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JUL 02 2012
SUPERFUND DIVISION

July 2, 2012

Mr. Jim Seiler
AES Project Officer
U.S. Environmental Protection Agency, Region 7
901 North 5th Street
Kansas City, KS 66101

RE: Groundwater Flow Modeling Technical Memorandum for the Garvey Elevator Superfund Site, Hastings, Nebraska
U.S. EPA Region 7 AES Contract No. EP-S7-05-05; Task Order No. 0034
EPA Task Order Project Officer: Brian Zurbuchen, Ph.D.

Dear Mr. Seiler:

HydroGeoLogic, Inc. (HGL) is pleased to submit a hard copy (with an electronic copy on CD) of the Groundwater Flow Modeling Technical Memorandum for the Garvey Elevator Superfund Site, Hastings, Nebraska. This document was prepared in accordance with Task Order 0034 and our EPA-approved Task Order Proposal Amendment 1, Revision 1 submitted on September 19, 2011.

As requested by EPA, two additional hard copies of the Final Groundwater Flow Modeling Memorandum will be sent to Laurie Brunner at the Nebraska Department of Environmental Quality. Should you have any questions or comments, please contact us at 913-317-8860.

Sincerely,

[redacted]

[redacted]
HGL [redacted]ager

[redacted]
[redacted] P.G., CHMM
AES Program Manager

Enclosures

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GROUNDWATER FLOW MODELING TECHNICAL MEMORANDUM
GARVEY ELEVATOR SUPERFUND SITE
HASTINGS, NEBRASKA

TO:	Brian Zurbuchen, Ph.D., EPA TOPO
FROM:	[redacted], P.E., TOM
THROUGH:	[redacted], P.G., CHMM
DATE:	July 2, 2012
SUBJECT:	Groundwater Flow Modeling Garvey Elevator Site, Hastings, Nebraska
CONTRACT NO:	EP-S7-05-05
TASK ORDER NO:	0034

1.0 INTRODUCTION

HydroGeoLogic, Inc. (HGL) is conducting remedial investigation (RI)/feasibility study (FS) and remedial design (RD) activities at the Garvey Elevator site in Hastings, Nebraska, under Region 7 U.S. Environmental Protection Agency (EPA) Architect and Engineering Services (AES) contract EP-S7-05-05, Task Order 0034. The Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS) ID# for the site is NEN000704351. EPA has organized the site into two operable units (OUs). OU 1 is designated as the area of soil and groundwater contamination that is generally within the boundaries of the former Garvey Elevators, Inc. facility property and also known as the source area. OU 2 is the associated groundwater contaminant plume that extends east-southeast from OU 1 approximately 4.3 miles, in the direction of groundwater flow. This Technical Memorandum details the modeling approach and results that are being used to support the FS currently in progress for both OU 1 and OU 2, and for the expansion of the existing groundwater extraction well network at the Garvey Elevator Site. A similar modeling exercise is being conducted for the West Highway 6 & Highway 281 Site, located approximately 1,500 feet northeast of the Garvey Elevator Site.

This memorandum is divided into nine sections. Following this introduction, Section 2 presents the modeling objectives and overall approach; Section 3 identifies the major components of the conceptual model; Section 4 addresses the computer code selection; Section 5 presents the construction of the numerical model; Section 6 details the activities undertaken for the groundwater flow calibration and sensitivity analysis; the modeling performed to support the remedial alternative design is presented in Section 7; Section 8 presents a summary and conclusions of the groundwater flow, particle tracking and contaminant transport analysis; and Section 9 lists the references cited in preparing this memo. Tables and Figures cited throughout this memo are provided in Attachments 1 and 2, respectively.

2.0 MODELING OBJECTIVES AND OVERALL APPROACH

2.1 BASIC ASPECTS OF COMPUTER (NUMERICAL) MODELING

The flow model constructed for this exercise uses finite-difference techniques which require that the groundwater system be divided ('discretized') into finite-sized blocks or 'cells'. Each cell is assigned unique hydraulic properties depending on the available field data and the goals for the analysis. In this way, complex features of the groundwater system can be accommodated in the model. The time represented by the modeling effort must also be divided into discrete periods or 'time steps. These steps must be short enough to provide an accurate solution, but not so short that they require an excessive number of calculations to run a simulation. The finite-difference method also requires that values for head be assigned at flow boundaries (referred to as 'boundary conditions'), as well as for the initial time period of the simulation (referred to as 'initial conditions'). This is a requirement for producing a unique solution with any numerical method that depends on iteration, as does the finite-difference method.

After assigning properties, initial conditions, and boundary conditions, the finite-difference equations for flow are solved to produce a mathematically approximate but scientifically reliable value of the average groundwater head (potentiometric surface elevation) within each cell. Subsequently, a different set of equations (which usually are also finite-difference equations) that describe chemical transport are solved to generate the average value of chemical concentration within each cell of the modeled groundwater system. Models that use the finite-difference numerical technique allow rapid analysis of complex, time-dependent groundwater systems; as such they are preferable for all but the simplest scenarios.

Numerical models are operated by a computer code or program. The code is a generalized set of steps, to which specific field conditions, such as initial and boundary conditions, are imposed. Various model codes are available; some are proprietary (privately owned), while others are in the public domain (available to everyone). The most widely used codes for describing groundwater flow and contaminant transport are MODFLOW and MT3D; both are in the public domain.

Because computer codes are generic in nature and must be adapted to actual field conditions in order to be helpful, a clear understanding of the existing physical system (a conceptual model) is required. The hydrogeologist develops a conceptual model of the hydrogeologic environment based on field experience, available literature, and site data. This conceptual model provides a vital guide in creating a numerical model that represents actual field conditions.

2.2 MODELING OBJECTIVES AND APPROAH

It is important to establish why the model is being created, and to properly design the model simulations to sufficiently address the data needs that the modeling effort is intended to satisfy. The objectives of this current exercise were to: (1) Evaluate the overall effectiveness of the current extraction well system; (2) identify areas outside of the capture zone that may require enhancements; and (3) develop a tool to assist in "what if" scenarios for the remedial alternative development.

These three objectives were satisfied by:

1. Constructing and calibrating a three-dimensional groundwater model that generates a flow field (array of head values) representing average conditions in the vicinity of the site.
2. Performing a particle-tracking analysis with the calibrated flow field to define groundwater flow directions and estimate capture zones.
3. Conducting chemical transport analyses to evaluate potential remediation alternatives and estimate remediation times.

The three-dimensional (3-D) computer model for analyzing groundwater flow was constructed first, then the model was calibrated and used as the basis for the flow and transport model of plume development.

The following discussion describes the procedures used in creating the groundwater flow model and the plume development model.

Steps Required in Creating the Flow and Transport Model

Steps completed in creating the numerical model included the following:

1. Adopting a conceptual model to guide creation of model elements.
2. Choosing an appropriate computer code for the analysis.
3. Establishing the time period represented by the model and the duration of subdivisions of this period (time steps) required for modeling;
4. Selecting a suitable model domain, and determining the dimensional (horizontal and vertical) limits of the analysis.
5. Establishing the model structure by determining the number of model layers and the grid spacing requirements.
6. Incorporating hydraulic boundaries and features, including the shape and characteristics of constant-head boundaries, such as rivers, precipitation/recharge, and pumping.
7. Assigning hydraulic parameters consisting of hydraulic conductivity and porosity;
8. Selecting hydraulic calibration targets.
9. Evaluating and assigning appropriate model computational characteristics, for example, solution method, iteration limits and convergence criteria, to enhance model stability, computational efficiency, and solution accuracy.
10. Running the model and adjusting assigned model parameters within predetermined limits to achieve the closest fit between model results (hydraulic heads) and calibration targets.
11. Evaluating the sensitivity of model results to changes in model parameters.
12. Assigning transport parameters, including the distribution coefficient (defines contaminant adsorption to soil and affects transport by retarding the rate of contaminant

movement) and the degradation coefficient for the modeled chemical species (relates to the rate of chemical decay in the groundwater system).
13. Placing particles within the model to determine groundwater flow directions and capture zone characteristics.
14. Initializing the contaminant plume based on measured concentrations.
15. Simulating remedial scenarios.

Completion of these steps is necessary to create a model that represents field conditions as accurately as possible within the constraints of practicality and data availability. The remainder of this report details how each of the steps outlined above was accomplished.

3.0 CONCEPTUAL MODEL

A conceptual model was developed to serve as the basis for the construction of the flow and transport model. A conceptual model generally summarizes the theoretical understanding of the primary conditions that affect groundwater flow and chemical transport and fate. Additionally, the current nature and extent of the groundwater contamination in OU 1 is also presented. Unless otherwise indicated the information below was excerpted from the Focused Feasibility Study (HGL, 2009).

3.1 SITE HYDROGEOLOGY

For additional information, the Remedial Investigation (RI) report provides a comprehensive description of the hydrogeology (HGL, 2011).

Regional Characteristics

Hastings is located in the Little Blue River Natural Resource District. Depth to groundwater in the Hastings area is typically about 100 feet (ft) below ground surface (bgs) with localized zones of perched groundwater that can occur as shallow as 7 to 10 ft bgs. The regional groundwater flow generally follows the direction of the Little Blue River toward the east to southeast.

The principal aquifer for the Hastings area is the Pleistocene aquifer, which is typically 100 ft to 150 ft thick. The Pleistocene aquifer is composed of unconsolidated sand and gravel that extends from about 100 ft bgs to the top of the Niobrara Formation which occurs at about 233 ft bgs.

Groundwater from the Pleistocene aquifer in the Hastings area is used for municipal, domestic, and agricultural use. Due to high use of the Pleistocene aquifer, the water table has dropped more than 20 ft between pre-1950s and 1992.

Transmissivity ranges from more than 200,000 gallons per day per foot in the central part of the county, to less than 50,000 gallons per day per foot in the northeastern corner and southernmost portions of the county.

Site-Specific Characteristics

Groundwater typically occurs between 110 to 115 ft bgs at the site. Three aquifer zones exist at the site based on the lithologic descriptions for their monitoring well boring logs. These three aquifer zones are referred to as the shallow, medial, and lower zones.

The shallow aquifer zone is unconfined and extends from about 115 ft bgs to 130 ft bgs and, based upon lithology, is divided into A and B Zones. A fine-grained (aquitard) forms the base of the shallow aquifer and acts as a semi-confining layer to the underlying medial aquifer. The medial aquifer extends from the bottom of the upper aquitard to the top of the lower aquitard at approximately 150 ft bgs (Zone C). The lower aquifer zone is believed to be from approximately 155 ft bgs to 240 ft bgs (Zones D and E). The weathered shale of the Niobrara Formation forms the base of the aquifer. Groundwater flow in all aquifer zones is to the southeast.

In 2011, discrete pumping tests were conducted using recovery wells RW-2 in the shallow aquifer and RW-7 in the medial aquifer (HGL, 2011). The RW-2 constant-rate test was conducted at a pumping rate of approximately 9.5 gallons per minute (gpm) after the pumping rate stabilized. The RW-7 constant-rate test was conducted at a pumping rate of approximately 100 gpm.

For the RW-2 pumping test conducted in the shallow aquifer, the average shallow aquifer hydraulic conductivity (K) value calculated from the constant-rate pumping test data was 24.5 (feet per day) ft/day. This is fairly consistent with the average shallow aquifer K value of 46 ft/day measured by the EPA for the RI using the bi-chamber dipole flow testing analysis in well MW-33, a hydraulic testing well located at the northwestern perimeter of the site property. A geotechnical analysis of an aquifer sample collected from the screened interval of MW-49B had a K value of 48.5 ft/day, which also is consistent with the two field-derived measurements.

During the constant-rate test at RW-7 for the medial aquifer, drawdown was observed in two monitoring wells, MW-13C and MW-50C. The average K value for the three MW-13C data analyses was 249.4 ft/day; while the average K value for the same three analyses for the MW-50C dataset was 164.7 ft/day. In contrast, an average medial aquifer K value of 98 ft/day was measured by EPA for the RI using the bi-chamber dipole flow testing analysis in well MW-33. A geotechnical analysis of an aquifer sample collected from the screened interval of MW-50C had a K value of 58.7 ft/day. Given that the geotechnical sample was disturbed, its K value is marginally valid in comparison to the aquifer parameters derived from the pumping test. An acceptable K value for the medial aquifer would be an average of the three field-derived measurements, which would yield a K value of 171 ft/day.

3.2 NATURE AND EXTENT OF VOCS

The contaminants in the groundwater were evaluated using data collected during the RI activities conducted at the site and from previous investigations. The nature and extent of the volatile organic compounds (VOCs) in the groundwater are summarized below. Unless otherwise referenced, the following sections are adapted from the RI Report (HGL, 2011).

The VOCs detected in groundwater at the Garvey Elevator Site exceeding their preliminary remediation goals (PRGs) are tetrachloroethene (PCE), trichloroethene (TCE), and carbon tetrachloride. The elevated PCE detections are attributed to the adjacent West Highway 6 & Highway 281 Site. The contaminant plume originating at the West Highway 6 & Highway 281 Site is commingled with the contaminant plume originating at the Garvey Elevator Site. The elevated TCE detections appear to be limited to the upper aquifer zone (Zone A/B at 115 to 130 feet bgs) in an area east of the railroad tracks north of the grain storage facility. The carbon tetrachloride contamination appears to originate from two soil source areas: the former liquid fumigant AST, and an area in the northeastern corner of the grain storage facility (possibly from the treatment of rail cars or stockpiled grain). Carbon tetrachloride has migrated through the soil to the groundwater. The carbon tetrachloride contamination extends from the groundwater underlying the grain storage facility to approximately 4.7 miles downgradient to the east-southeast from the source areas. Carbon tetrachloride plume is present above PRGs in the upper (Zone A/B 115 to 125 feet bgs), medial (Zone C 130 to 155 feet bgs), and lower (Zone D/E 160 to 235 feet bgs) aquifer zones. One aquitard occurs between the upper (Zone A) and medial (Zone C) aquifer zones, and another aquitard occurs between the medial (Zone C) and lower (Zone D/E) aquifer zones. The two aquitards vary in thickness and composition. The carbon tetrachloride plume appears to migrate deeper in the aquifer zones as it migrates farther downgradient from the Site.

The carbon tetrachloride concentrations that were used to initialize the shallow, medial, and lower aquifers in the model were derived from those observed during the September 2011 sampling event. These isoconcentration maps are presented as Figures 3.1, 3.2 and 3.3, for the shallow, medial and lower aquifers, respectively.

4.0 COMPUTER CODE SELECTION

The computer codes that were used for this analysis are MODFLOW-2000, MT3DMS, PEST and MODPATH. MODFLOW-2000, the U. S. Geological Survey finite-difference groundwater flow model, is a popular and widely used computer code (Harbaugh et al., 2000). Groundwater flow within the aquifer is simulated using a block-centered finite-difference approach. Layers can be simulated as confined, unconfined, or a combination of confined and unconfined. Flow associated with external stresses, such as wells, areal recharge, evapotranspiration, drains, and streams can also be simulated.

The modular 3-D flow and transport model referred to as MT3D was originally developed by Zheng (1990) and subsequently updated to MT3DMS (Zheng and Wang, 1999). MT3DMS has a comprehensive set of options and capabilities for simulating advection, dispersion/diffusion, and chemical reactions of contaminants in groundwater flow systems under general hydrogeologic conditions. Although both codes use the same model structure, MODFLOW is run first using the physical and hydraulic data entered into the model to produce a groundwater flow field (array of hydraulic heads). Subsequently, MT3D is run using the head results from the flow model to produce a transport simulation.

MODPATH is a particle tracking post-processing package that was developed to compute 3-D flow paths using output from steady-state or transient groundwater flow simulations by MODFLOW. MODPATH is described in USGS Open-File Reports 89-381 and 89-622 (Pollock, 1994). MODPATH uses a semi-analytical particle tracking scheme that allows an analytical expression of the particle flow path to be obtained within each finite-difference grid cell. Particle paths are computed by tracking particles from one cell to the next until the particle reaches a boundary, an internal sink or source, or satisfies some other termination criterion.

To facilitate the model calibration, a parameter estimation tool was implemented. PEST (Parameter ESTimation) is a calibration tool, developed by Watermark Computing (Doherty, 2006), that uses non-linear least-squares techniques to adjust model parameter data in order that the discrepancies between the pertinent model-generated numbers and the corresponding measurements are reduced to a minimum. It does this by taking control of the model and running it as many times as is necessary to determine this optimal set of parameters.

The pre- and post-processing of data input/output for these codes was performed with Groundwater Vistas (Rumbaugh and Rumbaugh, 1998).

5.0 MODEL CONSTRUCTION

One primary goal of mathematical modeling is to synthesize the conceptual model into numerical terms from which flow and transport processes may be investigated under specified conditions. This process entails several discrete steps: (1) partitioning the conceptual model into units of time and space; (2) assignment of boundary conditions; and (3) specification of the values for the parameters. The following sections briefly discuss the approach taken and the relevance of each of these topics to the modeling process.

5.1 DOMAIN, STRUCTURE AND GRID

The model domain is 10,100 ft by 28,200 ft (10.2 square miles) and extends horizontally from about 800 feet west of the site property boundary to approximately 6,000 ft north and 2,500 ft south of the site and about 25,000 ft east of the site, as shown in Figure 5.1. This is an area large enough to include all of the contaminant plumes and ensure that the effects of proposed pumping for the remedial alternatives will not reach the boundaries and cause boundary effects on the predicted drawdowns.

In a numerical model, the region of interest is partitioned into a series of cells (that is, elements), which are arranged in layers. This practice, termed discretization, effectively replaces the continuous problem domain with an array of cells. The basic concept involves dividing up the area as realistically as practical. One of the critical steps in applying a groundwater model is selecting the size of the cells. Smaller cells lead to more accurate numerical solutions. The desire for accuracy, however, must be balanced against the impracticality of solving for large numbers of nodes and the long computer run times that may be involved. For this modeling exercise, a finite-difference grid (squares and rectangles) was adopted with 404 rows, 510 columns, and 5 layers. The rows and columns are evenly spaced at 25 ft intervals over the area encompassing the site and extending approximately 8,000 feet downgradient from the western model boundary. The remaining portion of the model is uniformly spaced at 100 ft intervals, creating 1,030,200 active cells.

The grid is oriented to be approximately parallel to the measured plumes, or 9 degrees south of east. This orientation is representative of the net groundwater flow directions (as expressed by the plume). Based on regional potentiometric surface maps, the ambient groundwater gradients are closer to 20 degrees south of east. The natural gradients, however, may be shifted locally by pumping for irrigation and water supply.

The shallow, medial and lower aquifers are each discretized into single model layers (Figure 5.2). The shallow and medial aquifers are separated by a confining unit which is simulated with a single model layer. A deeper confining unit separates the medial from the lower aquifer and is also simulated with a single model layer. The base of the model is set to an elevation consistent with the base of the Pleistocene aquifer, which is defined by the weathered shale of the Niobrara Formation (Figure 5.3). The lithologic contact information is provided in Table 5.1.

