GROUNDWATER MODELING REPORT FOR ON-SITE SUBSURFACE WASTEWATER DISPOSAL SYSTEM

PROPOSED CROTON OVERLOOK DEVELOPMENT
YORKTOWN HEIGHTS, NEW YORK

PREPARED FOR:

CROTON OVERLOOK, CORP.

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1.0 INTRODUCTION

HydroEnvironmental Solutions, Inc (HES) has completed the preparation and implementation of a three-dimensional groundwater flow model to predict if any potential groundwater 'mounding' will occur from the construction of an appropriately sized 16,320 gallon per day (gpd) on-site wastewater treatment system on the subject property located in Yorktown Heights, New York (**Figure 1**). The purpose of the modeling is to determine to what extent the existing soils at the site are capable of handling the proposed septic effluent while complying with the requirements of the Westchester County Department of Health (WCDOH) and New York City Department of Environmental Protection (NYCDEP) for subsurface wastewater disposal at a site within the New York City Reservoir Watershed.

Prior to constructing the groundwater model, HES first conducted a site visit and reviewed previous field work conducted by American Water Applied Water Management New York, LLC (American Water) to be used as critical model input. In this regard, HES reviewed the following field activities, data collection and data analyses completed in 2004-2005 and 2009:

- <u>Installation of Soil Profile Test Pits</u>

  In 2004-2005 twelve preliminary test pits were excavated and logged in order to determine which areas of the site would be favorable for subsurface wastewater disposal. An additional seven preliminary test pits were excavated and logged for confirmatory purposes.

- <u>Installation of Pumping and Observation Wells</u>

  In order to determine soil profiles and aquifer characteristics at the site, American Water designed and supervised the installation of 3 wells in the general vicinity of the proposed sewage disposal area in May 2009. The wells were installed using the air rotary drilling technique.

- <u>Aquifer Pump Testing</u>

  Following observation well installation, American Water conducted short-term pump testing on the central well (pumping well), OW-2, in the vicinity of the proposed sewage disposal area. The field pump test was conducted to collect drawdown data at a known pumping rate so that hydraulic conductivity for the sandy loam soil overlying the granitic gneiss aquifer beneath the subject site could be calculated.

- <u>Development of a Conceptual Site Model</u>

  Using the data compiled by American Water and our field inspection, HES developed a conceptual site model to aid in the development of the three dimensional groundwater mounding model.

Once the historical work completed to date at the site was reviewed, construction of the comprehensive groundwater flow model was initiated. HES selected the Visual MODFLOW (Version 4.1) groundwater modeling software package for use at the subject site because it contains a three-dimensional groundwater model that utilizes the United States Geological Survey (USGS) MODFLOW finite-difference model code to simulate groundwater flow and mounding effects. This model is the industry benchmark for simulating groundwater flow and is the most used modeling software in the hydrogeologic consulting community.

2.0 PREVIOUS FIELD ACTIVITIES COMPLETED BY AMERICAN WATER

2.1 Well Installation

Between May 4 and 5, 2009, American Water was present on-site to oversee the installation of three wells (one pumping well and two observation wells) in the area of the proposed septic system. A New York Registered Water Well Contractor conducted the drilling which was completed using the air rotary drilling technique. Each sample was logged by American Water field personnel. Copies of the geologic logs are attached as **Appendix 1**.

According to American Water geologic logs and our research, the overburden sediment consists of silt and fine sand with some clay sized particles and some subangular gravel throughout. The drilling and soil sampling indicated that the overburden beneath the site is composed of till. Results of the well drilling reveal that groundwater was present in the overburden soils at a depth of 10 to 12 feet below grade (ftbg).

The wells installed at each drilling location were installed using 20-slot PVC well screen and solid riser pipe. Four-inch diameter PVC piping was used for the wells. A summary of well details are included in **Appendix 1**.

2.2 Field Pump Testing and Permeability (Slug) Testing

American Water conducted two single well pumping tests and a series of slug tests to determine the hydrogeologic parameters of the soil in the proposed disposal area. During testing, the pumping wells and observation wells were measured using dataloggers (pressure transducers) and a water level indicator. The tests were conducted on OW-2 on May 14, 2009 and on OW-3 on May 18, 2009. The tests were approximately one hour (May 18) and six hours (May 14) in duration. Additionally, a series of five slug tests were conducted on observation well OW-1 during the testing program. During pump testing no drawdown was observed in either of the nearby observation wells. The pump tests and slug testing were used to calculate aquifer parameters for the overburden aquifer at the site in the proposed disposal area including hydraulic conductivity (K) and transmissivity (T). American Water calculated these parameters using the straight line method (Cooper-Jacob) for the pump test data and the Hvorslev method for the slug tests. **Appendix 1** contains the data and aquifer testing data compiled by American Water. These data were subsequently reviewed and checked for accuracy by HES and were used as input parameters in the groundwater mounding analysis that is outlined below.

3.0 CONCEPTUAL SITE MODEL/SITE GEOLOGY

A conceptual model of the subsurface was prepared prior to the construction of the MODFLOW model. The conceptual model of the site is prepared to address and organize the associated field data so that the subject site can be analyzed and understood more readily (Anderson and Woessner, 1992). The following section presents the conditions and assumptions used as the basis for the computational model.

