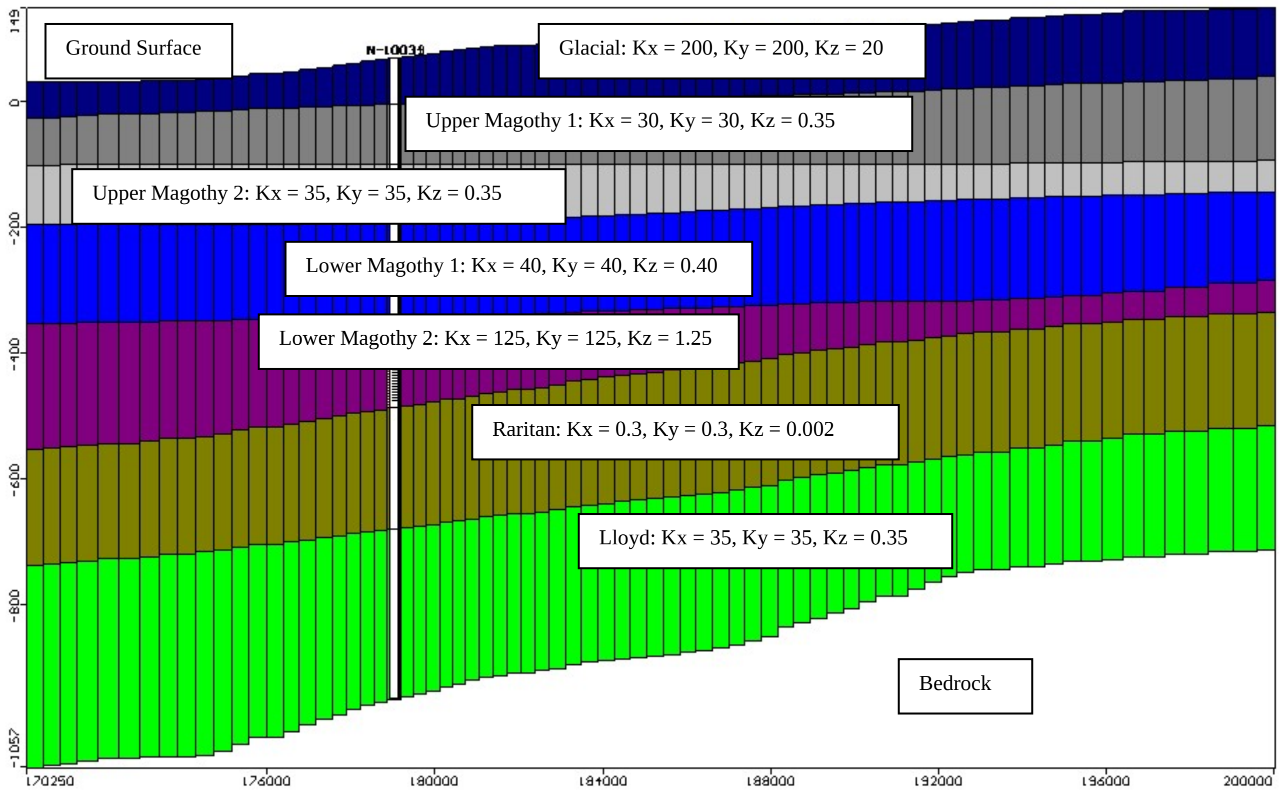

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