The elevation of the top of the lower aquifer (model layer 5) is shown in Figure 5.4. An isopach map presented in Figure 5.5 shows that the thickness of the lower aquitard (model layer 4) that separates the lower aquifer from the medial aquifer. As shown in the figure, the thickness varies from being non-existent in approximately the northern third of the model domain to a thickness of about 7.5 feet near the eastern boundary. The top and bottom of the medial aquifer is defined as the base of the upper aquitard and top of the lower aquitard. The elevation of the base of the medial aquifer is depicted in Figure 5.6. The thickness of the upper aquitard (model layer 2) is presented in Figure 5.7. The thickness ranges from about 1 to 8 feet except in an area immediately north of the Garvey Elevator site where the aquitard is missing. The elevation of the base of the upper aquifer is shown in Figure 5.8. The top of the upper aquifer is defined as the water table surface and is depicted in Figure 6.13.

5.2 TIME BASIS

All of the calibration simulations, capture zone, and contaminant transport analyses were performed to steady-state conditions. These conditions best represent the effects of long term pumping on the water levels and plume development and provide the best estimates of the capture zone and contaminant transport under the current conditions.

5.3 BOUNDARY AND INITIAL CONDITIONS

5.3.1 Boundary Conditions

To obtain a solution for the governing equation of groundwater flow, information is required about the physical state of the groundwater system. This information is described by boundary and initial conditions. Boundary conditions are the conditions the modeler specifies as known or estimated values to solve for the unknowns in the problem. Boundaries generally are quantified in terms of the volume of groundwater moving through the system. The physical boundaries are then translated into mathematical terms and input into the computer model.

Constant-head boundary conditions (i.e., groundwater elevations remain constant with time) were extrapolated from the regional gradients and assigned at the upgradient (northwestern) and downgradient (southeastern) model limits for all of the model layers (Figure 5.1).

The model boundaries to the northeast and southwest are approximately parallel to groundwater flow lines and are considered 'no-flow' boundaries across which no groundwater moves. The base of the model is considered a no-flow boundary.

Shallow Aquifer

The top of the model was set as a uniform recharge boundary (2.6 inches per year [in/yr]) with the rate determined as part of the model calibration.

As presented below and shown in Figure 5.9, all of the recovery wells are set to their average pumping rates for the week prior to and during the collection of the water level data calibration set (September 26-27, 2011). These rates are listed below:

Garvey Elevator Site

- RW-1 = 0.0 gallons per minute (gpm)
- RW-2 = 8.0 gpm
- RW-3 = 7.4 gpm
- RW-4 = 9.8 gpm
- RW-5 = 5.1 gpm

West Highway 6 & Highway 281 Site

- EW-1 = 6.1 gpm
- EW-2 = 8.3 gpm
- EW-3 = 4.1 gpm
- EW-4 = 0.0 gpm

Medial Aquifer

There are no wells pumping from the medial aquifer at the West Highway 6 & Highway 281 Site. Recovery wells RW-6, RW-7 and RW-8 at the Garvey Elevator Site are set to their average rates observed for the week prior to and during the collection of the water level calibration set (Figure 5.10). These pumping rates are as follows:

Garvey Elevator Site

- RW-6 = 92.5 gpm
- RW-7 = 66.7 gpm
- RW-8 = 90.5 gpm

West Highway 6 & Highway 281 Site

- No wells are pumping from the medial aquifer.

Lower Aquifer

All of the water pumped from the shallow and medial aquifers at the Garvey Elevator Site is treated and injected into the lower aquifer through two injection wells, located as shown on Figure 5.11. The total amount of pumped water is approximately 280 gpm. Since there are no flow meters on the injection wells it is assumed that 10 percent of the pumped water is lost to leaks and evaporation and the remaining 250 gallons is injected at an equal rate (125 gpm) into each of the two injection wells.

Pumping records for the month of September 2011 indicate that the pumping rate for Municipal Well 9 averaged 577 gpm. The close proximity of this well to a no-flow boundary (Figure 5.11), however, would result in over predictions of the hydraulic conductivities in this area during the model calibration. Therefore, the pumping rate of Municipal Well 9 was reduced during the model calibration until the hydraulic conductivities approximated those in the general vicinity but outside the influence of the pumping. Since this well is away from the contaminant plumes, the modeling results will be relatively insensitive to the hydraulic conductivities predicted in this area. Since the calibration set was collected in September, it is assumed that the irrigation wells located within the model domain were not pumping water. Injection and pumping rates from the lower aquifer are shown below:

Garvey Elevator Site

- IW-1 = 125 gpm
- IW-2 = 125 gpm

West Highway 6 & Highway 281 Site

- Municipal Well 9 = 342 gpm

5.3.2 Initial Conditions

As described in Section 3.2, carbon tetrachloride contamination is present in the upper, middle, and lower aquifers. Groundwater contaminant concentration data presented on Figures 3.1, 3.2 and 3.3 were used as the basis for estimating the initial plume concentrations within the model. The actual concentrations specified as initial conditions for the shallow, medial and lower aquifers are shown in Figures 5.12, 5.13 and 5.14, respectively.

6.0 MODEL CALIBRATION

Traditionally, the term "model calibration" is used to refer to the trial-and-error adjustment of parameters of the groundwater system by comparing the model's output (calculated values of hydraulic head or concentration) and the measured output (observed values of hydraulic head or concentration). In essence, such a calibration procedure involves the following routines: (1) operating the model, using initial estimates of the values of the parameters, (2) history-matching, or comparing computed and observed values of hydraulic head or concentration, and (3) adjusting the values of the parameters and repeating the simulation.

Calibration of the model is aimed at demonstrating that it can produce realistic, accurate and reliable predictions. The flow model is calibrated by determining a set of parameters, boundary conditions, and hydraulic stresses that generate simulated potentiometric surfaces and fluxes that match field-measured values to within an acceptable range of errors. The end result of the process of model calibration is an optimal set of values for parameters that minimize the discrepancy between the model output and the observed data. The iterative process of matching calculated values with observed (historical) data by adjusting the model input can be a manual trial-and-error procedure or can be automated. The calibration process, also known as history-matching, is closely related to estimating parameters. This process might result in the refinement of initial estimates of aquifer properties (parameters), the establishment of the location of the boundaries (areal and vertical extent of aquifer), and the determination of flow and transport conditions at the boundaries.

Calibration can be performed to steady-state or transient data sets. Although most flow model calibration exercises involve steady-state data, in some hydrogeologic settings assumption of steady-state conditions may be inappropriate due to large fluctuations in the water table or boundary conditions. For this modeling exercise, only steady-state calibrations were performed.

To facilitate the model calibration, PEST was used in conjunction with the groundwater flow code (MODFLOW-2000). PEST is a calibration tool that uses non-linear least-squares techniques to adjust model parameter data in order to reduce the discrepancies between the pertinent model-generated numbers and the corresponding measurements to a minimum. It does this by taking control of the model and running it as many times as is necessary to determine this optimal set of parameters within a user-specified range.

Calibration of the steady state flow model was accomplished iteratively by adjusting model parameters during successive model runs to match the water-level data that was collected from all of the wells on September 26-27, 2011 under stressed (i.e. pumping) conditions. Since most of the recovery wells had been running for at least several weeks prior to and during the collection of these water levels, is it assumed that the levels are representative of steady-state pumping conditions. The water-level calibration targets for all of the aquifers are provided in Table 6.1.

As part of the model calibration, adjustments were made to the areal recharge (shallow aquifer), range of hydraulic conductivities, ratio of vertical to horizontal hydraulic conductivities and minor adjustments to the constant head boundaries. The general calibration approach that was followed involved adjusting the parameters mentioned above and inputting the parameters into a PEST simulation. PEST would subsequently run MODFLOW thousands of times in which the hydraulic conductivities were adjusted for each iteration until the difference between the observed water levels (targets) and the model predicted values (error residuals) were minimized. If these error residuals were too high, further adjustments were made to the recharge, hydraulic conductivity range, etc. and the PEST simulation was initiated again.

During the model flow calibration it was found that the parameter imparting the most sensitivity to the model results is the areal recharge reaching the water table. The Corps of Engineers proposed in their 1990 Final Groundwater Modeling Report of the Hastings East Industrial Park area, that net recharge for non-irrigated grassland was estimated to be 2.6 inches per year (USACE, 1990). After performing a number of simulations during the model calibration it was found that a value of 2.6 inches per year provided the best match to the measured water levels.

The error residuals (that is, the differences between model predicted/computed and measured/observed values) are depicted graphically in Figures 6.1 and 6.2. The error residuals and calibration statistics are also presented in tabular form in Table 6.1. As shown in Figure 6.1, most of the error residuals are within $\pm$0.5 ft. The minimum residual is -3.2 ft (over prediction of the hydraulic head) and the maximum residual is 1.96 ft (under prediction of hydraulic head). The graph depicted in Figure 6.2 shows that there is a good fit along the entire range of observed water level elevations.

A common measure of the quality of the model calibration is the percent error. The percent error is the root mean square error (RMSE) divided by the total change in the observed head. As shown in Table 6.1 the RMSE is 0.75 and the range in observations is 43.26. This leads to a percent error of about 1.7 percent which is well below the 10 percent error often cited as the cutoff for a well calibrated model.

The areal distribution of error residuals for the shallow aquifer (model layer 1) near the Garvey Elevator Site and over the entire model domain are shown in Figures 6.3 and 6.4, respectively. All of the error residuals shown in the figures are relatively small. In fact, the largest error residuals in the shallow aquifer are found in the immediate vicinity of the West Highway 6 & Highway 281 Site and do not significantly impact the flow and transport results. These error residuals were further lowered as part of the West Highway 6 & Highway 281 model calibration, performed as a separate exercise.

The error residuals for the medial aquifer (model layer 3) are presented in Figure 6.5. With the exception of two wells that are located to the northeast of the Site in the vicinity of the West Highway 6 & Highway 281 Site, all of the residuals are relatively low.

The areal distribution of error residuals for the lower aquifer (model layer 5) near the Garvey Elevator Site and over the entire model domain are depicted in Figures 6.6 and 6.7, respectively. The large residual shown on Figure 6.6 is associated with MW-20C (-3.0 ft). The water levels and residuals for the MW-20 well series are as follows:

MW-20C: residual -3.00 ft; water level 1808.92 ft above mean sea level (amsl)
MW-20D: residual 0.04 ft; water level 1811.96 ft amsl
MW-20E: residual -0.37 ft; water level 1811.55 ft amsl

As shown in Table 5.1, the top of the lower aquifer for the MW-20 series is encountered at a depth of 152 feet. This is also the depth that the well screen begins for MW-20C. Therefore, MW-20C, -20D and -20E are all screened in the lower aquifer.

Historically, the water level for MW-20C behaves somewhat erratically when compared to MW-20D and MW-20E. For instance, all of the measurements for the 3 wells are relatively close in 2009 and 2010. However, in June of 2011, the water level observed in MW-20C is 4 feet above that observed in MW-20D and 3 feet above the water level measured in MW-20E. Therefore, primary reliance was placed on the water levels from MW-20D and MW-20E for the model calibration.

The residuals for the lower aquifer monitoring wells farther downgradient of the site are all very low and demonstrate an excellent calibration (Figure 6.7).

The calibrated hydraulic conductivities for the shallow, medial, and lower aquifers are presented in Figures 6.8, 6.9 and 6.10, respectively. In the vicinity of the Site, the calibrated horizontal hydraulic conductivity for the all of the aquifers ranges between 50 and 250 ft per day (ft/d). It is assumed that the vertical hydraulic conductivity is a factor of 5 less than that of the horizontal hydraulic conductivity.

Near the Site, most of the shallow aquifer is characterized by hydraulic conductivities between 50 to 100 ft/d. The hydraulic conductivities in the medial aquifer, however, tend to range between 100 and 250 ft/d over most of the Site. The calibrated hydraulic conductivities for the lower aquifer range between 50 and 150 ft/d over most of the eastern portion of the Site and between 100 and 250 ft/d along the western boundary and in the northwest area of the Site.

The model predicted hydraulic conductivities for the lower aquifer are less certain, however, because there are no pumping wells stressing the system in this aquifer.

The hydraulic conductivities farther downgradient of the Site indicate that large areas in the shallow and medial aquifers have relatively low hydraulic conductivities, ranging from 50 to 100 ft/d. The hydraulic conductivities of the lower aquifer over much of this area tend to be significantly higher and range between 100 and 250 ft/d. These higher hydraulic conductivities are consistent with the large production rates (e.g., 300 to 600 gpm) of the irrigation wells located in the area, which draw from the lower aquifer during the summer months.

The hydraulic conductivities of the upper and lower aquitards are show on Figures 6.11 and 6.12, respectively. The upper aquitard is continuous except for an area located immediately north of the Site. The lower aquitard is absent from approximately the northern one third of the model domain.

The calibrated potentiometric surfaces for the shallow, medial and lower aquifers are presented in Figures 6.13 through 6.15, respectively. The calibrated potentiometric surface for the shallow and medial aquifers show some bending in the vicinity of the Site due to the pumping wells. The potentiometric surface of the lower aquifer is clearly impacted by the injections wells (for example, elevation line 1817). Downgradient from the Site, the potentiometric lines are generally perpendicular to groundwater flow.

As a qualitative check on the calibrated hydraulic conductivity fields and hydraulic gradients, a particle tracking analysis was performed to estimate travel times. Approximately 52 years has elapsed since Garvey Elevators began operation as a grain storage facility in 1959 and the 2011 sampling event. As illustrated by Figure 6.16, it takes about 50 years for a particle to move from the Site boundary to the toe of the plume. Although it is unknown when contamination reached the water table and the overall influence of municipal and irrigation wells on transport rates, the results of the travel time analysis suggest that the calibrated hydraulic conductivities and gradients are reasonable. A general discussion pertaining to particle tracking (e.g., computer code) is provided in Section 7.2.2.

7.0 REMEDIAL ALTERNATIVE DESIGN

7.1 CONTAMINANT TRANSPORT PARAMETERIZATION

Once the calibration of the flow model was complete, contaminant transport and particle tracking simulations were performed. Parameters that are required to conduct contaminant transport modeling include effective porosities, dispersivities, retardation and chemical and biological transformations. A brief description of each of these processes is presented below.

Effective Porosity. The effective porosity is the ratio of the volume of interconnected pore spaces available for transport to the total system volume. It is used to estimate the velocity at which groundwater and contaminants travel through a porous medium. The smaller the effective porosity the higher the groundwater velocity and the more rapidly contaminants will be transported. A reasonable value for sand, silts and gravels is 25 percent, and therefore this value was assigned to the model.

Dispersivity. The equations of solute transport that are solved in contaminant-transport codes are derived assuming that the solute migration is due to advection and hydrodynamic dispersion. Advection describes the bulk movement of groundwater flow, where hydrodynamic dispersion is caused by the tendency of the solute to spread out from the path that it would be expected to follow if transported only by advection. This spreading of the contamination over an ever-increasing area is called hydrodynamic dispersion and has two components: mechanical dispersion and diffusion. Hydrodynamic dispersion causes dilution of the solute and occurs because of spatial variations in groundwater flow velocities and mechanical mixing during fluid advection. Molecular diffusion, the other component of hydrodynamic dispersion, is due to the thermal kinetic energy of solute molecules and also contributes to the dispersion process. Thus, if hydrodynamic dispersion is factored into the solute transport processes, ground-water contamination will cover a much larger region than in the case of pure advection, with a corresponding reduction in the maximum and average concentrations of the contaminant. Dispersion also increases the velocity of the contaminants because it considers the fact that some contaminants will travel through faster pathways (and some slower) than if only pure advection was assumed.

The relatively narrow plume with respect to the plume length suggests relatively low dispersivity values. Furthermore, numerical dispersion occurring as part of the solution method has to also be factored into the dispersion estimate. Finally, if too large of a dispersion value is assigned, contaminants will be artificially dispersed vertically through the upper and lower aquitards into the underlying aquifers. Therefore, the relatively low values of 50, 5, and 1 ft were assigned to the longitudinal, transverse and vertical dispersivities, respectively.

Retardation Factor.

The rate at which contaminants migrate relative to groundwater is termed the retardation factor and is determined by the effective porosity (see definition above), bulk density and distribution coefficient. Adsorption of carbon tetrachloride and other chlorinated solvents is expected to be relatively low in the upper, medial, and lower aquifer zones, leading to a low degree of retardation. For modeling purposes a retardation factor of zero was assumed.

Chemical and Biological Transformations

Most VOCs and chlorinated solvents, including carbon tetrachloride, are subject to biological and chemical transformations in the subsurface environment. Biological transformations include aerobic degradation, anaerobic degradation, and co-metabolism. Several chemical properties of both water and soil influence the stability of chlorinated solvents in an aquifer. Chemical transformations include hydrolysis, dehydrohalogenation, and reduction in water. These typically require low groundwater flow rates and, therefore, it is unlikely that these chemical transformations will play a significant role at the Site.

Carbon tetrachloride can be reduced under anaerobic conditions via three different pathways:

- reductive dechlorination where carbon tetrachloride is reduced to chloroform, chloroform is reduced to methylene chloride, and methylene chloride is reduced to methane;
- a simple two-electron reduction process in which chloroform is only a minor product; and
- a one-electron reduction via sulfur and oxygen where carbon tetrachloride is reduced to carbon dioxide and chloroform is not produced.

Based on the groundwater sample analytical results collected during the RI field investigation, some degree of biodegradation of the carbon tetrachloride groundwater plume is occurring as evidenced by the presence of the degradation products chloroform and methylene chloride (HGL, 2011). Concentrations of these degradation products are typically one to two orders of magnitude less than those of carbon tetrachloride in samples collected at the Site. However, chloroform concentrations are similar to or slightly greater than carbon tetrachloride concentrations in many of the groundwater transect samples collected downgradient of the Site, indicating that biodegradation is occurring, but not at an accelerated rate. Therefore, no degradation of carbon tetrachloride was assumed in the model.

7.2 OU 1 - REMEDIAL ALTERNATIVES

The remedial scenarios being considered as part of the FS are presented in Table 7.1. As shown in the table, there are four scenarios included under OU 1. The No Action Alternative (SG-1) and Maintaining and Operating the Existing Groundwater Extraction System (SG-2) would require a significant length of time for on-site carbon tetrachloride concentrations to fall below the maximum contaminant level (MCL) of 5 micrograms per liter (μg/L), which is established as the preliminary cleanup level (PCL). These alternatives were not explicitly modeled.

For the no action alternative (SG-1), the duration to reach MCLs should intuitively be longer than other alternatives that use active treatment methods. However, for cost estimating purposes, it is assumed that the duration for SG-1 is 30 years.

For alternative SG-2, the duration to achieve MCLs was estimated using groundwater contamination data from monitoring wells and recovery wells at the site. Table 7.1 summarizes analytical data from these wells, including projected times to achieve MCLs based on concentration trends. Using these data, an estimated duration of 30 years has been assumed for alternative SG-2 to achieve MCLs.

7.2.1 SG3 - In-Situ Treatment via Groundwater Amendments

This alternative involves shutting off the existing groundwater extraction system and injecting amendments to remediate contaminated groundwater within the 500 μg/L contour. As shown in Figure 7.1, the initial conditions for this portion of the plume have been set to zero, and the pumping and injection wells in the upper, medial, and lower aquifers have been shut off. The model predicts that it would take approximately 4 years for the plume to disperse and the concentrations of carbon tetrachloride to decrease below the MCL of 5 μg/L. These predictions are unrealistically short, however, for the following reasons: diffusion back out of the finer grained clays is limited by concentration gradients that often lead to very long cleanup time frames and, although sorption is probably low, it can significantly increase remediation times particularly when coupled with diffusion processes. For these reasons, the remediation time for alternative SG3 was increased to 15 years.