The proposed Croton Overlook property located along the east side of Route 100 in Yorktown Heights, New York (**Figure 1**) is within the watershed of the Croton Reservoir, located to the north. The general topography of the property ranges from gentle to steep with grades ranging from less than 5 percent to greater than 15 percent. Elevations at the site range from approximately 230 feet above mean sea level (ftamsl) to 335 ftamsl.

Review of the geologic logs from the observation well installation (**Appendix 1**) and the soils data contained in the United States Department of Agriculture Westchester County Soil Survey (USDA WCSS) (April 1994) indicates that primary soil on-site and in the surrounding area is a sandy loam. In the proposed septic and nearby area the soil consists of a brown sandy loam to a depth of approximately 10 to 30 ftbg.

Review of the USDA WCSS indicates that the subject site in the proposed subsurface disposal area is underlain by soils that consist of the Charlton Chatfield Complex series, moderately deep to excessively deep well drained loam to sandy loam soils. These soils typically contain a groundwater table at a depth of greater than 6 ftbg throughout the year.

Groundwater was noted during drilling activities to be located above the granitic gneiss bedrock at a depth of 10 ftbg. During observation well gauging activities completed by American Water, the depth to groundwater was measured to be approximately 6.5 to 15 ftbg (**Appendix 1**). The direction of groundwater flow is to the west at a hydraulic gradient of 0.17 ft/ft (according to American Water groundwater monitoring data). HES was on-site on December 22, 2009 to conduct additional observation well gauging activities. During these activities HES noted that the depth to groundwater was encountered a depths ranging from 9.30 to 17.13 ftbg. Due to the unavailability of a proper site datum for the data collected on December 22, 2009 a hydraulic gradient and a flow direction between the three wells could not be calculated. The Croton Reservoir was modeled using the RIVER package supported by MODFLOW.

The model was assigned relative topographic elevations obtained from the topographic map of the site. For the purposes of the model, the topography of the ground surface was designated as the top of model layer 1 and the remaining subsurface was divided into a second layer that follows the topography of the site. These characteristics give the maximum model thickness as approximately 25 feet in the vertical direction due to shallow bedrock in many areas across the site. Within these two major model layers there are seven layers of varying hydraulic conductivities to realistically represent the subsurface geology in the proposed disposal area. The model layers and corresponding hydraulic conductivities (K) are summarized on **Table 1**.

The geology of the uppermost unit was closely considered because it is the unit where most of the vertical septic effluent flow and primary treatment will occur (2 to 6 ftbg). Layer 1 was assigned a thickness of 15 feet in order to contain all of the model boundary conditions. **Figure 2** shows the extent of the model area that was overlaid on the site map to appropriately assign model elevations, permeabilities, recharge and other properties that have differing spatial distributions in the model. **Figure 2** also depicts the distribution of river cells in the model domain overlaid on a topographic map of model surface elevations and also shows inactive flow cells, in which the program does not calculate head due to topographic changes across the site and the groundwater table located in the second layer of the model.

Permeability (K) values for the upper surficial unit were obtained from the American Water report (**Appendix 1**). The K values that were used in the model are summarized on **Table 1** and range from 0.05 feet/day (ft/d) for bedrock to 3 ft/d for glacial till overburden.

To properly calculate the solution for head in a given cell, an initial head must first be assigned. Initial heads for the model were assigned a value of 85 feet according to model parameters listed on **Table 2**.

Recharge to the regional area was estimated to be 18-inches per year. This value is used and generally accepted as a high value for recharge in till-derived soils.

To simulate the addition of septic effluent into the model domain, an appropriately sized area of recharge was added to the model where wastewater treatment is proposed. **Figure 3** shows the location of the septic recharge area in the model domain. The proposed disposal area encompasses approximately 4 acres or 174,240 square feet (ft^2). The model was set up and run in a specific scenario to simulate septic effluent generation based on the proposed development for the subject property as follows:

Scenario 1: To simulate an area of septic recharge to support a total effluent volume of 16,320 gallons per day (gpd), 144 inches per year (in/yr), in order to support 240 gpd/unit.

4.0 CONSTRUCTION OF THE MODFLOW MODEL

4.1 MODFLOW Description

The USGS MODFLOW code was chosen because it is a three-dimensional finite-difference groundwater flow program that incorporates separate packages to simulate the effects of pumping/injection wells, recharge, rivers, drains, evapotranspiration, and general head boundaries. According to McDonald and Harbaugh (1988), the program developers, the primary objective in developing the MODFLOW code was to produce a program to accurately model subsurface hydrogeology that could be readily modified, is simple to use and maintain, could be executed by a variety of computers with minimal changes, and that is relatively efficient with respect to computer memory and execution time. Another benefit of the MODFLOW code is that all input procedures are generalized so that each type of model input (i.e.: well, recharge, etc.) may be stored in external data files and read separately into the program.