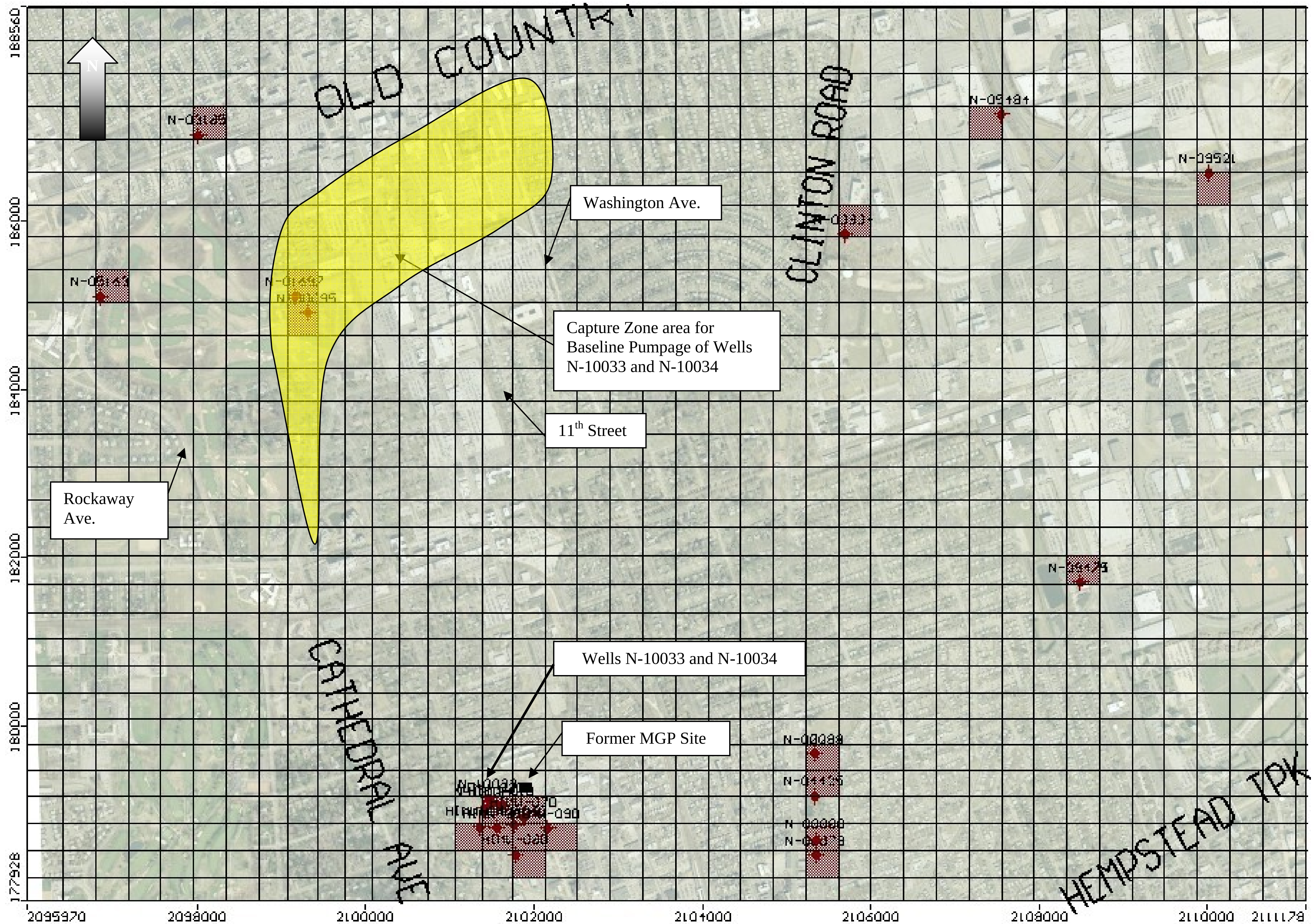
FIGURE 5-1
CAPTURE ZONE FOR BASELINE PUMPAGE SCENARIO