7.2.2 SG4 - Maintain and Operate Existing GET System and Treat Via Amendments

This alternative is identical to SG3 except that the existing groundwater extraction and treatment (GET) system remains on. To ensure that the existing GET system is effective at capturing the contamination, a capture zone analysis was conducted with the computer code MODPATH.

MODPATH is a widely accepted 3-D particle-tracking model that uses the flow fields created by MODFLOW to predict groundwater flow directions. Particle tracking is a form of flow and transport modeling that represents the bulk movement of groundwater. Particle tracking neglects the effects of chemical reactions, dispersion, and diffusion. The particle tracking analysis involves adding particles to the model at selected locations and then allowing the model to move the particles in the direction of groundwater flow. The results of a particle tracking simulation are displayed by plotting pathlines through the aquifer. Although both forward and reverse particle tracking can be performed with MODPATH, for the Garvey Elevator Site, only forward-tracking analyses are conducted.

Before initiating the capture zone analysis, the groundwater extraction rates were changed from those used to calibrate the model to rates that better reflect long term pumping rates. The revised rates are as follows:

Garvey Elevator Site

- RW-1 = 3.5 gpm
- RW-2 = 6.8 gpm
- RW-3 = 9.0 gpm
- RW-4 = 10.2 gpm
- RW-5 = 5.0 gpm
- RW-6 = 90.0 gpm
- RW-7 = 68.0 gpm
- RW-8 = 128.0 gpm

West Highway 6 & Highway 281 Site

- EW-1 = 6.1 gpm
- EW-2 = 8.3 gpm
- EW-3 = 4.1 gpm
- EW-4 = 0.0 gpm

Shallow Aquifer

As shown on Figure 7.2, particles released to all the model layers indicate that the extraction wells are effectively containing the on-site carbon tetrachloride plume. At some point downgradient, however, capture is lost and the contaminants will continue to migrate with the groundwater.

Medial Aquifer

The results of the particle-tracking analysis for the medial aquifer are presented as Figure 7.3. The particle tracking illustrates that the modeled capture zone extends sufficiently downgradient to capture the contamination that has moved immediately off site.

The predicted remediation time for this alternative is about 2 years (Table 7.2). The removal of the contamination with the pumping wells has shortened the time from that predicted for Alternative SG3. As was the case for Alternative SG3, these predictions are unrealistically short, for the same reasons. For these reasons, the remediation time for alternative SG3 was increased to 10 years.

7.3 OU 2 - REMEDIAL ALTERNATIVES

Six remedial alternatives were considered for OU 2 (Table 7.2). Although it was not modeled, based on the predicted remediation times of greater than 100 years for the G2 scenario, the No-Action alternative (G1) remediation time is predicted to take more than 100 years. However, for cost estimating purposes, it will be assumed that the duration for SG-1 is 30 years.

7.3.1 G2 - Groundwater Recovery and Treatment at Leading Edge of Plume

This alternative involves pumping and treating the groundwater from the toe of the medial and lower aquifer plumes. As shown in Figures 7.4 and 7.5, three wells would need to be placed in both the medial and lower aquifers to ensure capture of the plume. The relative position of the two sets of wells is depicted on Figure 7.6. Each of the medial wells would be pumped at 50 gpm, and the lower aquifer wells would each be pumped at 150 gpm. The predicted remediation time for this alternative is greater than 100 years. For costing purposes, a duration of 100 years is assumed.

7.3.2 G3a - Groundwater Recovery and Treatment at Leading Edge and Midpoint of Plume

This alternative is the same as Alternative G2 but in addition to pumping and treating contaminated groundwater from the toe of the plume, contaminated groundwater is also pumped and treated from the midpoint of the medial and lower aquifer plume(s). A series of simulations were run in which the midpoint wells were located along different transects in order to decrease the remediation times; the most optimal locations are shown in Figures 7.7 and 7.8.

The relative position of the two sets of wells is depicted on Figure 7.9. Each of the medial wells would be pumped at 50 gpm, and the lower aquifer wells would each be pumped at 150 gpm. The predicted remediation time for this alternative is between 75 and 95 years. For cost estimating purposes, a duration of 75 years will be assumed.

7.3.3 G3b - Groundwater Recovery and Treatment at Leading Edge and Midpoint of Medial Aquifer and Two Recovery Well Transects in Lower Plume

The results from G3a indicate that the contamination in the lower aquifer takes the longest time to remediate. Therefore, this alternative was added to determine how much the remediation times could be reduced if a second set of recovery wells was added to the lower aquifer. The placement of the recovery wells in the medial aquifer remains the same as for Alternative G3a (Figure 7.7). The locations of the two transects of recovery wells in the lower aquifer are shown on Figure 7.10. Their placement relative to the medial wells is shown in Figure 7.11. Each of the medial wells would be pumped at 50 gpm, and each of the lower aquifer wells would be pumped at 150 gpm. The predicted remediation time for this alternative is about 53 years.

7.3.4 G4a - Establishment of In Situ Treatment Zone at Midpoint of Lower Aquifer Plume and Groundwater Recovery and Treatment at Leading Edge of Medial and Lower Plumes

This alternative involves adding a treatment curtain to the pumping wells specified in the G2 alternative (Figure 7.12). The transect is simulated as a zero concentration boundary which effectively removes all of the carbon tetrachloride from the groundwater moving through it. The relative position of the transect and wells is depicted on Figure 7.13. Each of the medial wells would be pumped at 50 gpm, and each of the lower aquifer wells would be pumped at 150 gpm. The predicted remediation time for this alternative is between 75 and 95 years. For cost estimating purposes, a duration of 75 years is assumed.

7.3.5 G4b - Establishment of In Situ Treatment Zone(s) at Two Transects of Lower Aquifer Plume and Groundwater Recovery and Treatment at Leading Edge of Medial and Lower Plumes

This alternative involves adding two treatment curtains to the pumping wells specified in the G2 alternative (Figure 7.14). The relative position of the transects and recovery wells is depicted on Figure 7.15. Each of the medial wells would be pumped at 50 gpm, and the lower aquifer wells each at 150 gpm. The predicted remediation time for this alternative is about 56 years.

8.0 SUMMARY AND CONCLUSIONS

A hydrogeologic conceptual site model of the subsurface groundwater flow and contaminant transport was developed to guide the creation of a numerical model. The numerical model was subsequently calibrated with existing field data (known water levels and pumping rates) to address the following objectives: (1) evaluate the overall effectiveness of the current extraction well system; (2) identify areas outside of the capture zone that may require enhancements; and (3) develop a tool to assist in "what if" scenarios for the remedial alternative development.

MODFLOW-2000, MT3D-MS and MODPATH are the computer codes applied to conduct the flow and transport analysis. The output from MODFLOW-2000 is a groundwater velocity field which is used by MT3D-MS, in conjunction with fate and transport parameters, to simulate the migration of carbon tetrachloride. Particle tracking analyses were also conducted with MODPATH to illustrate the groundwater flow directions, travel times, and capture zones. All of these computer codes are widely used, well documented, and in the public domain.

With respect to the construction of the model, a three layer finite difference grid was utilized that simulates the upper, middle and lower aquifers, covers 10.2 square miles, and includes 1,030,200 active cells.

Calibration of the steady state flow model was accomplished iteratively by adjusting model parameters during successive model runs to match the water level data that was collected from all of the wells on September 26-27, 2011, under stressed (pumping) conditions.

The flow and transport model was initialized with measured carbon tetrachloride data obtained during a 2011 sampling event. These initial concentrations were used as the basis to predict future concentrations under various remedial alternatives involving extraction wells and treatment curtains.

Remediation times for OU 1 scenarios varied from 10 to 30 years. Scenarios from the No Action alternative and alternative SG-2 were not modeled, but were based on an assumed cost basis period and a duration based on existing concentration data trends, respectively. Remediation times for OU 2 scenarios range from 30 years to more than 100 years.

9.0 REFERENCES

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Attachments

Attachment 1	Tables
Attachment 2	Figures

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ATTACHMENT 1
TABLES

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Table 5.1
Contact Elevations of the Major Lithologic Units
Garvey Elevator Site
Hastings, Nebraska

Site	Well ID	Northing[2]	Easting[2]	Boring Depth	Top of Lithologic and Hydrostratigraphic Units[1]																
					Surface Elevation - Surficial Soil, Peoria and Loveland Loess	Very Fine Sand, Silty Fine Sand, Clayey Silt		Silty Sand and Gravel (contains Upper Aquifer)		Upper Aquitard			Medial Aquifer		Lower Aquitard			Lower Aquifer		Decomposed / Weathered Shale	
					Elev.	Depth	Elev.	Depth	Elev.	Depth	Elev.	Thickne	Depth	Elev.	Depth	Elev.	Thickne	Depth	Elev.	Depth	Elev.
		(ft)	(ft)	(ft bgs)	(ft amsl)	(ft bgs)	(ft amsl)	(ft bgs)	(ft amsl)	(ft bgs)	(ft amsl)	(ft)	(ft bgs)	(ft amsl)	(ft bgs)	(ft amsl)	(ft)	(ft bgs)	(ft amsl)	(ft bgs)	(ft amsl)
Monitoring Wells																					
OU1	MW-1A	270590.926	2080164.407	125	1925.80	64.5	1861.30	99.5	1826.30	--	--	--	--	--	--	--	--	--	--	--	--
OU1	MW-2A	271240.410	2080539.870	123.5	1927.33	68.5	1858.83	83.5	1843.83	--	--	--	--	--	--	--	--	--	--	--	--
OU1	MW-3A,B,D,E	270755.170	2080773.994	243	1930.99	59.5	1871.49	111	1819.99	134	1797.07	1	135	1796.07	155	1775.30	1	156	1774.30	238.5	1692.49
OU1	MW-4A,B	270341.995	2080827.075	132	1931.84	58.5	1873.34	89	1842.84	--	--	--	--	--	--	--	--	--	--	--	--
OU1	MW-5A,B,D	269943.836	2080752.777	188	1930.06	63.5	1866.56	88.5	1841.56	132	1797.85	1	133	1796.85	--	--	--	--	--	--	--
OU1	MW-6A,D,E	271237.345	2081216.968	238	1929.48	73.5	1855.98	93.5	1835.98	129	1800.46	1	130	1799.46	155	1774.46	5	160	1769.46	--	--
OU1	MW-7A,B	269088.475	2079699.700	135	1920.92	55	1865.92	90	1830.92	--	--	--	--	--	--	--	--	--	--	--	--
OU1	MW-8A	271214.203	2079067.544	132	1940.80	60.8	1880.00	90	1850.80	--	--	--	--	--	--	--	--	--	--	--	--
OU1	MW-9A	272193.736	2080628.145	116	1925.40	70	1855.40	90	1835.40	--	--	--	--	--	--	--	--	--	--	--	--
OU2	MW-10A,B	272535.399	2081973.782	130	1923.81	65	1858.81	85	1838.81	125	1798.70	1	126	1797.70	--	--	--	--	--	--	--
OU2	MW-11A	271826.499	2083509.070	110	1912.28	70	1842.28	90	1822.28	--	--	--	--	--	--	--	--	--	--	--	--
OU2	MW-12A,C	270399.710	2085390.335	170	1917.13	50	1867.13	80.5	1836.63	--	--	--	--	--	--	--	--	--	--	--	--
OU2 (new)	MW-12D	270399.901	2085403.521	178	1916.98	57	1859.98	88	1828.98	120	1796.98	7	127	1789.98	--	--	--	--	--	--	--
OU1	MW-13C,E	270368.902	2081015.694	238	1928.74	75	1853.74	90	1838.74	130	1798.74	1	131	1797.74	--	--	--	--	--	235	1693.74
OU2	MW-14A	270968.774	2084137.323	108.5	1909.56	69.5	1840.06	89.5	1820.06	--	--	--	--	--	--	--	--	--	--	--	--
OU2	MW-16A,C	267054.564	2084286.931	160	1915.45	50	1865.45	80	1835.45	--	--	--	--	--	--	--	--	--	--	--	--
OU2	MW-17A,C,D	268796.556	2082958.916	200	1901.85	60	1841.85	85	1816.85	--	--	--	--	--	--	--	--	--	--	--	--
OU2	MW-18A,C,D	268693.818	2085938.384	205	1910.64	55	1855.64	95	1815.64	115.5	1795.14	1	116.5	1794.14	--	--	--	--	--	--	--
OU1	MW-19A,C	270955.133	2081332.850	165	1927.81	61	1866.81	89.5	1838.31	128	1799.81	8	136	1791.81	150	1777.81	2	152	1775.81	--	--
OU1	MW-20A,C,D,E	270597.445	2081202.233	255	1927.97	54	1873.97	87	1840.97	129	1798.97	7	136	1791.97	150	1777.97	2	152	1775.97	236	1691.97
OU1	MW-30A,C,D,E	270271.723	2081095.430	255	1929.03	70	1859.03	85	1844.03	125.5	1803.53	7	132.5	1796.53	146	1783.03	2	148	1781.03	237	1692.03
OU1	MW-31A,C	269550.764	2080816.035	165	1930.08	63	1867.08	88.3	1841.78	--	--	--	--	--	--	--	--	--	--	--	--
OU1	MW-33	271206.314	2079068.057	255	1940.74	84	1856.74	95	1845.74	138.5	1802.24	5.5	144	1796.74	167	1773.74	6.75	173.75	1766.99	240	1700.74
OU1 (new)	MW-47B,C,D	270781.240	2081046.150	170.5	1929.95	--	--	--	--	131.5	1798.45	1.5	133	1796.95	151	1778.95	2	153	1776.95	--	--
OU1 (new)	MW-48B,C,D	270645.490	2080859.850	171	1928.87	--	--	--	--	129	1799.87	3.5	132.5	1796.37	149.8	1779.07	5	154.8	1774.07	--	--
OU1 (new)	MW-49B,C,D	270039.470	2080890.150	171	1929.34	--	--	--	--	130.5	1798.84	1.5	132	1797.34	149.5	1779.84	4	153.5	1775.84	--	--
OU1 (new)	MW-50B,C,D	270307.290	2080987.510	170	1929.25	--	--	--	--	127.5	1801.75	5	132.5	1796.75	149.5	1779.75	1	150.5	1778.75	--	--
OU1 (new)	MW-51B,C,D	270487.290	2080899.910	171	1929.43	--	--	--	--	126.8	1802.63	5.2	132	1797.43	149.5	1779.93	4.5	154	1775.43	--	--
OU2 (new)	MW-41D1	266698.811	2089673.996	171	1915.24	62	1853.24	92	1823.24	126	1788.99	2	128	1786.99	148	1766.99	2	150	1764.99	--	--
OU2 (new)	MW-41D2	266708.267	2089674.259	206	1914.99	62	1852.99	92	1822.99	126	1788.99	2	128	1786.99	148	1766.99	2	150	1764.99	--	--
OU2 (new)	MW-42D,E	269168.074	2100135.574	215	1902.07	66	1836.07	98	1804.07	124	1778.23	10	134	1768.23	--	--	--	--	--	--	--
OU2 (new)	MW-43D,E	265395.404	2097605.590	221.5	1908.35	48	1860.35	89	1819.35	--	--	--	--	--	153	1755.45	2	155	1753.45	--	--
OU2 (new)	MW-44D,E	267552.324	2105258.206	214	1885.30	63	1822.30	92	1793.30	119	1766.30	3	122	1763.30	142.5	1742.80	7.5	150	1735.30	--	--
OU2 (new)	MW-45C,D	270056.199	2083476.668	170	1909.82	50	1859.82	89	1820.82	112	1797.46	3	115	1794.46	--	--	--	--	--	--	--
OU2 (new)	MW-46D1	269055.295	2089632.928	167	1910.97	61	1849.97	94	1816.97	121	1790.03	3	124	1787.03	148	1763.03	6	154	1757.03	--	--
OU2 (new)	MW-46D2	269063.843	2089632.455	202	1911.03	61	1850.03	94	1817.03	121	1790.03	3	124	1787.03	148	1763.03	6	154	1757.03	--	--
Hwy 6	MW-104A,C,D	271937.379	2088225.393	235	1909.01	47.2	1861.81	93.6	1815.41	115	1794.01	12	127	1782.01	--	--	--	--	--	220	1689.01
Hwy 6	MW-105A,C,D	270069.428	2089866.388	257	1916.79	68	1848.79	105	1811.79	123	1793.79	10	133	1783.79	--	--	--	--	--	245.5	1671.29
Hwy 6	MW-106A,C,D	270452.369	2098166.199	255	1906.64	77	1829.64	107.5	1799.14	130	1776.64	5	135	1771.64	--	--	--	--	--	248	1658.64
OU1	I-1	270863.284	2080138.346	175	1921.2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
OU1	I-2	270331.729	2080131.336	175	1920.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
OU1	HTW-40	271217.856	2079157.749	--	1939.5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Hwy 6	HTW-100	273075.261	2082012.337	255	1906.6	77.0	1829.64	107.6	1799.04	130	1776.64	5.5	--	--	--	--	--	--	--	--	--

Table 5.1
Contact Elevations of the Major Lithologic Units
Garvey Elevator Site
Hastings, Nebraska