The MODFLOW program internally solves, through an iterative process, the finite-difference flow equation for the value of head in each cell in the model until the solution converges for all cells. Rushton and Redshaw (1979) derived the partial differential equation, from which the finite-difference equation was further derived, as the following:

$$\frac{\partial}{\partial_x}(K_{xx}\frac{\partial h}{\partial x})+\frac{\partial}{\partial_y}(K_{yy}\frac{\partial h}{\partial y})+\frac{\partial}{\partial_z}(K_{zz}\frac{\partial h}{\partial z})-W=S_s(\frac{\partial h}{\partial t}) \qquad (3)$$

Where, K_{xx}, K_{yy}, and K_{zz} are values of hydraulic conductivity along the x, y, and z axes; h is the potentiometric head; W is the volumetric flux per unit volume (represents recharge and pumping wells); S_s is the specific storage and t is time.

According to McDonald and Harbaugh (1988), equation (3) describes groundwater flow under nonequilibrium conditions in a heterogeneous and anisotropic medium, assuming that the principal axes of hydraulic conductivity are aligned with model coordinate directions. Equation (3) truly represents a mathematical representation of groundwater flow when combined with at least one boundary head condition and specification of initial head conditions.

It is important to note that analytical solutions of equation (3) are rare, so to arrive at a solution (head value), a numerical method must be used to approximate an answer (McDonald and Harbaugh, 1988). One approach, as mentioned above, is called the finite-difference method that is employed by the modeling program. It replaces the continuous system described in equation (3) with a finite set of points in time and space, and the partial derivatives are replaced by terms calculated from the differences in a head value at each point (McDonald and Harbaugh, 1988). Approximating equation (3) in this fashion involves solving simultaneous linear algebraic difference equations, with results being values of head at specific points and times.

To arrive at a solution (i.e.: solve the finite-difference equations for head at specific points and times), MODFLOW utilizes a series of iterations for each time step. The calculation of head values for individual cells in the domain is started by arbitrarily assigning a trial value for the head at each node with at least one node in the domain assigned a constant head value for all iterations (McDonald and Harbaugh, 1988). A procedure of calculation (relaxation method) is then initiated which alters these estimated values, producing a new set of head values which are in closer agreement with the system of equations (McDonald and Harbaugh, 1988). These new or interim head values then take the place of the initially assumed heads and the procedure of calculation is repeated producing a third set of head values. Each time the calculation is repeated the solution approaches values that approximate the set of finite-difference equations that describe the groundwater flow system.

The model stops when the solution converges or the maximum number of user defined iterations is reached. Convergence, as described by McDonald and Harbaugh (1988), is obtained when the largest head change for a given iteration is less than the user defined convergence criterion (which is usually at least one order of magnitude smaller than the level of accuracy desired in the head results). Once the convergence criterion is met internally by the model, the calculated head values are contoured and displayed so that the resultant head solution can be graphically displayed and quantified.

4.2 Model Certainty

Visual MODFLOW version 4.1 (product of Waterloo Hydrogeologic) was used as an interface to construct and simulate the MODFLOW models that were prepared. MODFLOW was used because it is widely published and generally accepted for simulating groundwater. The USGS and United States Environmental Protection Agency (USEPA) have accepted these models for use at hazardous waste sites throughout the country. An additional benefit of using these models is that the subject study area was easily modeled without having to modify the code of any of these programs to accommodate site specific characteristics or additional variables.

4.3 Model Design

The Visual MODFLOW package was used to construct the model of the site prior to running the model code. The existing site map was first adapted using Visual Cadd to include less of the area surrounding the site. This was done so that the area of importance could also be included and accurately simulated in the model. The finite-difference grid was developed and the elevations of all layers were imported into the model.

The finite-difference grid was developed with a grid pattern to include the areas of concern and the finished model grid contains 185,850 cells. As mentioned above, elevation data was imported into Visual MODFLOW for the surface (top of layer 1) and layer 2.

Once this was done the model domain was complete and values of K, specific storage (Ss) and specific yield (Sy) were then assigned to each of the model cells. Values of K were assigned based on the American Water permeability test results and the pump test analysis results. Ss and Sy were assigned as defaults in Visual MODFLOW and were confirmed as appropriate by an HES hydrogeologist. Boundary conditions were also assigned to model cells where appropriate. The properties assigned include: river cells, recharge (rain), initial heads and evapotranspiration. Cells in the septic area were assigned values of recharge to simulate disposal of septic effluent water from the proposed wastewater system in 144 in/yr 16,320 gpd.

The river cells, representing the Croton Reservoir and surrounding streams, allow for water to move into or out of the surrounding aquifer through leakage. River cells were input into the model based on topographic maps and field data. Input parameters are summarized on **Table 1**. Cells assigned in this fashion become the driving force along with gravity for moving groundwater through and removing groundwater from the domain. **Figure 2** shows the location of the river cells that were used in the MODFLOW simulation as dark blue in color.

4.4 MODFLOW Simulation

Once all the proper properties and boundaries were assigned to each cell in the domain, the MODFLOW model was run to simulate groundwater conditions beneath the subject site. The model was run until convergence and steady-state conditions were obtained. MODFLOW uses the initial conditions as a starting value of head for each cell and then the program uses the internal solver to integrate the system of simultaneous equations that are generated. The solver iterates until a solution is defined within the convergence criteria. The head distribution is then contoured (head equipotential contour) and displayed as output for graphical and quantitative analysis which is then checked against real world data in order to determine if the simulated results match real world findings.