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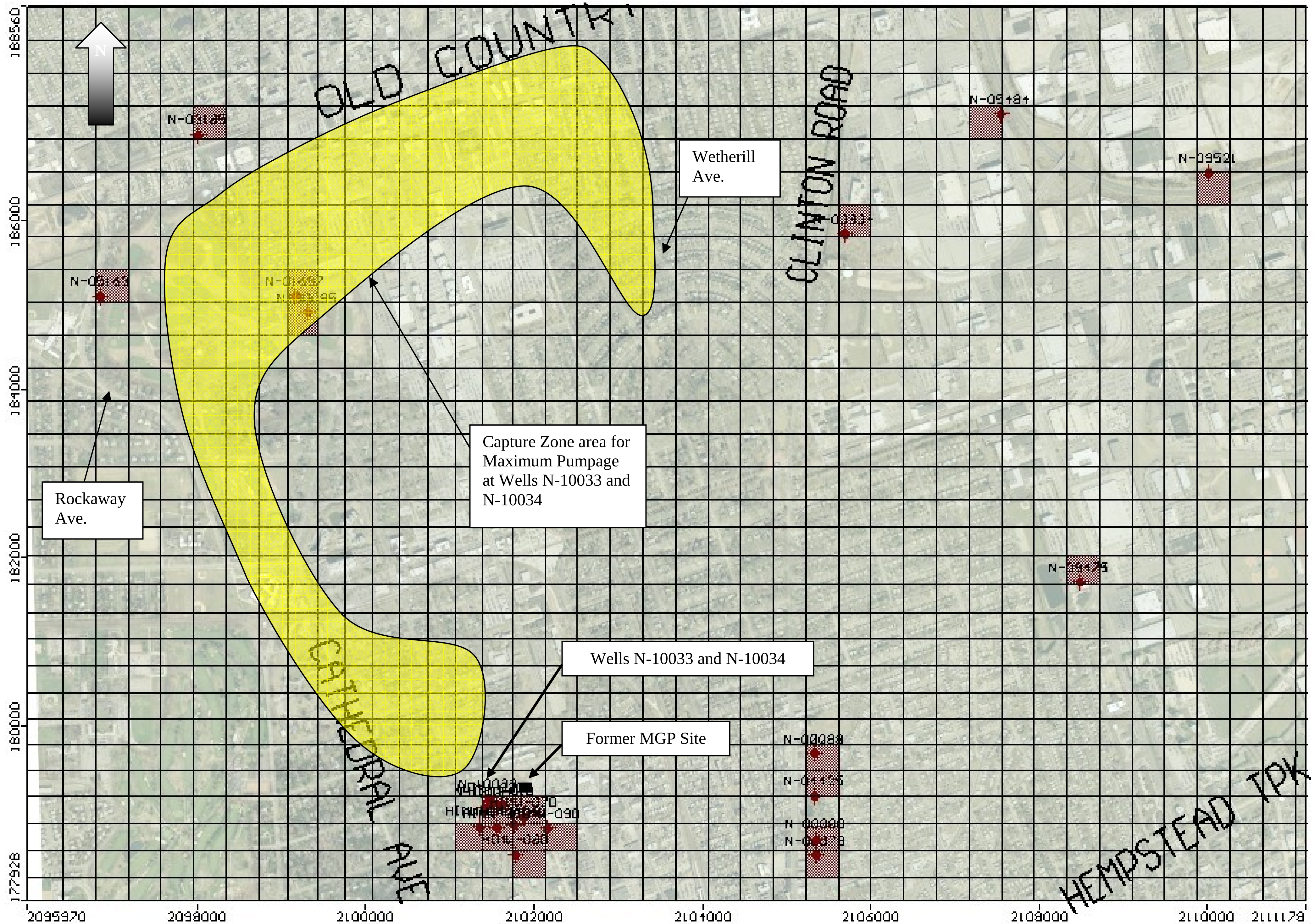
Note: The shape and configuration of the capture zone is influenced by several factors, including the subject well and other pumping wells in the region.

FIGURE 5-2

CAPTURE ZONE FOR MAXIMUM PUMPAGE SCENARIO



Note: The shape and configuration of the capture zone is influenced by several factors, including the subject well and other pumping wells in the region.