Site	Well ID	Northing[2]	Easting[2]	Boring Depth	Top of Lithologic and Hydrostratigraphic Units[1]: Surface Elevation - Surficial Soil, Peoria and Loveland Loess	Very Fine Sand, Silty Fine Sand, Clayey Silt		Silty Sand and Gravel (contains Upper Aquifer)		Upper Aquitard			Medial Aquifer		Lower Aquitard			Lower Aquifer		Decomposed / Weathered Shale	
					Elev.	Depth	Elev.	Depth	Elev.	Depth	Elev.	Thickne	Depth	Elev.	Depth	Elev.	Thickne	Depth	Elev.	Depth	Elev.
		(ft)	(ft)	(ft bgs)	(ft amsl)	(ft bgs)	(ft amsl)	(ft bgs)	(ft amsl)	(ft bgs)	(ft amsl)	(ft)	(ft bgs)	(ft amsl)	(ft bgs)	(ft amsl)	(ft)	(ft bgs)	(ft amsl)	(ft bgs)	(ft amsl)
Electrical Conductivity Borings																					
OU1 (new)	SB-09	270168.160	2080517.340	131.60	1929.84	59	1870.84	90	1839.84	130	1799.84	1	131	1798.84	--	--	--	--	--	--	--
OU1 (new)	SB-13	269654.838	2080309.785	143.40	1929.73	67	1862.73	87	1842.73	130	1799.73	3	133	1796.73	--	--	--	--	--	--	--
OU1 (new)	SB-29	270864.398	2081035.503	142.15	1929.89	68	1861.89	90	1839.89	--	--	--	--	--	--	--	--	--	--	--	--
OU1 (new)	SB-32	271237.915	2079979.855	148.65	1924.75	66	1858.75	92	1832.75	--	--	--	--	--	148	1776.75	297	149	1775.75	--	--
OU1 (new)	SB-33	269199.799	2080682.378	140.85	1934.46	63	1871.46	93	1841.46	--	--	--	--	--	--	--	--	--	--	--	--
OU1 (new)	SB-39	271537.352	2081550.026	135.60	1925.83	64	1861.83	89	1836.83	--	--	--	--	--	--	--	--	--	--	--	--
OU2 (new)	TS1-01	269515.615	2089614.339	86.4	1915.69	70	1845.69	86	1829.69	--	--	--	--	--	--	--	--	--	--	--	--
OU2 (new)	TS1-03	268313.868	2089646.765	167.36	1912.51	66	1846.51	86	1826.51	119.5	1793.01	0.5	120	1792.51	148	1764.51	5	153	1759.51	--	--
OU2 (new)	TS1-05	267030.127	2089665.004	166.81	1916.24	75	1841.24	87	1829.24	117	1799.24	2	119	1797.24	153	1763.24	308	155	1761.24	--	--
OU2 (new)	TS2-02	271456.113	2097510.251	136.80	1910.15	73	1837.15	104	1806.15	134	1776.14	3	137	1773.14	--	--	--	--	--	--	--
OU2 (new)	TS2-04	268939.527	2097554.155	167.46	1903.60	70	1833.60	89	1814.60	126	1777.60	9	135	1768.60	152	1751.60	306	154	1749.60	--	--
OU2 (new)	TS2-05	267717.573	2097569.698	171.61	1901.43	62	1839.43	99	1802.43	--	--	--	--	--	157	1744.43	2	159	1742.43	--	--
OU2 (new)	TS2-06	266250.085	2097592.053	119.80	1905.01	60	1845.01	100	1805.01	--	--	--	--	--	--	--	--	--	--	--	--
OU2 (new)	TS3-02	269400.264	2102787.273	156.90	1894.15	68	1826.15	96	1798.15	125	1769.15	7	132	1762.15	147	1747.15	297	150	1744.15	--	--
OU2 (new)	TS3-05	265786.308	2102812.115	143.80	1890.56	67	1823.56	96	1794.56	119.5	1771.06	1	120.5	1770.06	129	1761.56	261	132	1758.56	--	--
OU2 (new)	TS4-02	267112.179	2105261.928	170.31	1884.48	64	1820.48	96	1788.48	116	1768.48	3	119	1765.48	141	1743.48	284	143	1741.48	--	--
Hwy 6	TS3-01	271941.141	2089537.242	145.3	1915.3	72.0	1843.34	112.5	1802.84	125.6	1789.74	2.9	128.5	1786.84	--	--	--	--	--	--	--
Hwy 6	TS3-02	271499.828	2089579.255	141.4	1913.9	69.2	1844.66	102	1811.86	122.7	1791.16	5.9	128.6	1785.26	--	--	--	--	--	--	--
Hwy 6	TS3-03	270957.676	2089591.662	144.0	1908.7	71.0	1837.67	94.1	1814.57	117.8	1790.87	5.6	123.4	1785.27	--	--	--	--	--	--	--
Hwy 6	TS3-04	270411.434	2089597.601	140.3	1908.8	66.3	1842.54	100.6	1808.24	116.7	1792.14	6.1	122.8	1786.04	--	--	--	--	--	--	--
Hwy 6	TS3-05	272464.675	2089528.557	171.8	1917.3	68.5	1848.83	103.2	1814.13	123	1794.33	7	130	1787.33	--	--	--	--	--	--	--
Hwy 6	TS4-01	271882.569	2095813.356	165.8	1904.2	65.0	1839.20	98.7	1805.50	123.8	1780.40	5.2	129	1775.20	--	--	--	--	--	--	--
Hwy 6	TS4-03	270996.450	2096068.696	117.1	1905.0	81.0	1824.00	96.6	1808.40	115.4	1789.60	1.2	116.6	1788.40	--	--	--	--	--	--	--
Hwy 6	TS5-01	271766.686	2092074.297	156.2	1901.6	64.8	1836.80	90.5	1811.10	116.3	1785.30	5.3	121.6	1780.00	--	--	--	--	--	--	--
Hwy 6	TS5-03	270732.978	2092105.115	138.9	1900.8	70.9	1829.90	92.3	1808.50	114.7	1786.10	4.6	119.3	1781.50	--	--	--	--	--	--	--
Hwy 6	TS5-05	272269.991	2092059.880	171.7	1904.5	42.5	1862.00	94.2	1810.30	115.3	1789.20	8.3	123.6	1780.90	--	--	--	--	--	--	--

[1]Surface elevation listed for nested monitoring wells (A/B/C/D/E) is the surface elevation of the "A" well. Unit elevations are from the boring logs in which they were recorded.
[2]State Plane Coordinate system, Nebraska 2600.
amsl - above mean seal level
bgs - below ground surface
Elev. - elevation
ft - feet
Hwy 6 - Wells/borings installed for the West Highway 6 and Highway 281 Site Investigations
-- - not applicable or not available
OU1 - Operable Unit 1; these wells are associated with on-site groundwater
OU1 (new) - Operable Unit 1 wells/borings installed in April/May 2010 for the RI.
OU2 - Operable Unit 2; these wells are associated with off-site groundwater
OU2 (new) - Operable Unit 2 Monitoring wells/borings installed in April/May 2010 for the RI.

Table 6.1
Water Level Calibration Statistics
Garvey Elevator Site
Hastings, Nebraska

Name	Layer	Target Water Level Elevation - Sept, 2011 (feet amsl)	Model Water Level	Error Residual
MW-12U	1	1815.6	1814.424820	1.17518
MW-100A	1	1815.42	1814.519751	0.900249
MW-16U	1	1815.34	1814.385390	0.95461
MW-10A	1	1815.28	1814.182851	1.097149
MW-1A	1	1815.25	1815.209270	0.04073
MW-2A	1	1815.19	1815.393838	-0.203838
MW-05	1	1815.16	1814.358176	0.801824
MW-102A	1	1815.1	1813.770877	1.329123
MW-13U	1	1815.07	1813.730081	1.339919
MW-7A	1	1815.04	1815.242607	-0.202607
MW-04	1	1814.87	1814.376802	0.493198
MW-17U	1	1814.86	1814.230581	0.629419
MW-07	1	1814.75	1814.008616	0.741384
MW-03	1	1814.71	1813.907473	0.802527
MW-02	1	1814.68	1813.743101	0.936899
MW-08	1	1814.65	1814.180036	0.469964
MW-06	1	1814.6	1814.237391	0.362609
MW-10U	1	1814.53	1814.016597	0.513403
MW-14U	1	1814.51	1814.457639	0.052361
MW-6A	1	1814.44	1814.334070	0.10593
MW-01	1	1814.4	1814.062502	0.337498
MW-11A	1	1814.29	1812.347804	1.942196
MW-11U	1	1814.11	1814.658764	-0.548764
MW-10B	1	1813.72	1814.173608	-0.453608
MW-3A	1	1813.57	1813.385654	0.184346
MW-5B	1	1813.39	1813.199091	0.190909
MW-15U	1	1813.26	1814.948966	-1.688966
MW-47B	1	1813.16	1812.784852	0.375148
MW-50B	1	1813.14	1812.748409	0.391591
MW-4A	1	1813.1	1812.992455	0.107545
MW-3B	1	1813.08	1813.389494	-0.309494
MW-5A	1	1813.07	1813.165365	-0.095365
MW-19A	1	1813.01	1813.252060	-0.24206
MW-4B	1	1812.98	1812.954715	0.025285
MW-31A	1	1812.89	1812.885039	0.004961
MW-51B	1	1812.36	1812.125173	0.234827
MW-49B	1	1812.27	1812.349041	-0.079041
MW-48B	1	1812.2	1812.098306	0.101694
MW-30A	1	1811.94	1812.183956	-0.243956
MW-09U	1	1811.94	1814.076063	-2.136063
MW-20A	1	1811.79	1812.309176	-0.519176
MW-14A	1	1810.61	1810.498570	0.11143
MW-17A	1	1809.8	1809.745419	0.054581

Table 6.1
Water Level Calibration Statistics
Garvey Elevator Site
Hastings, Nebraska

Name	Layer	Target Water Level Elevation - Sept, 2011 (feet amsl)	Model Water Level	Error Residual
MW-12A	1	1807.06	1807.353224	-0.293224
MW-16A	1	1806.83	1806.758847	0.071153
MW-18A	1	1806.2	1805.744494	0.455506
MW-104A	1	1803.86	1804.035180	-0.17518
MW-105A	1	1799.94	1799.915974	0.024026
MW-106A	1	1788.57	1788.240807	0.329193
MW-18C	3	1804.09	1804.214829	-0.124829
MW-12C	3	1805.68	1805.675664	0.004336
MW-16C	3	1806.25	1806.232799	0.017201
MW-45C	3	1808.88	1809.089044	-0.209044
MW-17C	3	1809.18	1809.113670	0.06633
MW-47C	3	1810.47	1810.251020	0.21898
MW-101B	3	1810.66	1811.509656	-0.849656
MW-102B	3	1810.92	1811.706686	-0.786686
MW-13C	3	1811.07	1811.204349	-0.134349
MW-51C	3	1811.77	1811.366716	0.403284
MW-50C	3	1811.9	1811.832475	0.067525
MW-49C	3	1812.35	1812.474567	-0.124567
MW-48C	3	1812.5	1812.312538	0.187462
MW-7B	3	1814.97	1815.042613	-0.072613
MW-09M	5	1815.27	1813.657691	1.612309
MW-3D	5	1814.79	1814.354375	0.435625
MW-3E	5	1813.79	1814.210888	-0.420888
MW-5D	5	1813.66	1813.572038	0.087962
MW-47D	5	1813.65	1812.738611	0.911389
MW-49D	5	1813.4	1813.402643	-0.002643
MW-48D	5	1813.23	1812.926923	0.303077
MW-50D	5	1813.23	1812.962182	0.267818
MW-31C	5	1813.11	1813.127460	-0.01746
MW-51D	5	1813.02	1812.256458	0.763542
MW-13E	5	1812.34	1812.181638	0.158362
MW-100D	5	1812.23	1813.629694	-1.399694
MW-100C	5	1812.16	1813.634399	-1.474399
MW-30C	5	1812.08	1811.949179	0.130821
MW-19C	5	1812	1812.353637	-0.353637
MW-20D	5	1811.96	1811.924735	0.035265
MW-30D	5	1811.88	1811.949179	-0.069179
MW-20E	5	1811.55	1811.924735	-0.374735
MW-16M	5	1811.33	1811.653909	-0.323909
MW-13M	5	1811.17	1811.940971	-0.770971
MW-30E	5	1811.15	1811.949179	-0.799179
MW-11M	5	1810.97	1814.139713	-3.169713
MW-17D	5	1809.23	1808.958032	0.271968

Table 6.1
Water Level Calibration Statistics
Garvey Elevator Site
Hastings, Nebraska

Name	Layer	Target Water Level Elevation - Sept, 2011 (feet amsl)	Model Water Level	Error Residual
MW-20C	5	1808.92	1811.924735	-3.004735
MW-45D	5	1808.84	1809.292039	-0.452039
MW-12D	5	1805.75	1805.738454	0.011546
MW-18D	5	1804.13	1804.194578	-0.064578
MW-104D	5	1801.37	1801.272389	0.097611
MW-104C	5	1801.35	1801.269033	0.080967
MW-46D1	5	1797.96	1797.768438	0.191562
MW-105D	5	1797.94	1797.798970	0.14103
MW-46D2	5	1797.92	1797.771831	0.148169
MW-105C	5	1797.91	1797.803499	0.106501
MW-41D2	5	1797.02	1797.046783	-0.026783
MW-41D1	5	1796.97	1797.044368	-0.074368
MW-106C	5	1785.31	1785.334635	-0.024635
MW-106D	5	1785.27	1785.320367	-0.050367
MW-43D	5	1783.87	1783.880124	-0.010124
MW-43E	5	1783.86	1783.888909	-0.028909
MW-42D	5	1781.83	1781.770173	0.059827
MW-42E	5	1781.82	1781.753639	0.066361
MW-44D	5	1774.09	1774.079493	0.010507
MW-44E	5	1774.07	1774.078775	-0.008775
Residual Mean				0.046933
Res. Std. Dev.				0.743461
Sum of Squares				60.48817
RMS Error				0.744941
Min. Residual				-3.169713
Max. Residual				1.942196
Number of Observations				109
Range in Observations				43.62
Scaled Std. Dev.				0.017044
Scaled Abs. Mean				0.010505
Scaled RMS				0.017078

Notes:

amsl - above mean sea level

Table 7.1
Groundwater Data Summary, Projected Durations to Meet MCLs
Garvey Elevator Site
Hastings, Nebraska

Well	Data Collection Range	TCE Concentration, μg/L		Estimated Date to Reach MCLs	Duration from June 2012, yrs
		High	Low		
MW-3A	May 1997 - March 2012	20000	1.1	already achieved	NA
MW-3B	May 1997 - March 2012	23000	74	Nov. 2045	33
MW-3D	April 1997 - March 2012	5	0.5	already achieved	NA
MW-3E	April 1997 - March 2012	4	0.5	already achieved	NA
MW-4A	May 1997 - March 2012	18000	4.3	Sept. 2013	1
MW-4B	May 1997 - March 2012	29000	690	Dec. 2042	30
MW-5A	May 1997 - March 2012	24000	4.7	already achieved	NA
MW-5B	May 1997 - March 2012	15000	12	Jan. 2017	5
MW-5D	April 1997 - March 2012	4	0.5	already achieved	NA
MW-13C	May 1997 - March 2012	18000	28	Nov. 2061	49
MW-13E	May 1997 - March 2012	5	0.5	already achieved	NA
RW-1	1999 - 2011	490	10	May 2016	4
RW-2	1999 - 2011	3200	5	Nov. 2021	9
RW-3	1999 - 2011	3800	5	Feb. 2024	12
RW-4	1997 - 2011	5500	5	June 2016	4
RW-5	1999 - 2011	5500	5	achieved	NA
RW-6	1999 - 2011	590	10	Oct. 2018	6
RW-7	1995 - 2011	1000	5	Jan. 2025	13
RW-8	1998 - 2011	380	5	March 2047	35

Notes:

Dates and concentration data are from the site database; projections to reach MCLs are based on curves fitted to data plots, as provided by Dr. Brian Zurbuchen via email on June 11, 2012.

μg/L - micrograms per liter

Table 7.2
Remedial Alternatives Summary
Garvey Elevator Site
Hastings, Nebraska

Remedial Alternative	Assumptions	Remediation Times	Notes
OU 1			
SG-1-No Action	All extraction wells off.	30 years	This scenario was not explicity modeled. Based on the remedition duration predicted for SG2, remediation time will be greater than 30 years. However, for cost estimating purposes, a 30-year duration will be used.
SG2-- Maintain and Operate Existing GET System	No treatment of downgradient plume.	30 years	This scenario was not explicity modeled, but remediation time was estimated based on contaminant concentration trends (see Table 7.1).
SG3--In Situ Treatment Via Groundwater Amendments	Area within >500 ug/L set to 0.0; on-site treatment system shut off.	15 years	Remediation time estimates are for OU1 (on-site) plume using multiple injection treatments and existing GET system shut off.
SG4-- Maintain and Operate Existing GET System and Treatment Via Groundwater Amendments	Pump and treat system operating, groundwater within concentrations >500 ug/L set to 0.0.	10 years	Remediation time estimates are for OU1 (on-site) plume using multiple injection treatments and existing GET system operating.
OU 2			
G1-No Action	Pump and treat system operating; no treatment of downgradient plume	30 years	This scenario was not explicity modeled. For cost estimating purposes, a 30-year duration will be used.
G2-Groundwater Recovery, Treatment and Discharge at Leading Edge of Plume	On-site pump and treat system operating.	100 years	Based upon modeling results for more active remedies the remediation times for both the OU 1 and OU 2 plumes would exceed 100 years. This scenario was not explicity modeled.
G3a-Groundwater Recovery, Treatment and Discharge at mid point and Leading Edge of Plume	On-site pump and treat system operating.	75 years	Modeled duration ranges from 75 to 90 years.
G3b-Groundwater Recovery, Treatment and Discharge at two transects, and Leading Edge of Plume	On-site pump and treat system operating.	53 years	
G4a-In Situ treatment at midpoint of plume and Groundwater Recovery, Treatment and Discharge at leading edge of plume	On-site pump and treat system operating.	75 years	Same as G3 but a treatment zone replaces the recovery wells near the midpoint of the plume. Modeled duration ranges from 75 to 90 years.
G4b-In Situ treatment at two transects near core of plume and Groundwater Recovery, Treatment and Discharge at leading edge of plume	On-site pump and treat system operating.	56 years	Same as G3 but two treatment zones replace the recovery wells near the midpoint of the plume

Notes:

μg/L - micrograms per liter

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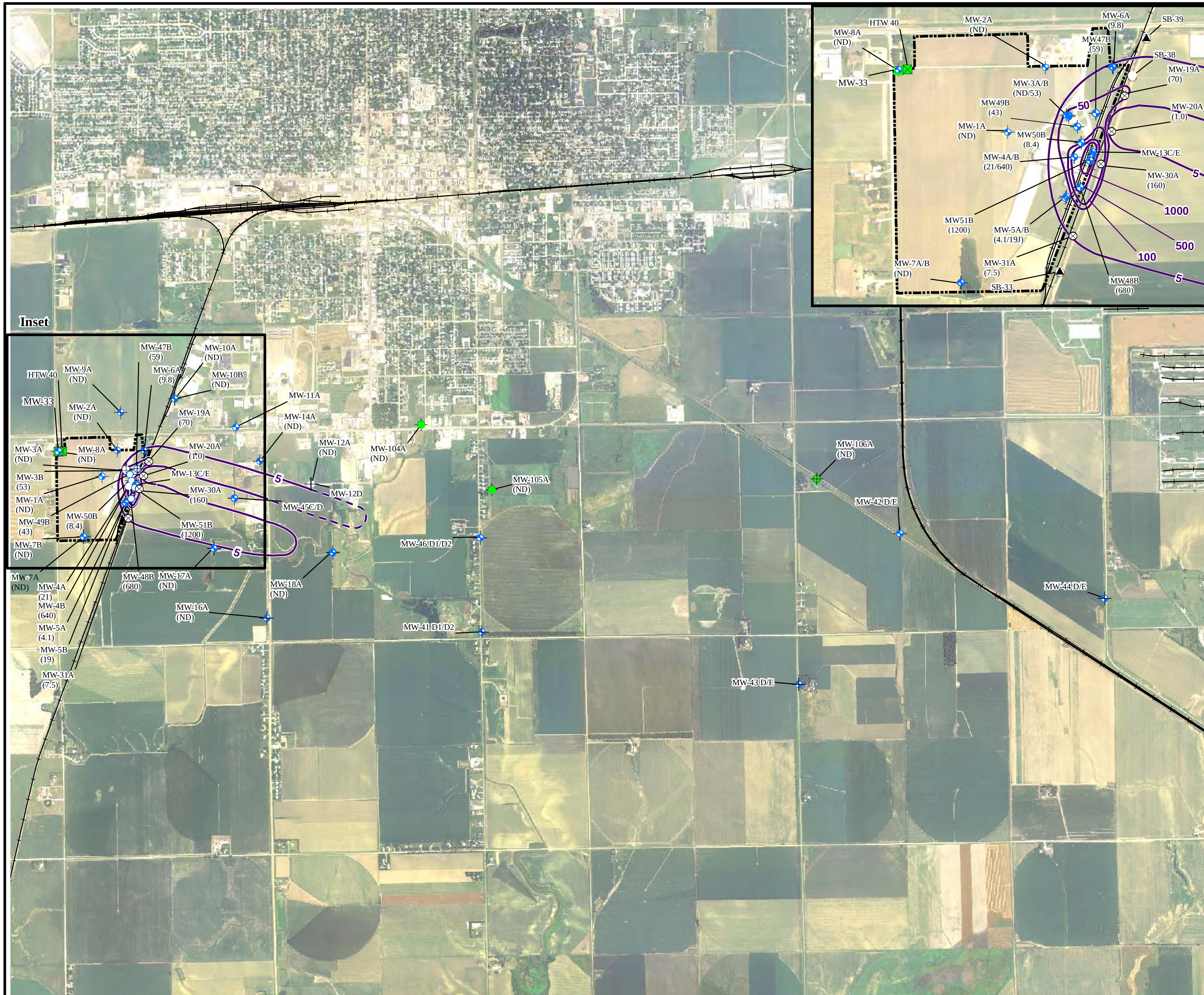
ATTACHMENT 2
FIGURES