5.0 MODELING RESULTS

5.1 MODFLOW Simulation Results

After the model was prepared and the program implemented, results were viewed and analyzed by HES staff to determine the affects of the proposed septic volumes at the site. **Figure 4** shows the calculated water table with no added septic effluent (dry-run). This result will be the basis to quantify groundwater mounding beneath the site due to septic effluent. Additionally, the dry-run provides simulated data related to head equipotentials and water table depths which can be checked against real world observations and measurements. This in turn provides a simple calibration for the model. **Figures 5** shows the water table elevation obtained from the model output, overlaid on the site map, for the analyzed scenario of septic effluent disposal. Scenario 1 at 16,320 gpd shows the simulated groundwater table to be at 8 ftbg at the highest area of the mound within the septic recharge area (**Figure 5**).

According to the WCDOH regulations at least 5 feet of unsaturated soil must be available from the bottom of the leaching fields to the groundwater table. Leach fields are approximately 2 feet in depth from the ground surface. Therefore, at least 7 feet of unsaturated soil are necessary between the ground surface and water table in order to be acceptable to the WCDOH. According to the simulated results for Scenario 1 (16,320 gpd), the mounding in the septic recharge area indicates the highest mounding to be 8 ftbg, which would be sufficient to meet the WCDOH requirements. These results demonstrate that the soils can effectively handle at least 16,320 gpd of septic effluent without any deleterious mounding and without any direct contamination of the water table.

6.0 DISCUSSION OF MODEL RESULTS

The cumulative results of the modeling effort show that groundwater flow was effectively simulated by MODFLOW. Effluent flows from the proposed wastewater treatment system down to the underlying groundwater table and west toward Route 100 and ultimately the Croton Reservoir. The model results demonstrate that there is very little groundwater mounding beneath the treatment system, which shows that the overburden soils and underlying granitic gneiss have the capacity to transport the proposed volume of wastewater effluent.

7.0 CONCLUSIONS

A site model was prepared utilizing known site specific information to predict the results of water from the two proposed septic system disposal scenarios. The MODFLOW groundwater modeling program was used to solve the equations for groundwater flow within the model. This program is widely accepted industry standard for simulating groundwater flow through porous media. The modeling effort resulted in a simulation that appears to accurately represent groundwater and wastewater flow across the subject site.

The groundwater head results indicate that for all trials no breakout of the water table at the surface will occur, as there is an adequate layer of unsaturated soils between the steady-state head and the site surface. This aeration zone between the slightly mounded water table and the septic area meets the appropriate requirements for the WCDOH and NYCDEP. For the simulated mound occurring within the proposed disposal area (approximately 174,240 ft^2) it has been calculated that only 6.5% (11,325 ft^2) of the mound makes up the mound crest which ranges at a depth of 7-8 ftbg. **Table 3** further summarizes the percentages of the mound that exist at varying depths below grade.

Based on these results, it is clear that the hydrogeology in the area of the proposed septic system can accommodate the discharge of 144 in/yr at an application rate of 16,320 gpd.

8.0 RECOMMENDATIONS

1.) Based on the results of groundwater modeling, HES recommends installing the septic disposal area for the proposed Scenario 1 analyzed so that no deleterious impacts to groundwater or to the downgradient reservoir and streams will occur.

2.) HES also recommends utilizing MODPATH to calculate the groundwater flow pathlines from the proposed septic disposal area to the adjacent downgradient Croton Reservoir. A modular three-dimensional transport model (MT3DMS) can be implemented with the MODFLOW output to simulate advective flow, dispersion and first order decay of nitrate in the groundwater system in order to determine flow of these wastewater constituents into the groundwater and potential contamination to the groundwater due to an inadequate buffer between leeching fields and the water table.

3.) Since it is likely that the project will consist of a phased approach, HES recommends running the MODFLOW model as the project evolves over time. The model should include refined wastewater effluent amounts, account for possible on-site additions such as on-site pumping supply well(s), storm water mitigation and changes in groundwater recharge due to ponding and additional impermeable surfaces.

9.0 REFERENCES

Anderson, M., and W.W. Woessner 1992. Applied Groundwater Modeling: Simulation of Flow and Advective Transport. Academic Press, Inc., San Diego, California. 381 pages.

McDonald, M.G., and A.W. Harbaugh, 1988. A Modular Three-dimensional Finite-difference Ground-water Flow Model. Techniques of Water Resources Investigations, O6-A, United States Geological Survey. 576 pages.