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FIGURE 5-3

3-D VIEW OF TRANSIENT SCENARIO PATHLINES FOR WATER PARTICLES SUBJECT TO 25 YEARS OF AVERAGE PUMPING CONDITIONS

(TRANSIENT SCENARIO 1)

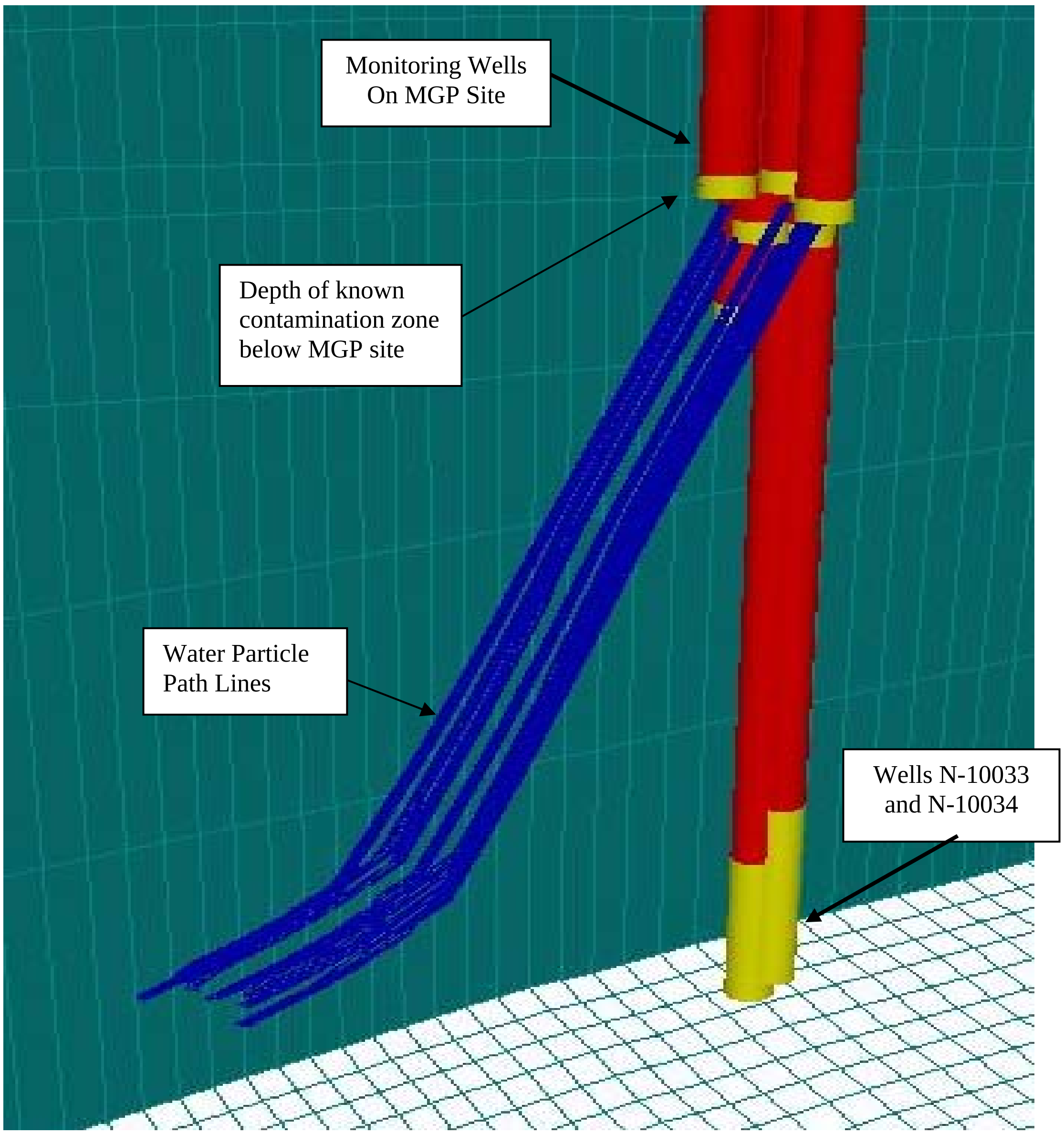

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FIGURE 5-4

CROSS SECTION OF TRANSIENT SCENARIO PATHLINES FOR WATER PARTICLES SUBJECT TO 6 YEARS OF AVERAGE PUMPING AND 13 YEARS OF MAXIMUM PUMPING CONDITIONS

(TRANSIENT SCENARIO 2)