ATTACHMENT 2
FIGURES
(continued)

Figure 3.1
Carbon Tetrachloride in the Upper Aquifer Zone A/B September 2011 Sampling



Legend

- Garvey Property Boundary
- Railroad
- Monitoring Well Location
- Multilevel Well
- Hydraulic Conductivity
- West Highway 6 & Highway 281 Site Monitoring Well
- (190) Carbon Tetrachloride Concentration in micrograms per liter (µg/L)
- (5) Carbon Tetrachloride Isoconcentration Contour (µg/L) (Dashed Lines are Estimated)

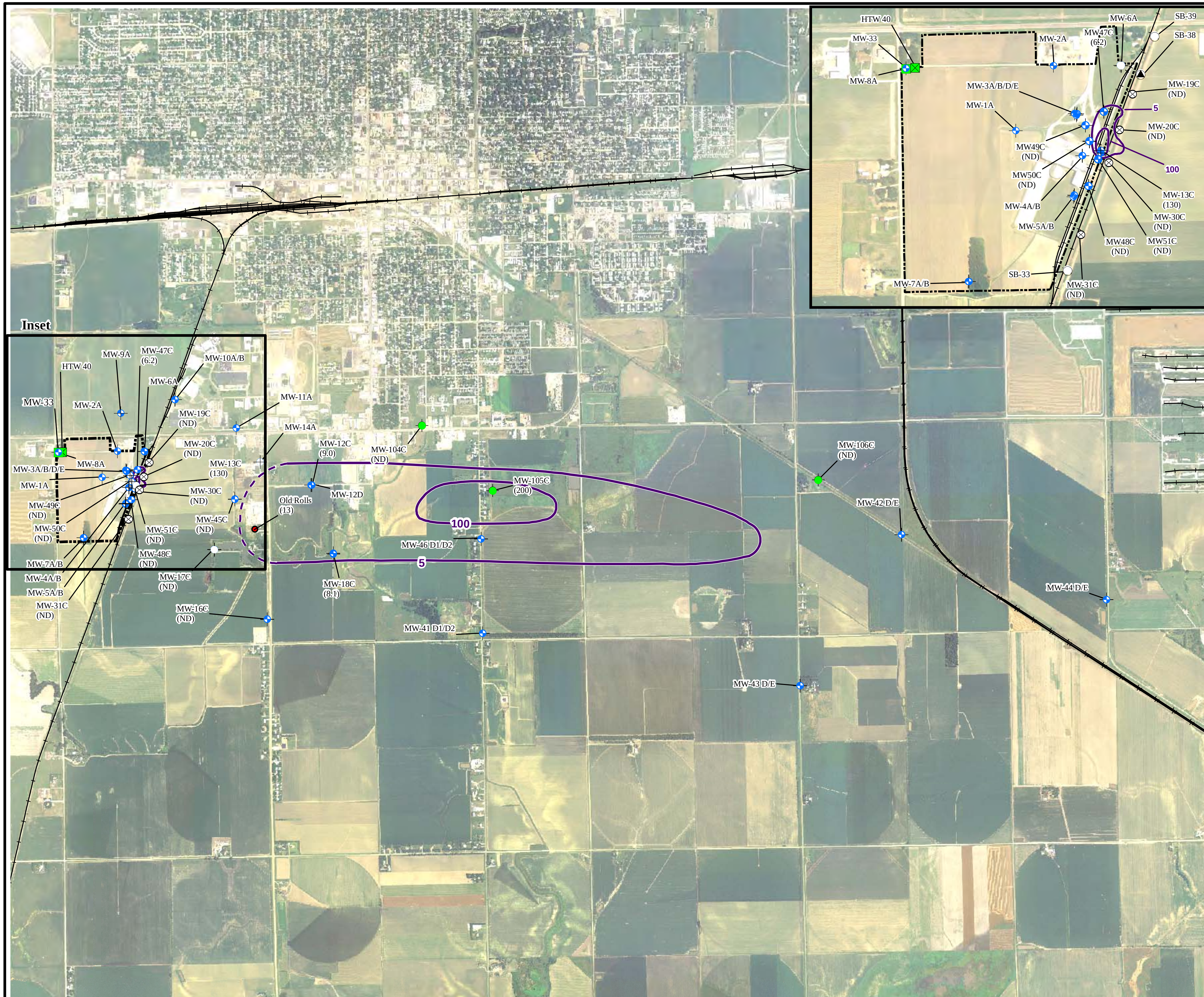
Notes:

(ND) Nondetect

Filename: X:/EPA009/Garvey/GW_Flow_Tech_Memo Carbon_TetChl_UpperAquifer_AB.mxd
Project: EP9034.01.22.02.02
Revised: 06/13/12 ST
Source: ENSR GDB 2008, DNR

HGL HydroGeoLogic, Inc

Figure 3.2
Carbon Tetrachloride in the Medial Aquifer Zone C
September 2011 Sampling



Legend

- Garvey Property Boundary
- Railroad
- Monitoring Well Location
- Multilevel Well
- Hydraulic Conductivity Well
- West Highway 6 & Highway 281 Site Monitoring Well
- (190) Carbon Tetrachloride Concentration in micrograms per liter (µg/L)
- (5) Carbon Tetrachloride Isoconcentration Contour (µg/L) (Dashed Lines are Estimated)
- Domestic / Irrigation Water Wells

Notes:

(ND) Nondetect

0 2,500 5,000
Feet

N

Filename:X:/EPA009/Garvey/GW_Flow_Tech_Memo/Carbon_TetChl_Medial_Aquifer_C.mxd
Project: EP9034.01.22.02.02
Revised: 06/13/12 ST
Source: ENSR GDB 2008, DNR

HGL HydroGeoLogic, Inc

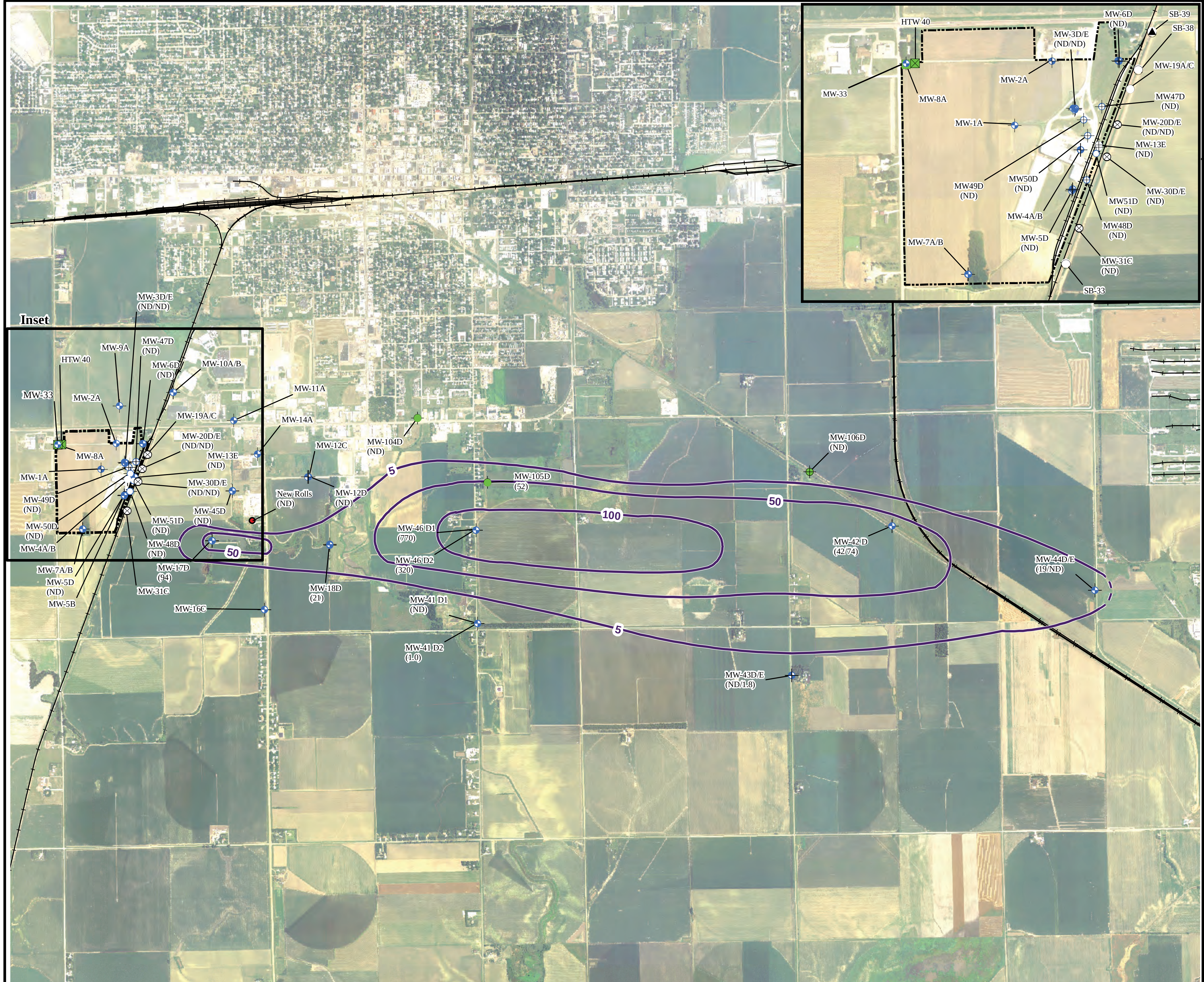


Figure 3.3
Carbon Tetrachloride in the Lower Aquifer Zone D/E September 2011 Sampling

Legend

- Garvey Property Boundary
- Railroad
- Monitoring Well Location
- Multilevel Well
- Hydraulic Conductivity Well
- West Highway 6 & Highway 281 Site Monitoring Well
- (190) Carbon Tetrachloride Concentration in micrograms per liter (µg/L)
- (5) Carbon Tetrachloride Isoconcentration Contour (µg/L) (Dashed Lines are Estimated)
- Domestic / Irrigation Water Wells

Notes:

(ND) Nondetect

0 2,500 5,000
Feet

N

Filename: X:/EPA009/Garvey/GW_Flow_Tech_Memo/Carbon_TetChl_LoweR_Aquifer_D.mxd
Project: EP9034.01.22.02.02
Revised: 06/13/12 ST
Source: ENSR GDB 2008, DNR

HGL HydroGeoLogic, Inc.

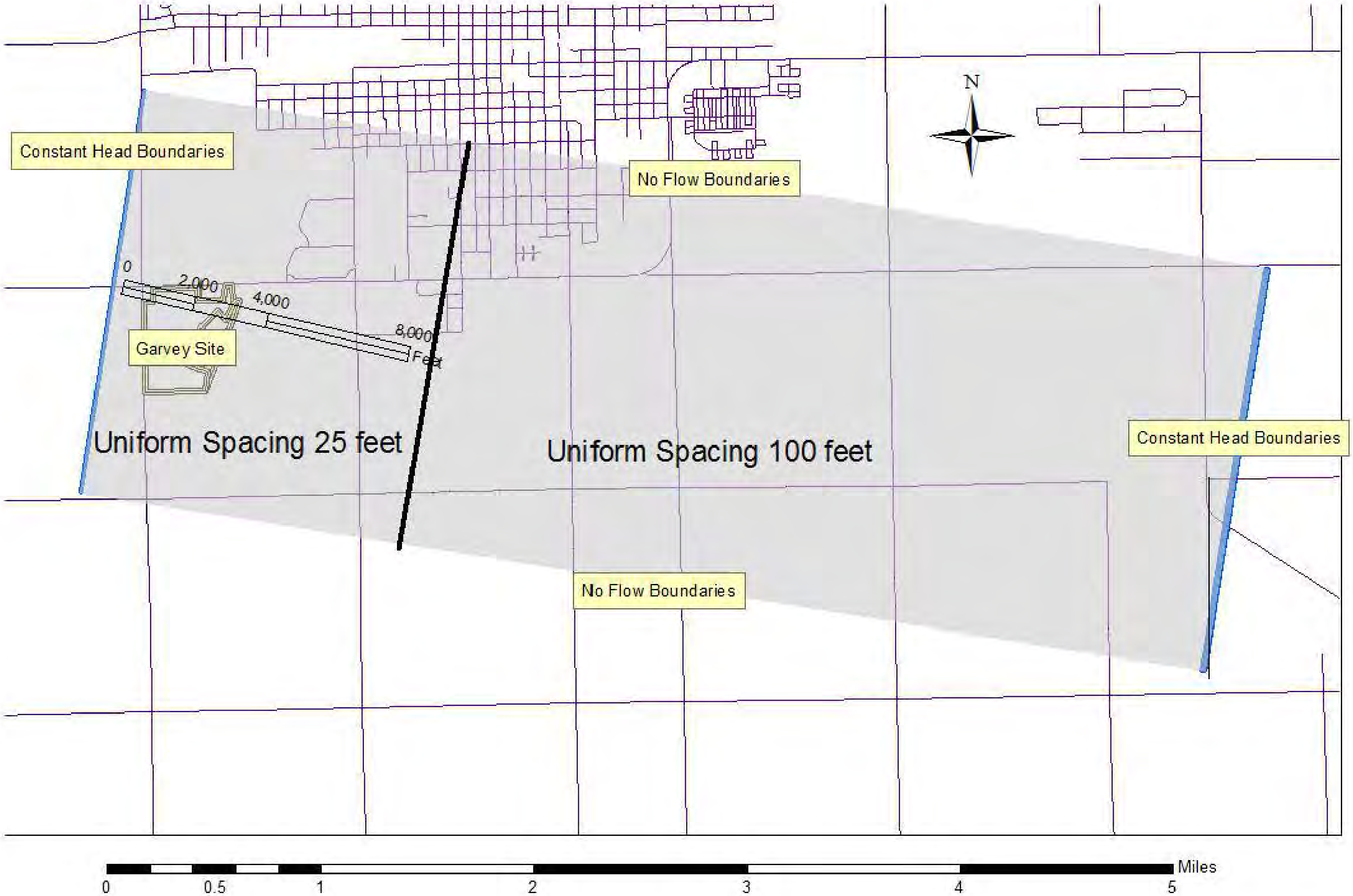


Figure 5.1. Model Domain, Gridding, and Boundaries.

Figure 5.2. Vertical Discretization of Model.

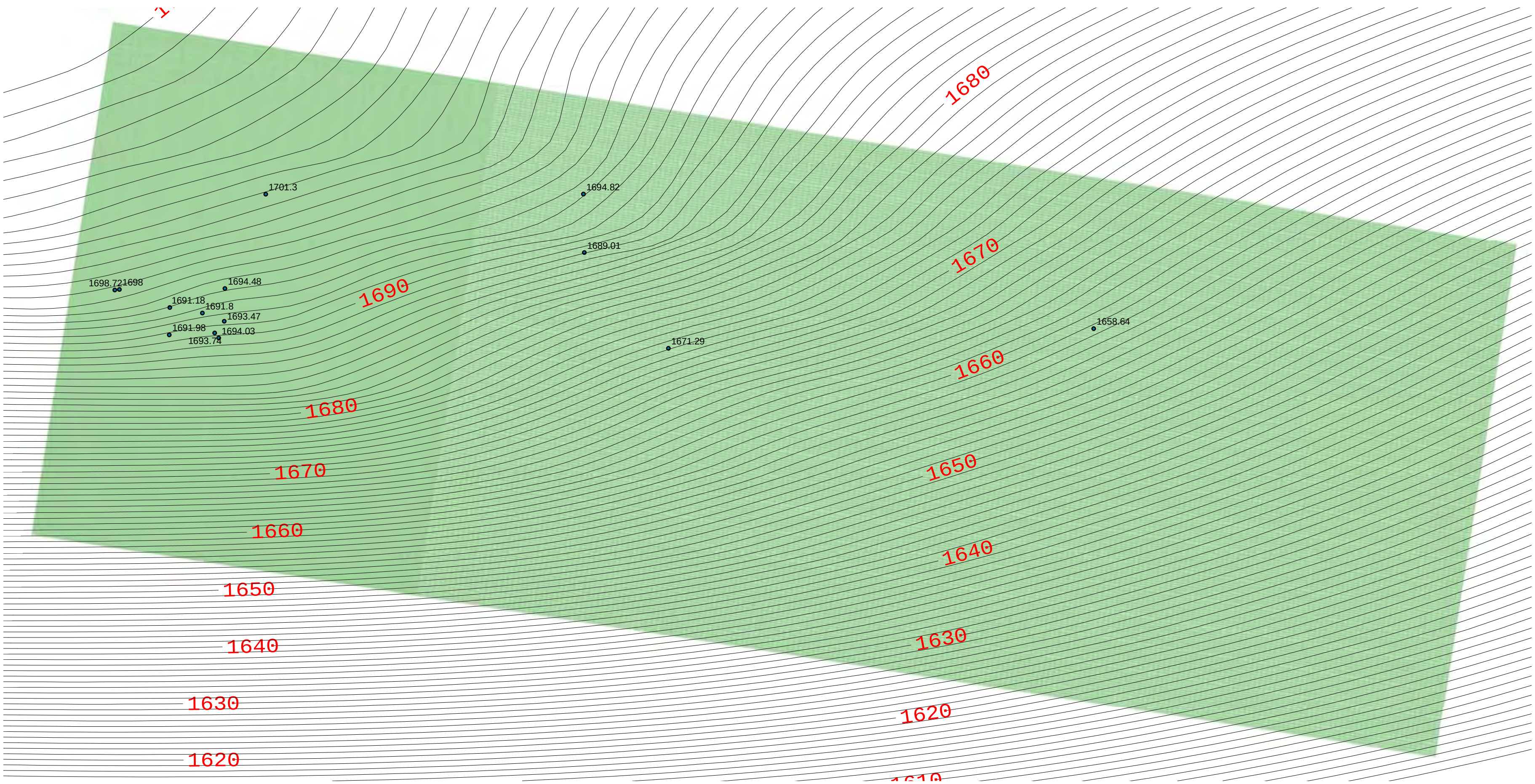


Figure 5.3. Elevation of the Model Base (weathered shale of the Niobrara Formation).

Figure 5.4. Elevation of the Top of the Lower Aquifer.