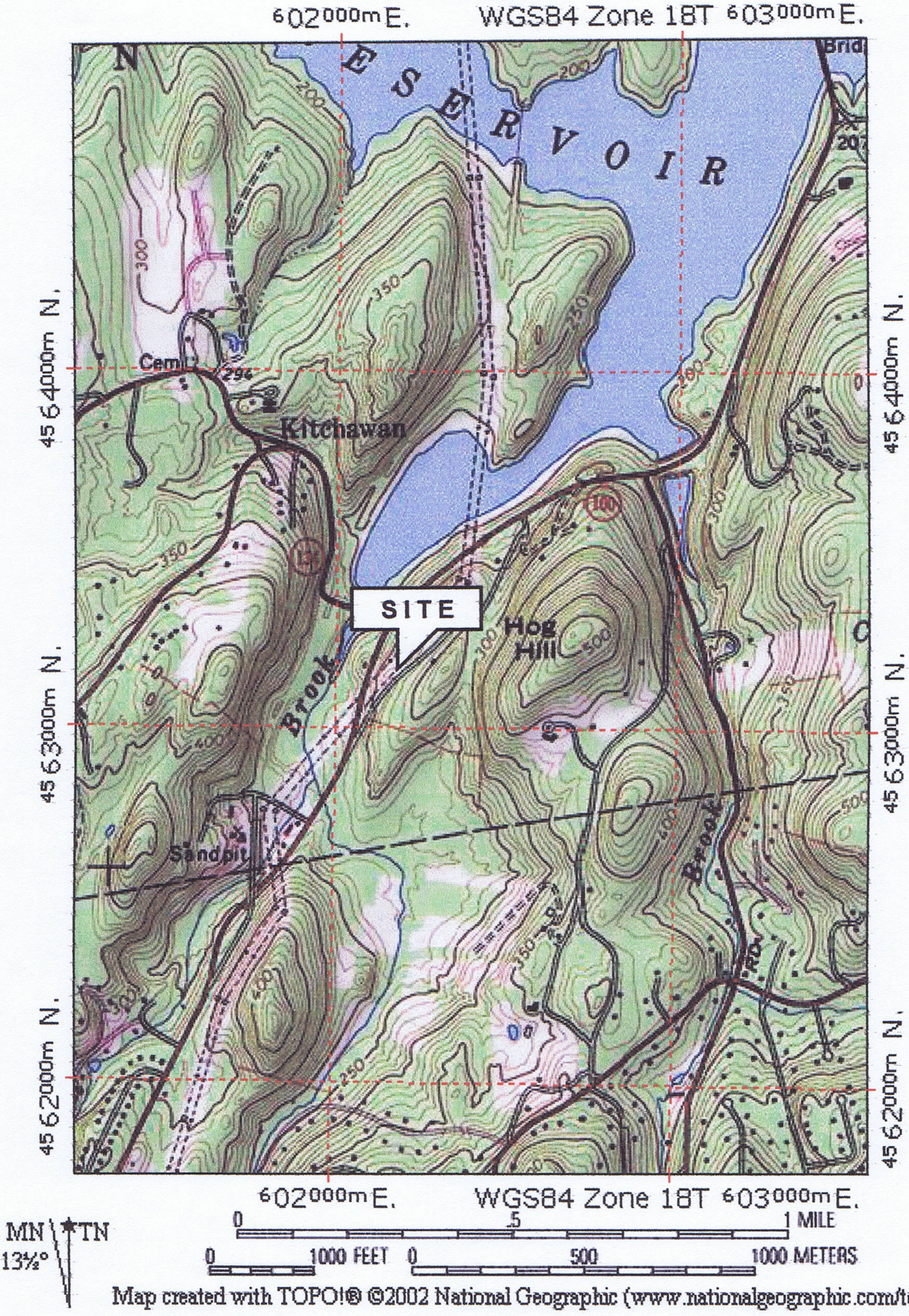
Rushton, K.R., and S.C. Redshaw, 1979. Seepage and Groundwater Flow, John Wiley and Sons, New York. 339 pages.

USDA-SCS The Soil Survey of Westchester County, NY, 1994. U.S. Department of Agriculture, Natural Resources Conservation Service and Soil Conservation Service.

Visual MODFLOW version 4.1 manual, 2005. Waterloo Hydrogeologic. Waterloo, Ontario, Canada. 613 pages.