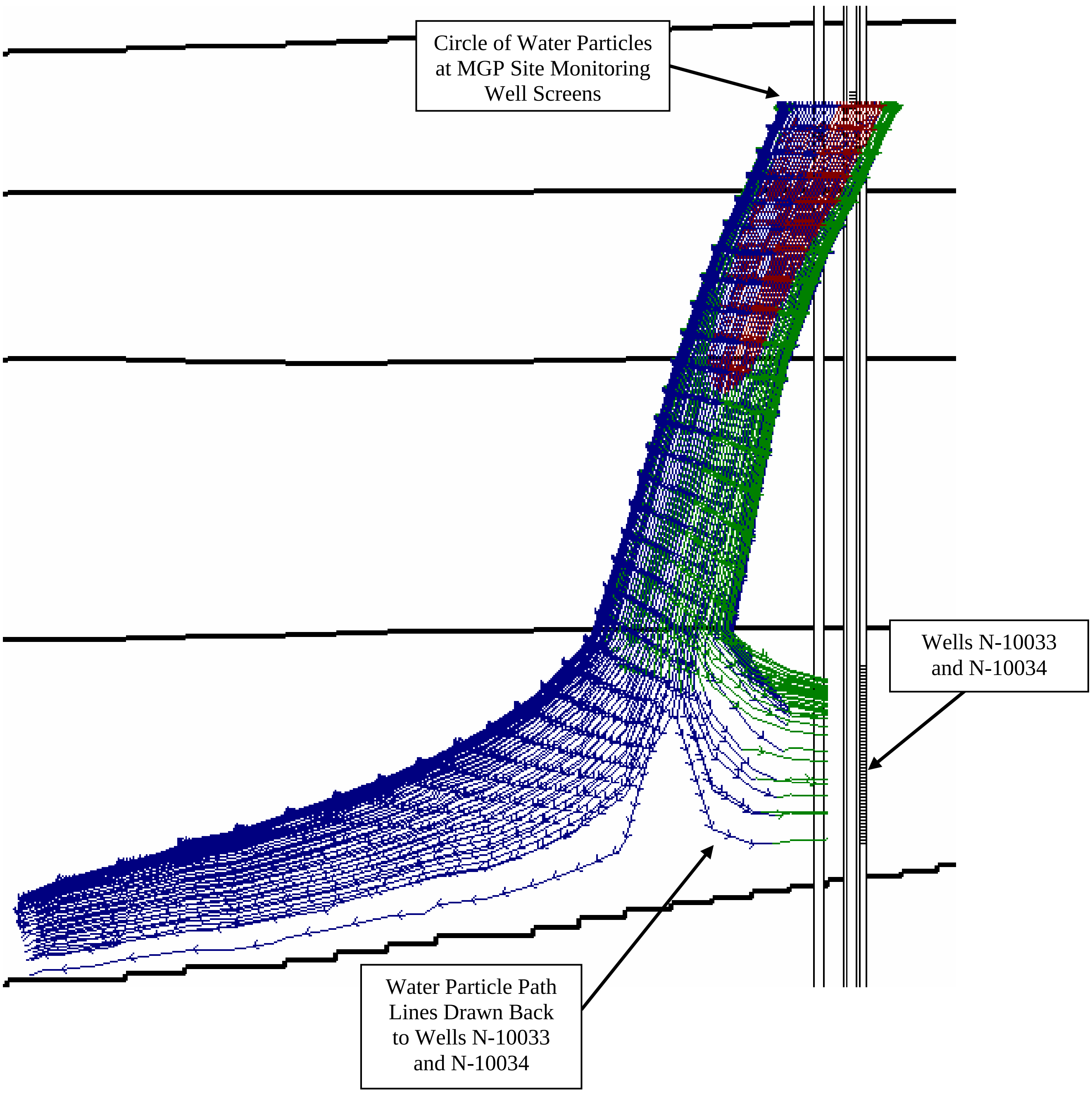

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FIGURE 5-5

CROSS SECTION OF TRANSIENT SCENARIO PATHLINES FOR WATER PARTICLES SUBJECT TO 16 YEARS OF MAXIMUM PUMPING CONDITIONS

(TRANSIENT SCENARIO 3)