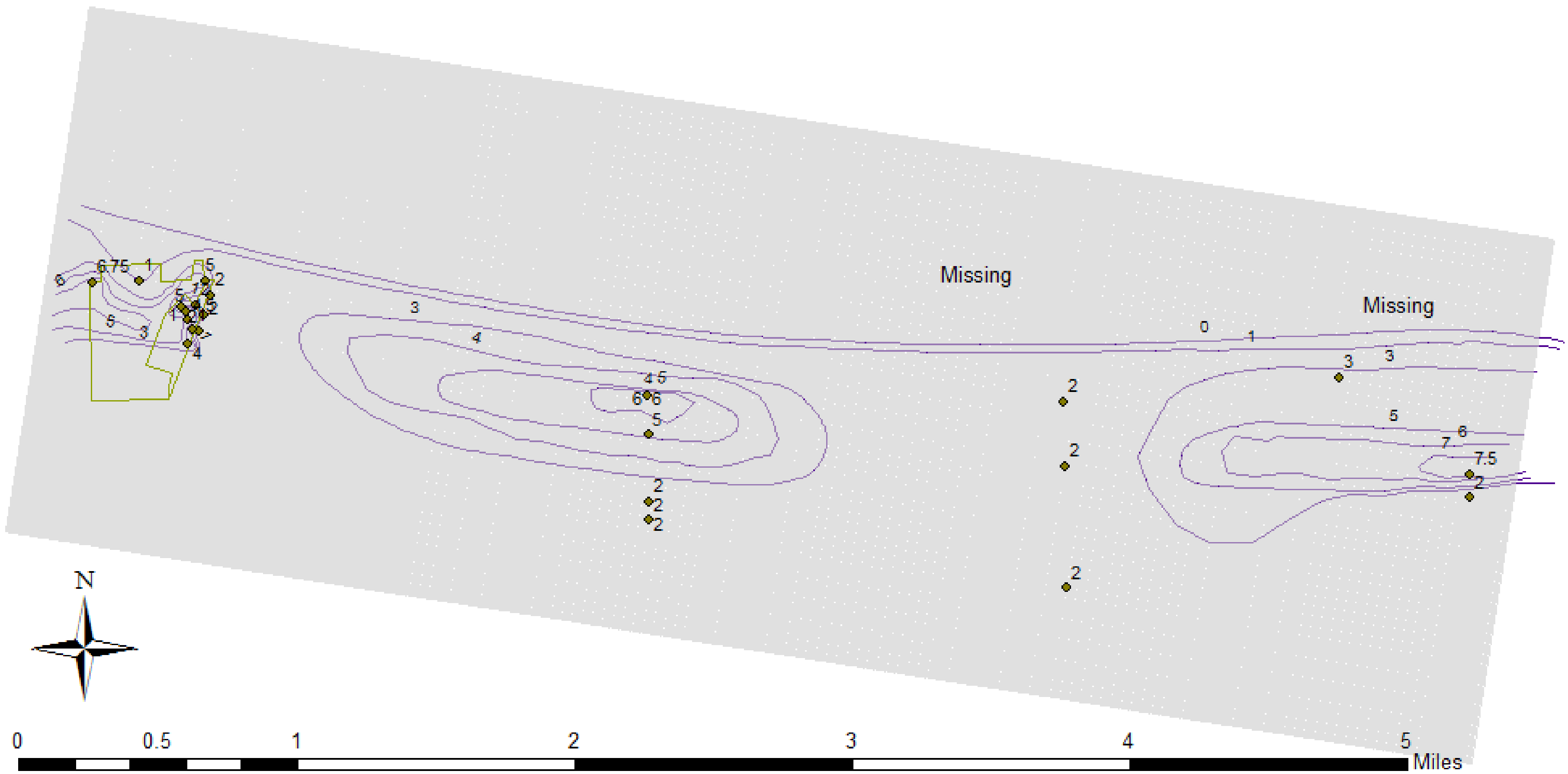


Figure 5.5. Isopach Map of Lower Confining Unit (model Layer 4).

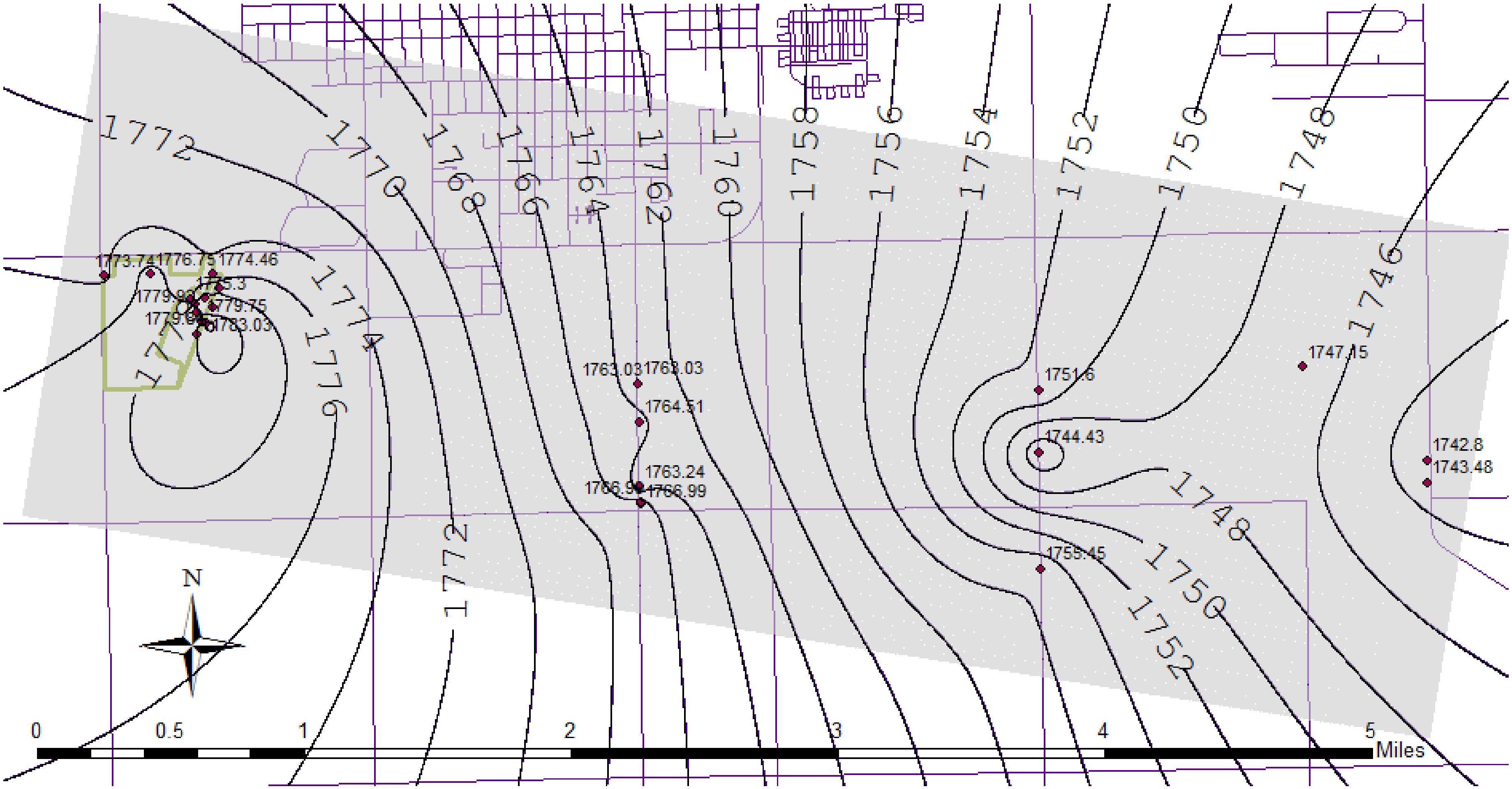


Figure 5.6. Elevation of the Base of the Medial Aquifer.

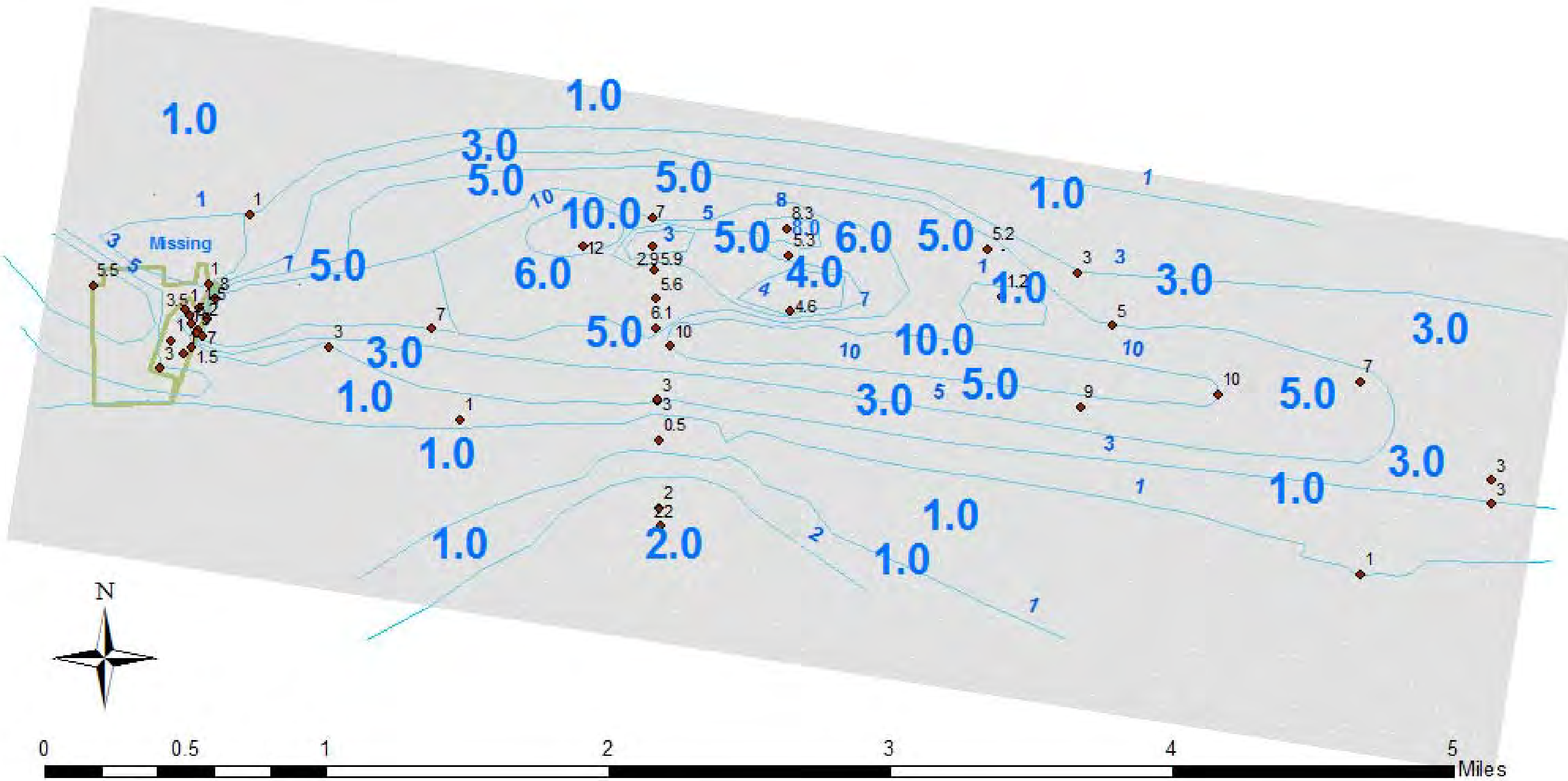


Figure 5.7. Isopach of Upper Aquitard (model layer 2).

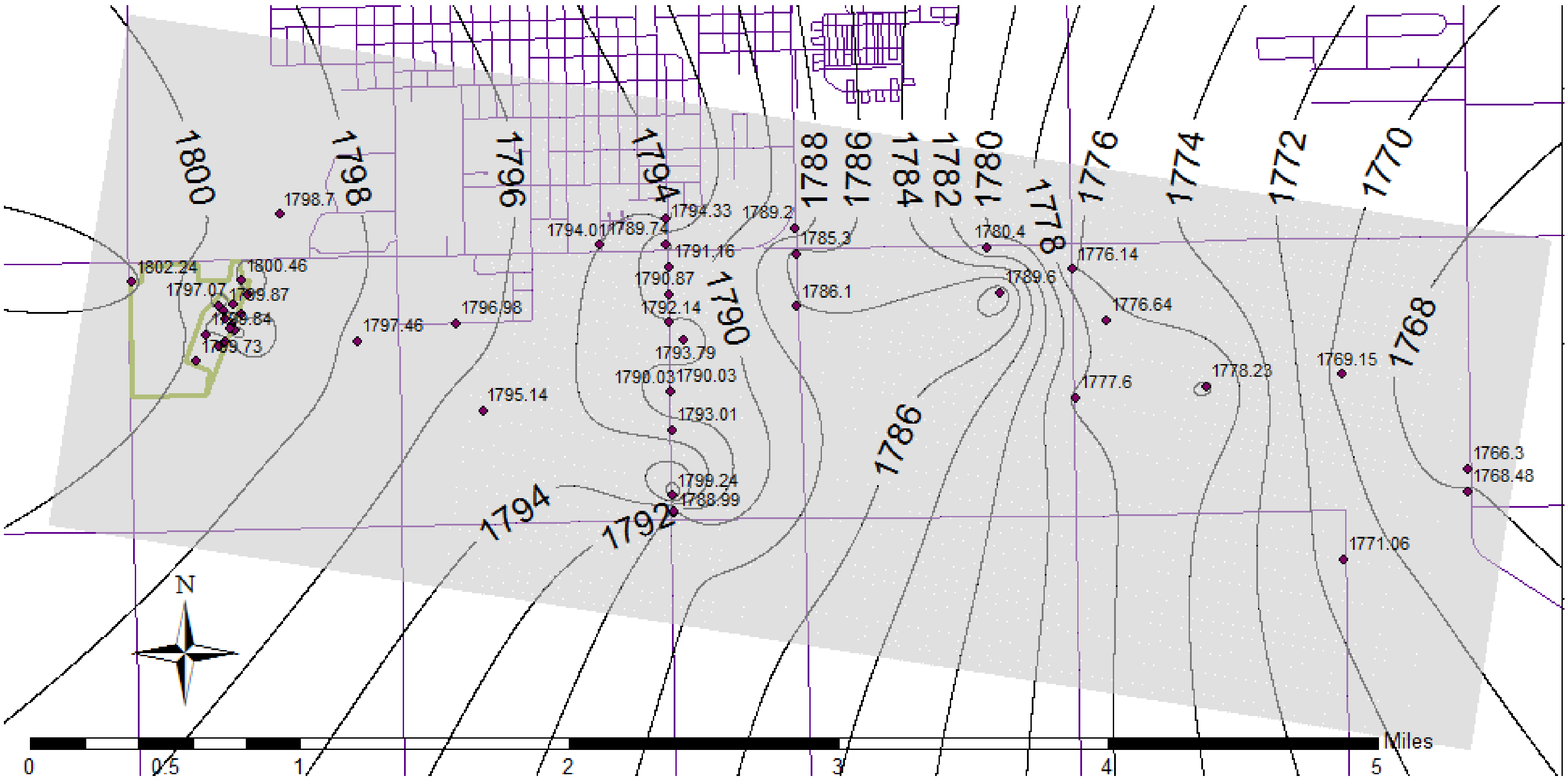


Figure 5.8. Elevation of the Base of the Upper Aquifer.

Figure 5.9. Location of Recovery Wells in the Shallow Aquifer.

Figure 5.10. Location of Recovery Wells in the Medial Aquifer.

Figure 5.11. Location of Injection and Municipal Wells in the Lower Aquifer.

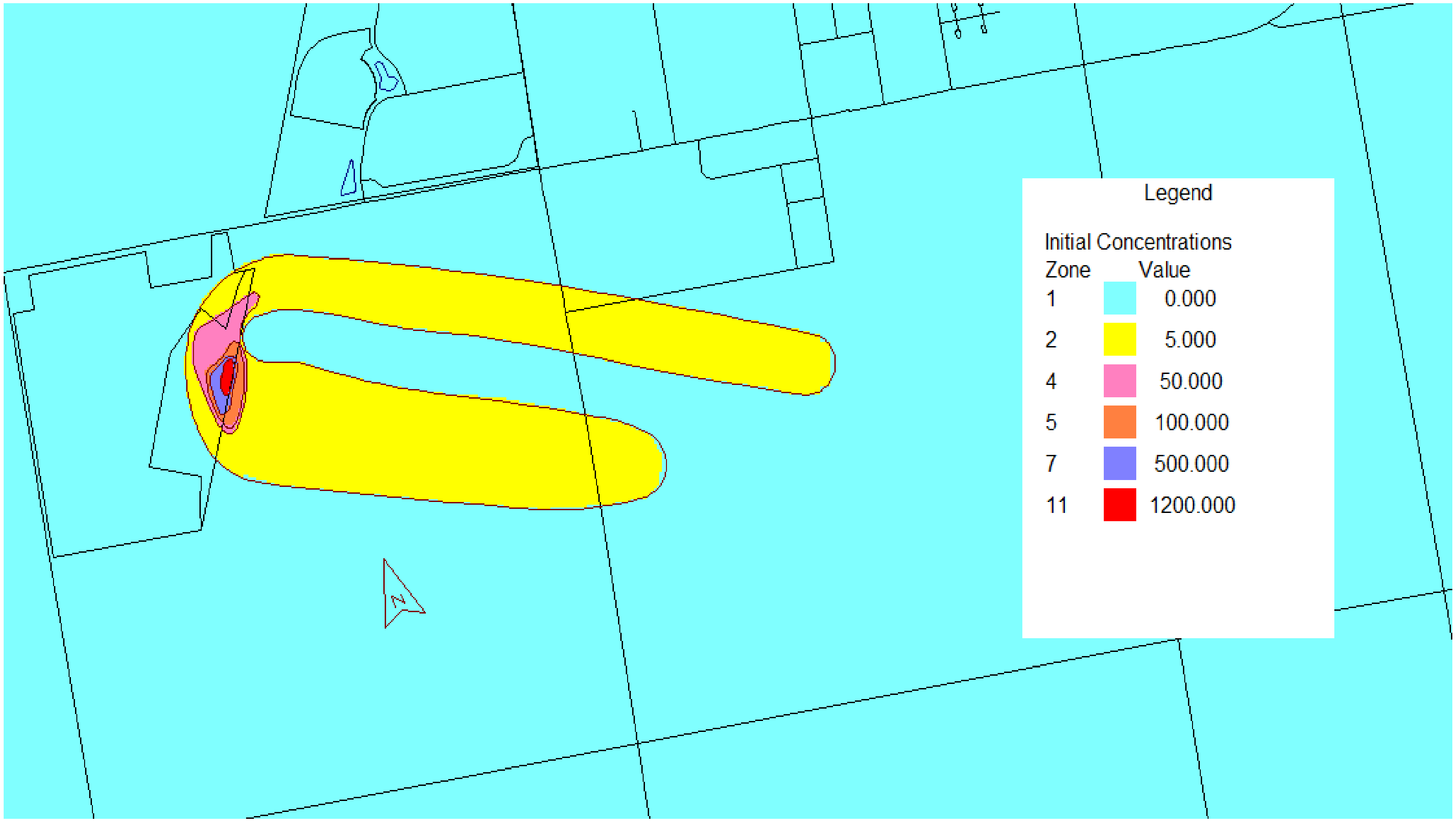


Figure 5.12. Initial Concentrations of Carbon Tetrachloride in the Shallow Aquifer.