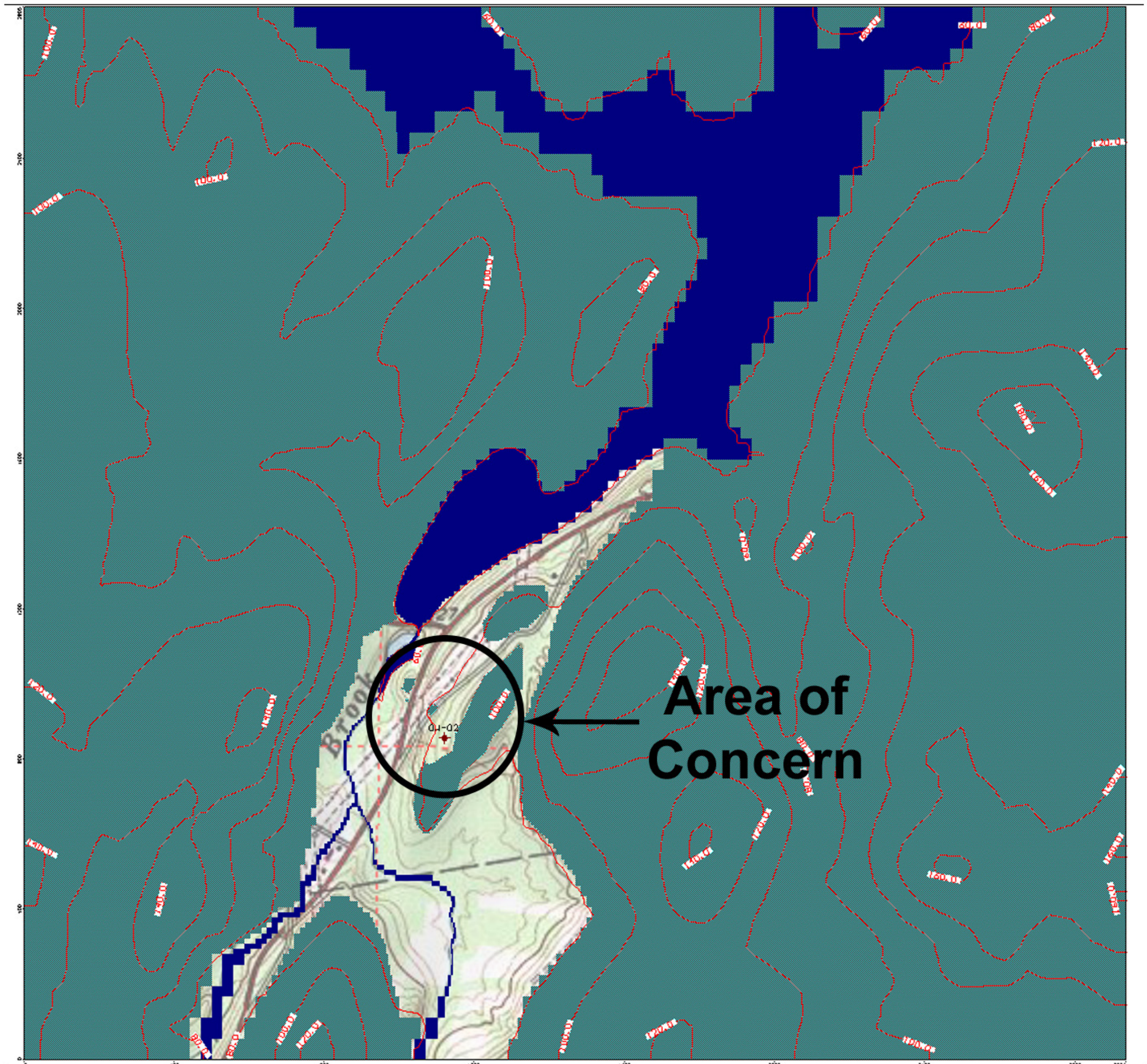
FIGURE 1
SITE LOCATION MAP

Croton Overlook
Yorktown Heights, New York



Map created with TOPO!® ©2002 National Geographic (www.nationalgeographic.com/topo)