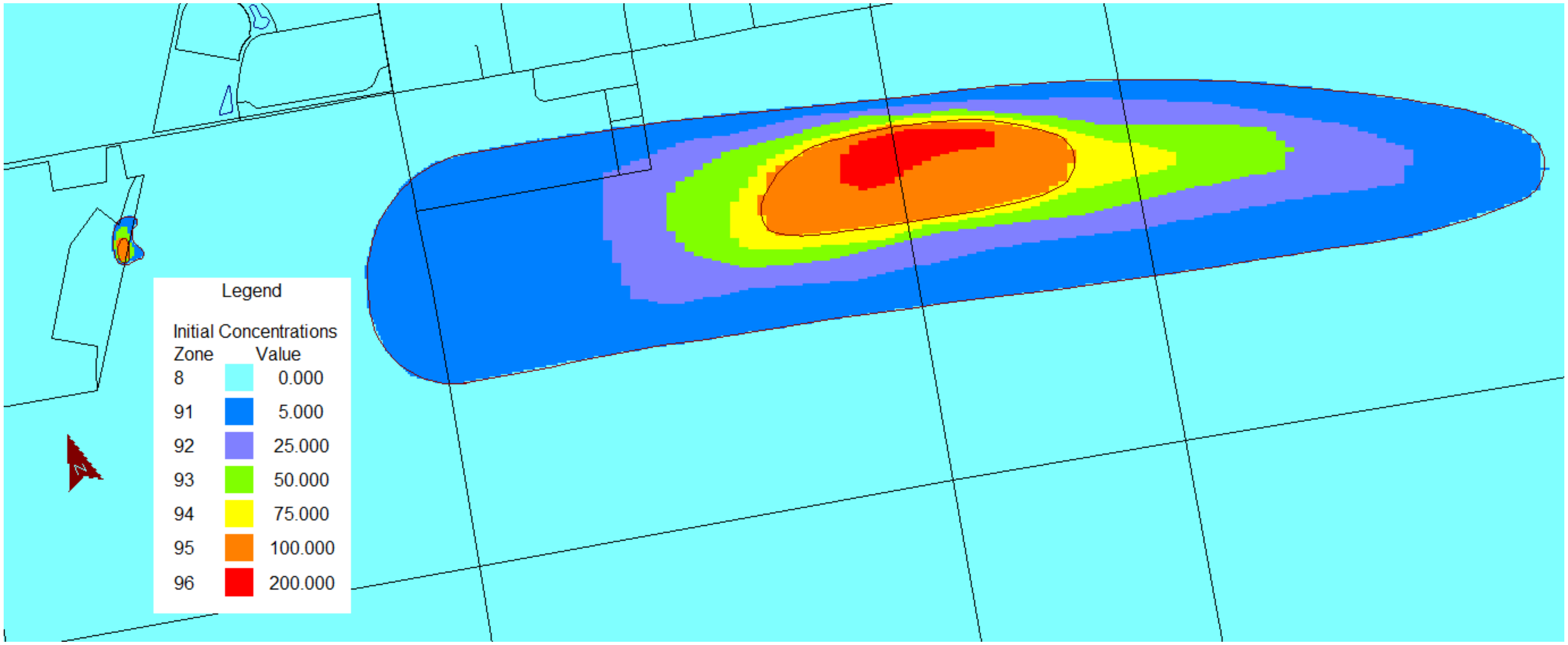


Figure 5.13. Initial Concentrations of Carbon Tetrachloride in the Medial Aquifer.

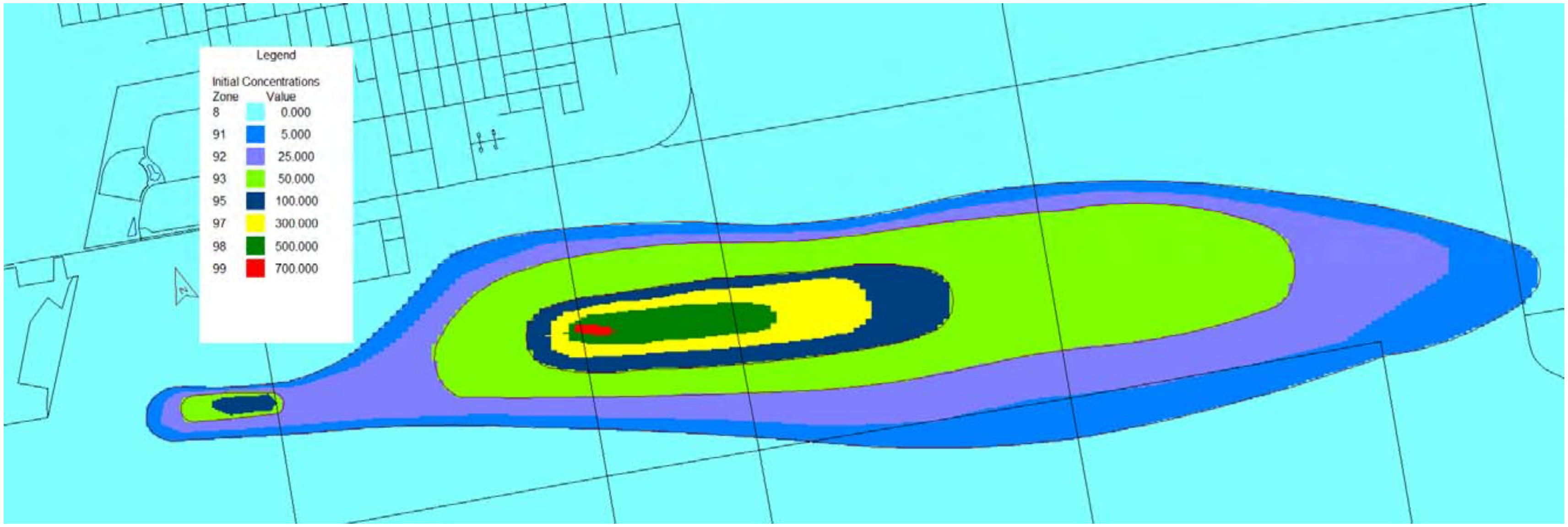


Figure 5.14. Initial Concentrations of Carbon Tetrachloride in the Lower Aquifer.

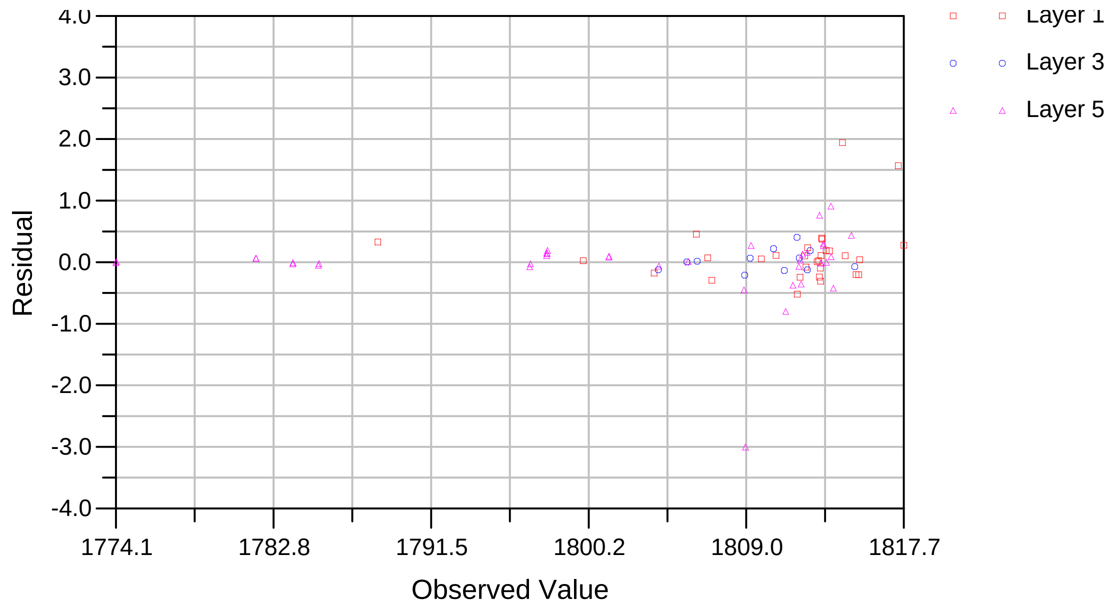


Figure 6.1. Error Residuals Versus Measured Water Levels.

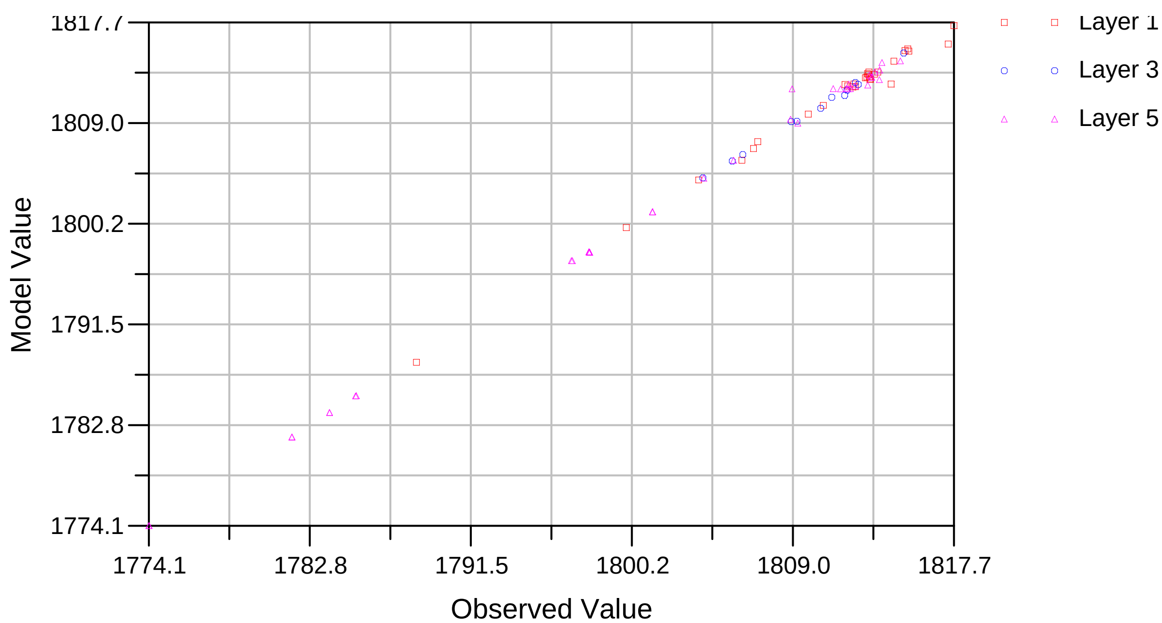


Figure 6.2. Measured Water Levels Versus Predicted Water Levels.

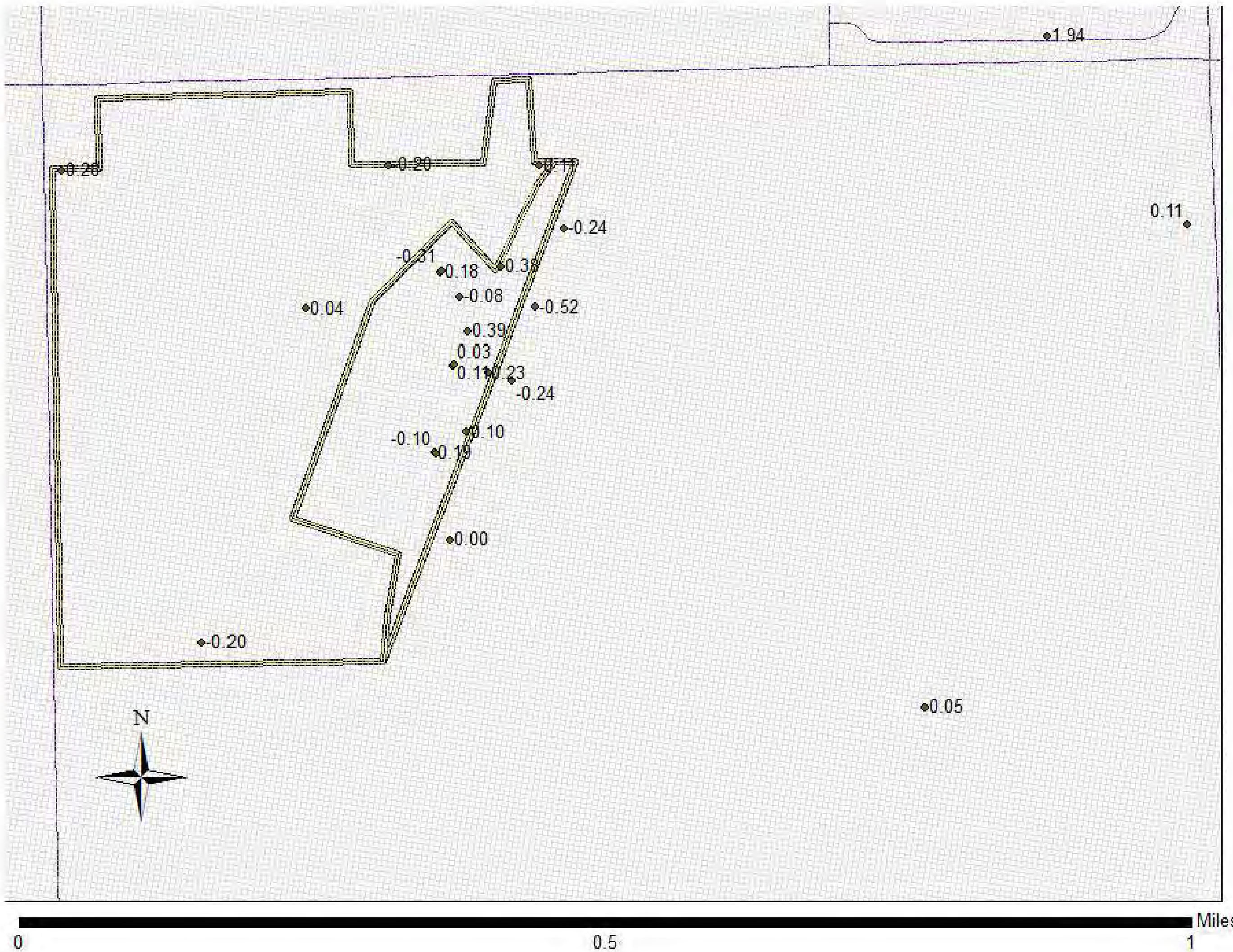


Figure 6.3. Error Residuals for the Shallow Aquifer in the vicinity of the Garvey Elevator Site.

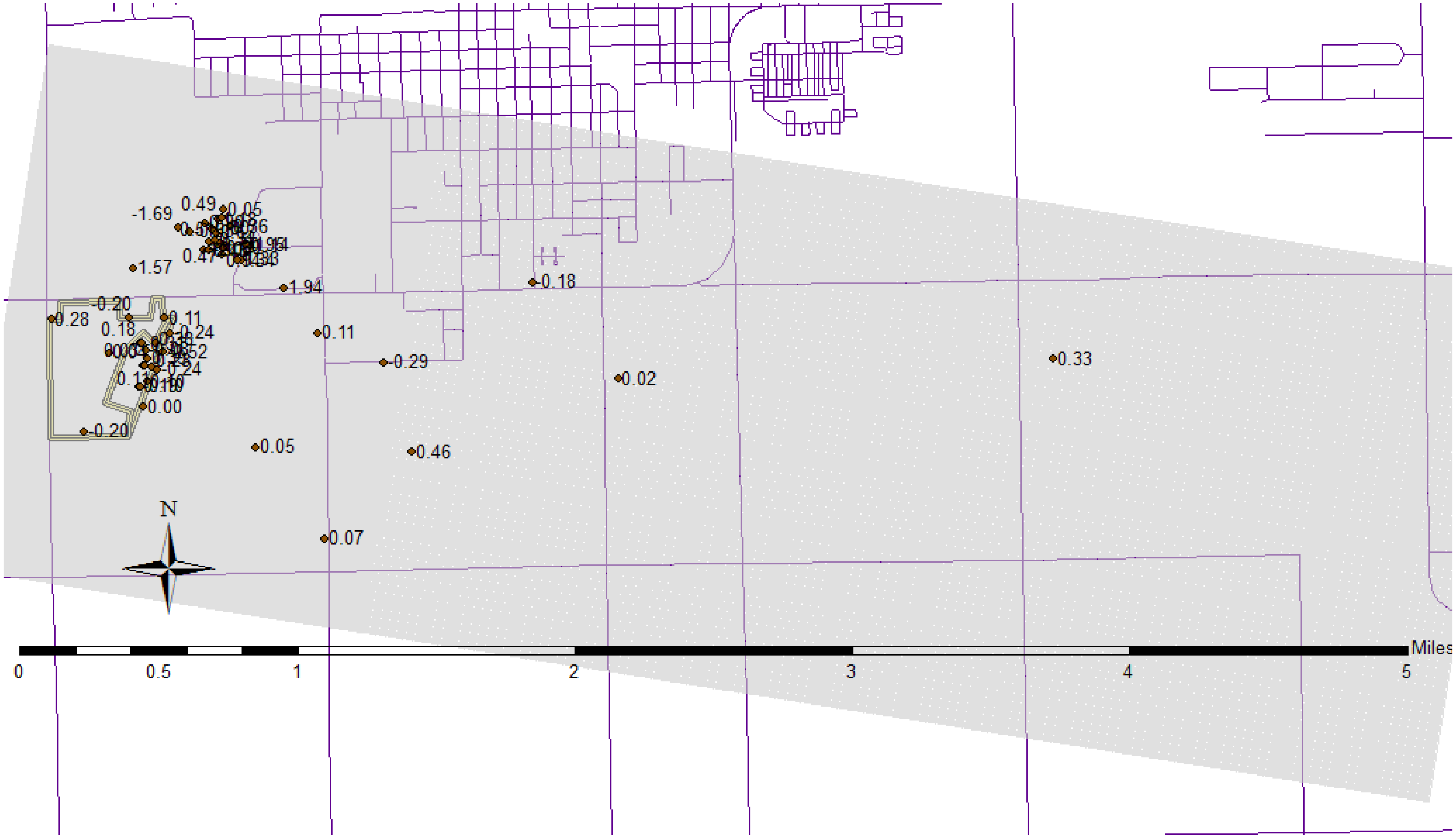


Figure 6.4. Error Residuals for the Shallow Aquifer Over the Model Domain.