FIGURE 2
Croton Overlook
Mounding Analysis
MODFLOW OUTPUT
Model Extents



Elevation Contour (RED) Interval = 20 ft

Croton Reservoir and Streams = BLUE

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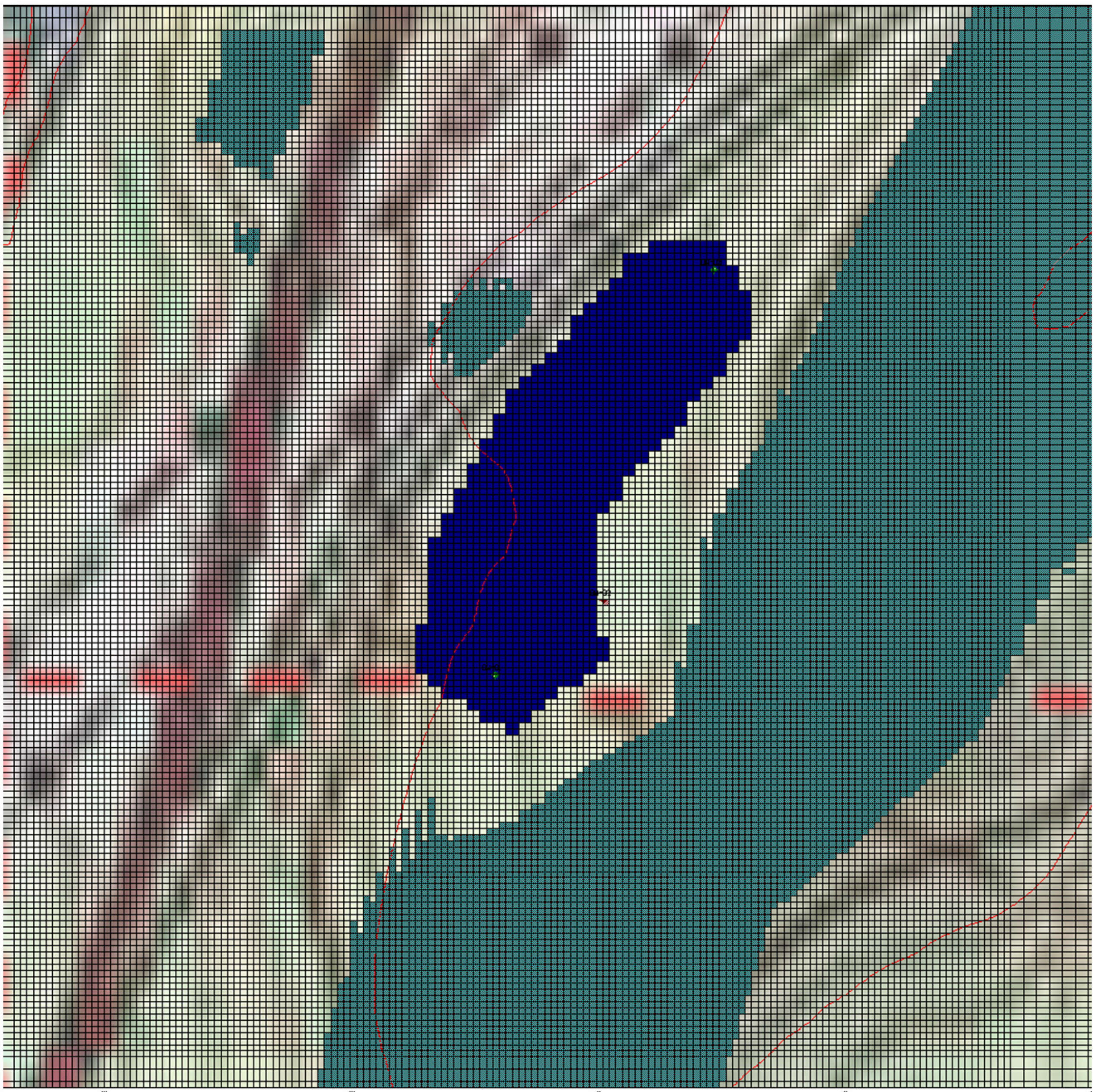
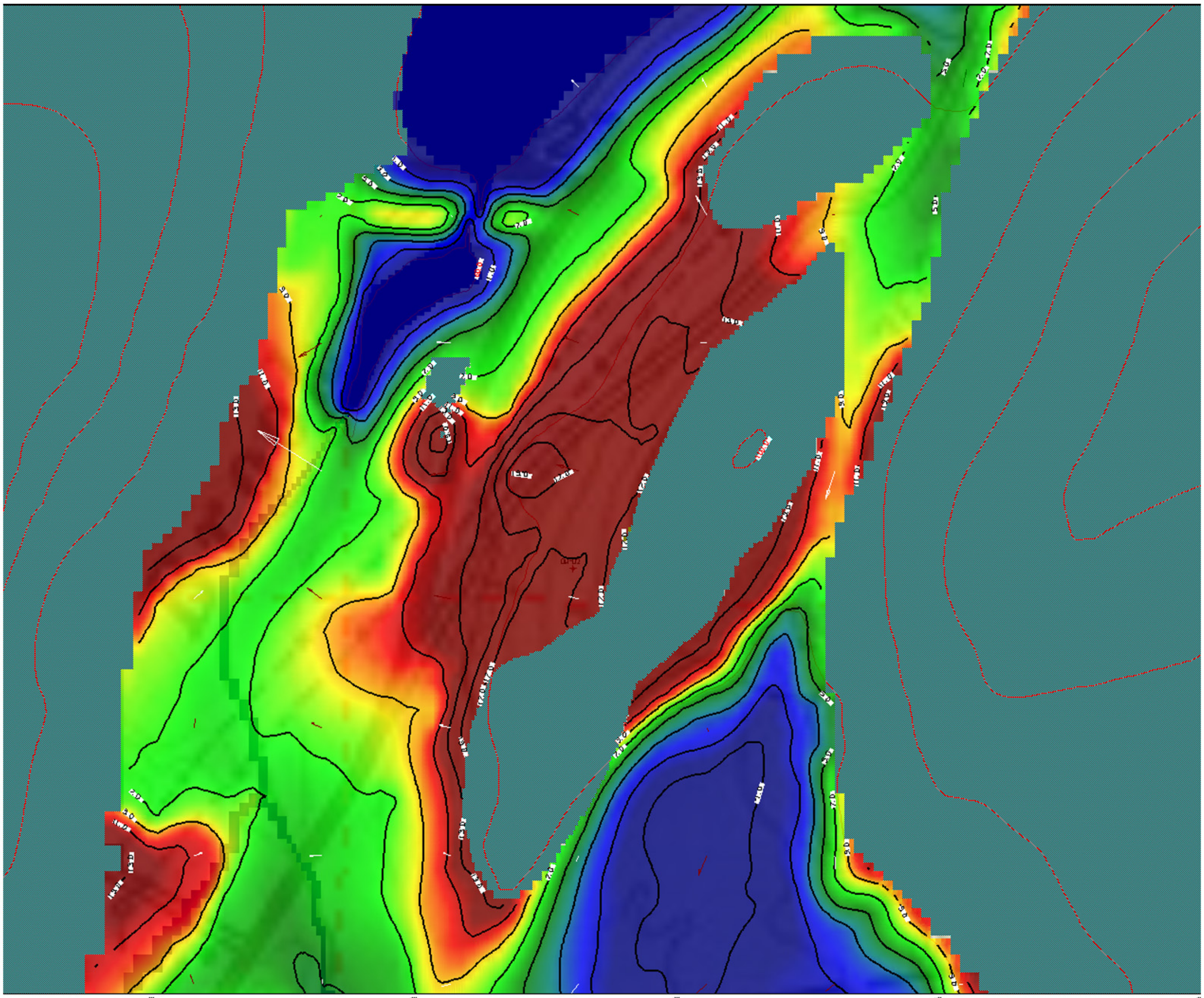
FIGURE 3
Croton Overlook
Mounding Analysis
MODFLOW OUTPUT
Septic Recharge Area



Septic Recharge Area (Blue) = 144 in/year = 16,320 GPD
Model Recharge = 18 in/year
Inactive Cells (unsaturated) = TEAL
Elevation Contour (RED) Interval = 20 ft

FIGURE 4
Croton Overlook
Mounding Analysis
MODFLOW OUTPUT
No Septic Effluent Recharge
Depth To Water Color Filled Relief



0 - 3 ftbg = Blue
3 - 7 ftbg = Green
7 - 9 ftbg = Yellow
9 - 19 ftbg = Red

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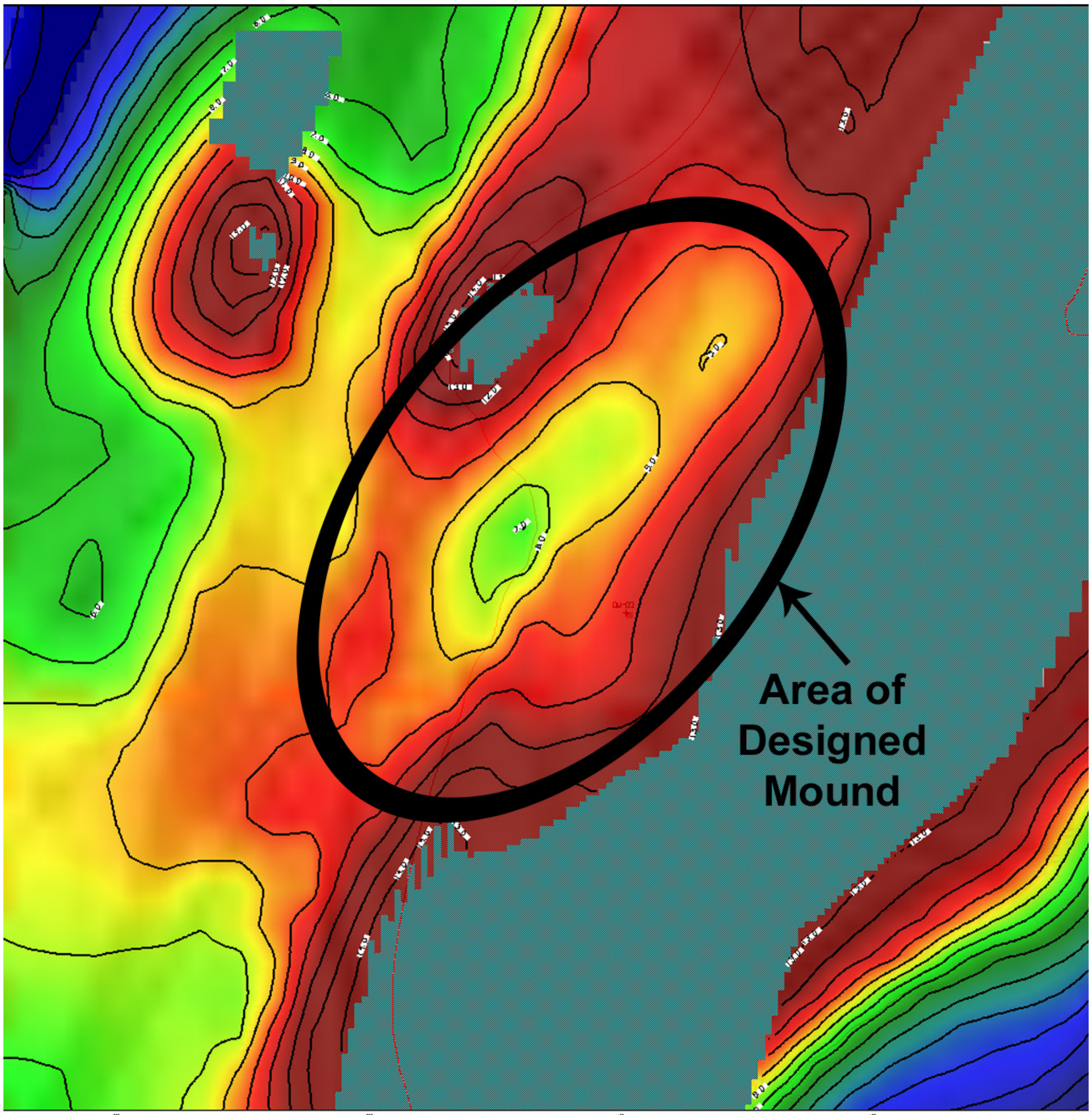
FIGURE 5
Croton Overlook
Mounding Analysis
MODFLOW OUTPUT
Scenario 1: 16,320 GPD Septic Recharge
Depth To Water Color Filled Relief



0 - 3 ftbg = Blue
3 - 7 ftbg = Green
7 - 9 ftbg = Yellow
9 - 12 ftbg = Red