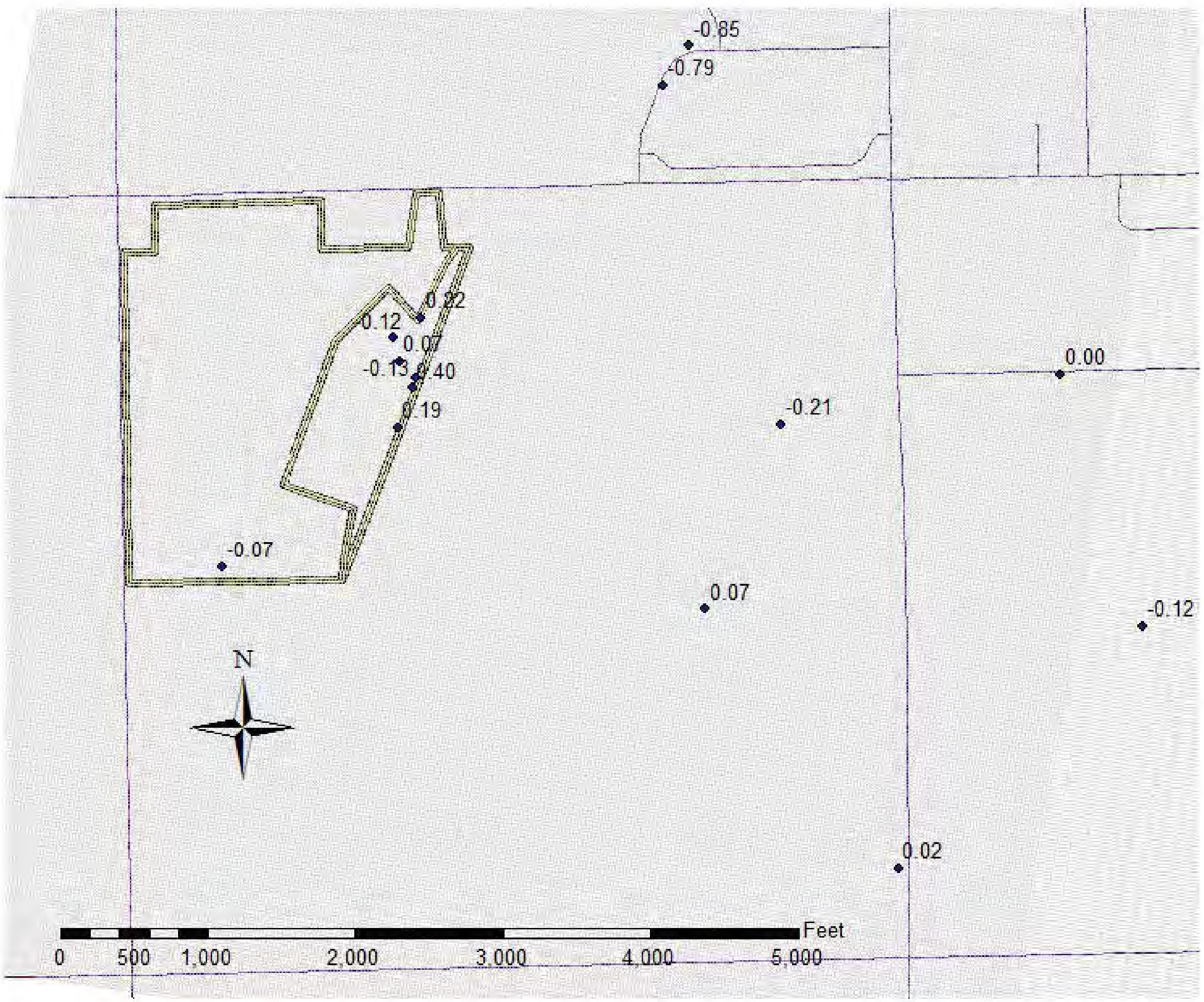


Figure 6.5. Error Residuals for the Medial Aquifer Over the Model Domain.

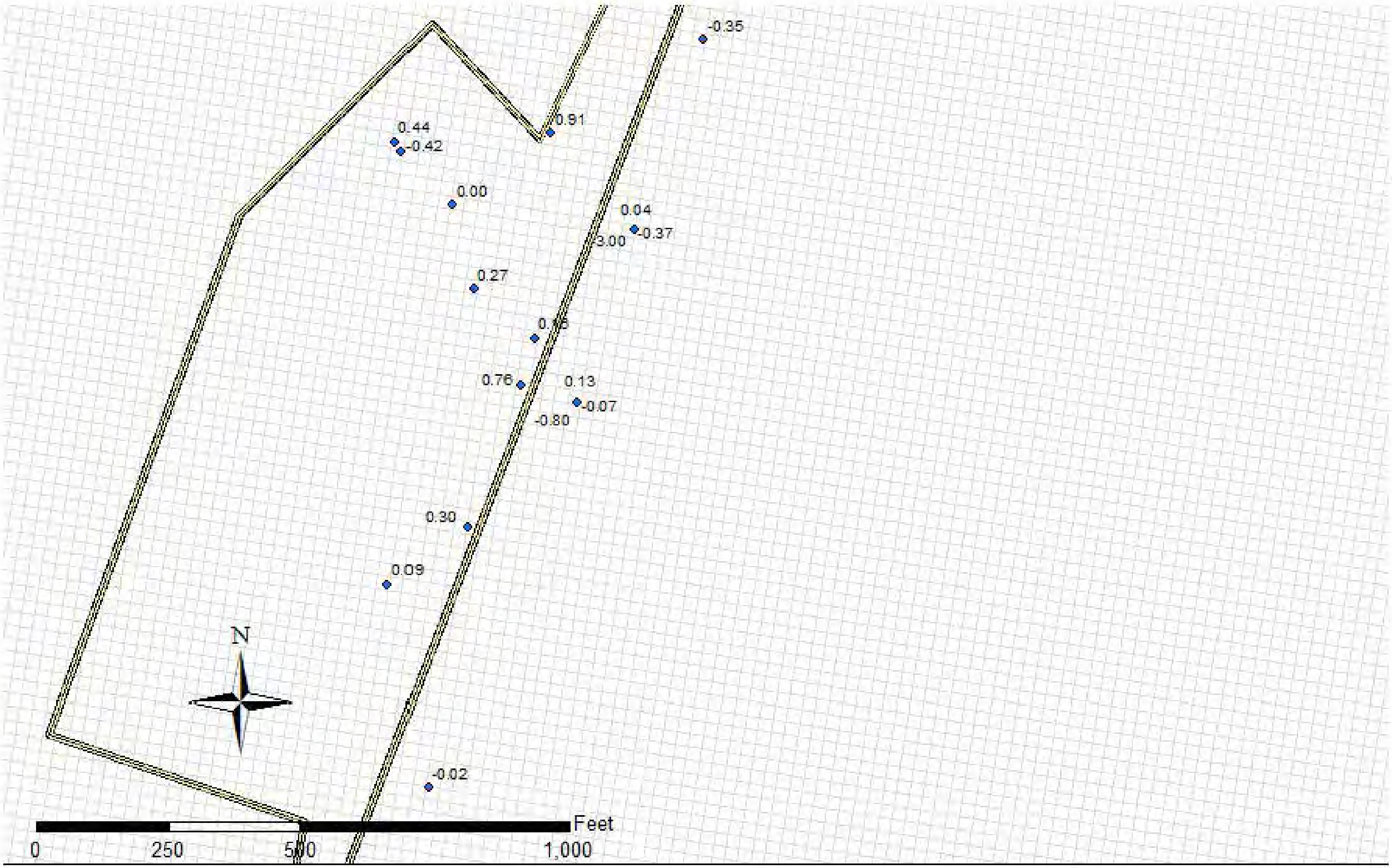


Figure 6.6. Error Residuals for the Lower Aquifer in the Vicinity of the Garvey Elevator Site.

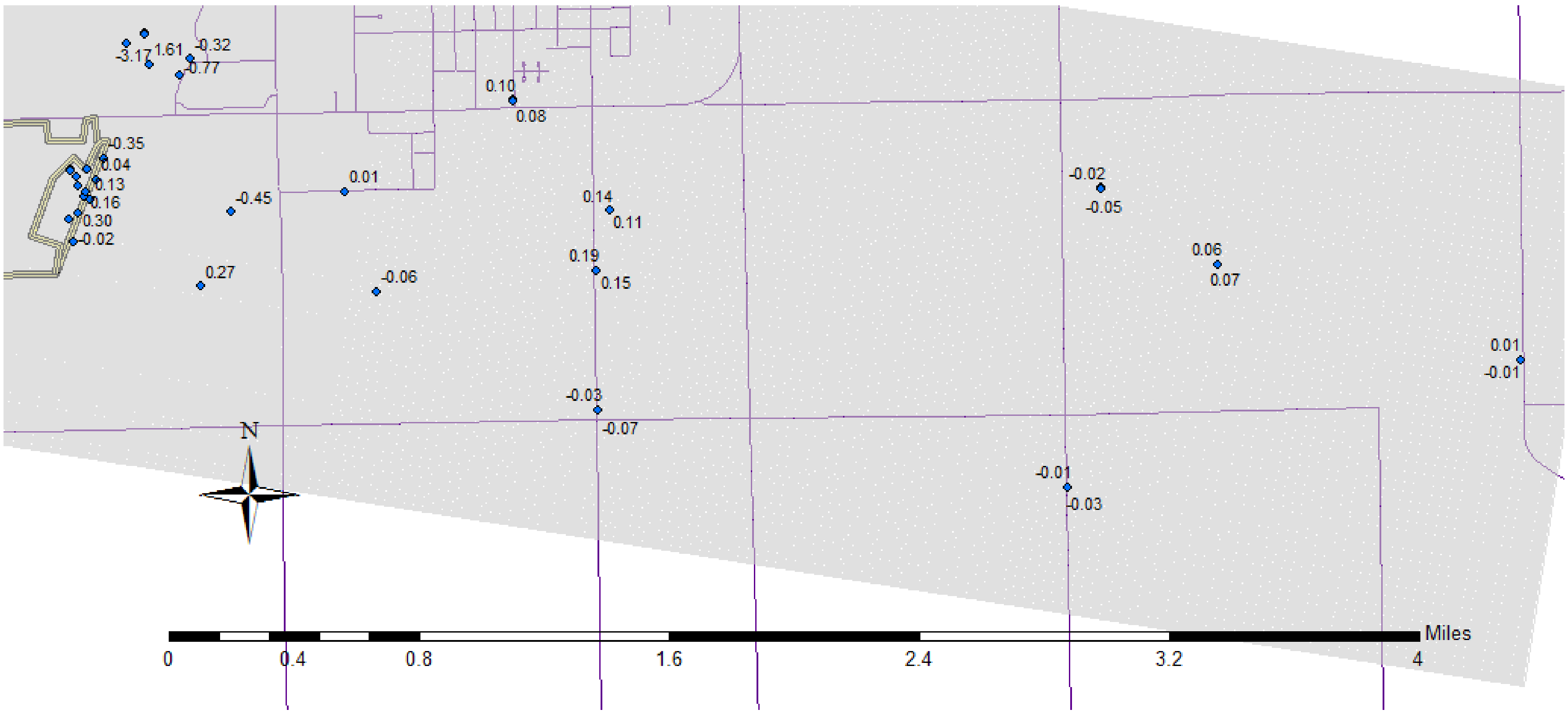


Figure 6.7. Error Residuals for the Lower Aquifer in the Entire Model Domain.

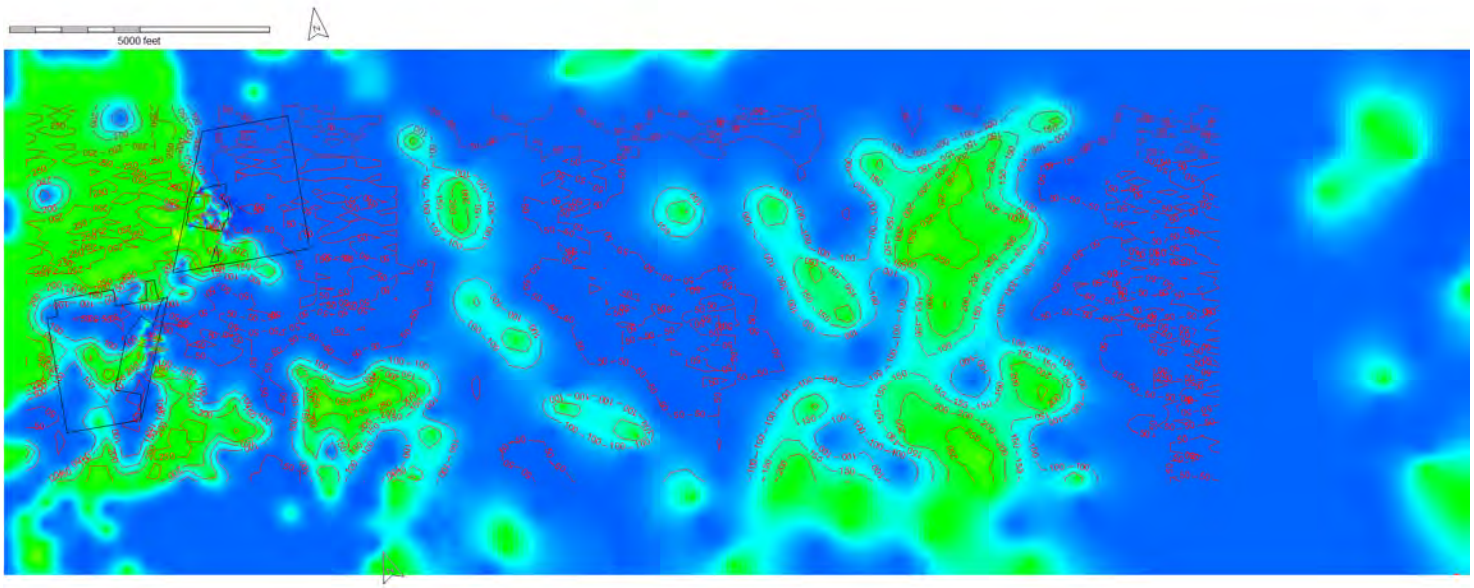


Figure 6.8. Calibrated Hydraulic Conductivities of the Shallow Aquifer (ft/d) (model layer 1).

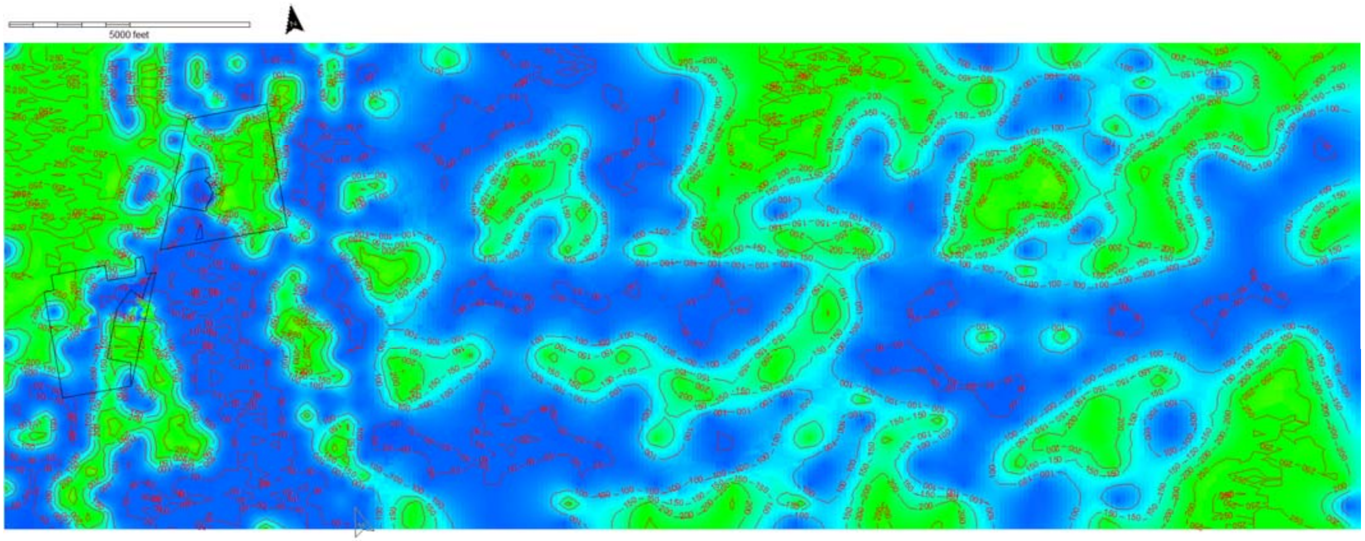


Figure 6.9. Calibrated Hydraulic Conductivities of the Medial Aquifer (ft/d) (model layer 3).

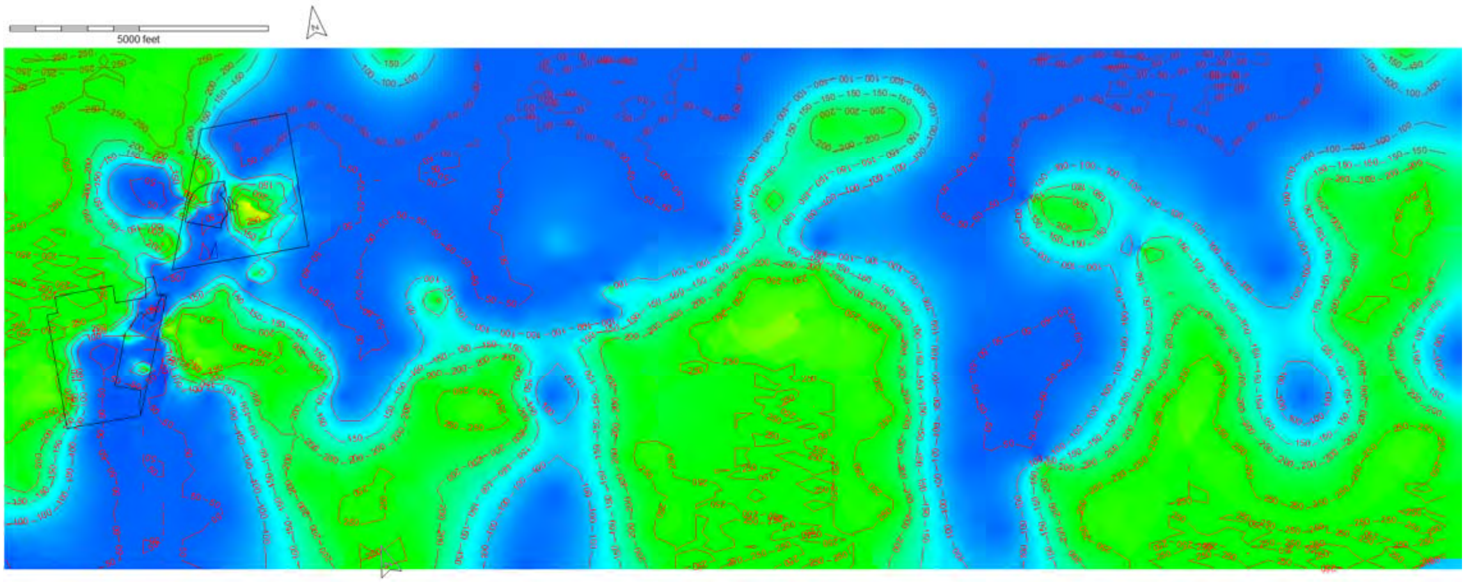


Figure 6.10. Calibrated Hydraulic Conductivities of the Lower Aquifer (ft/d) (model layer 5).

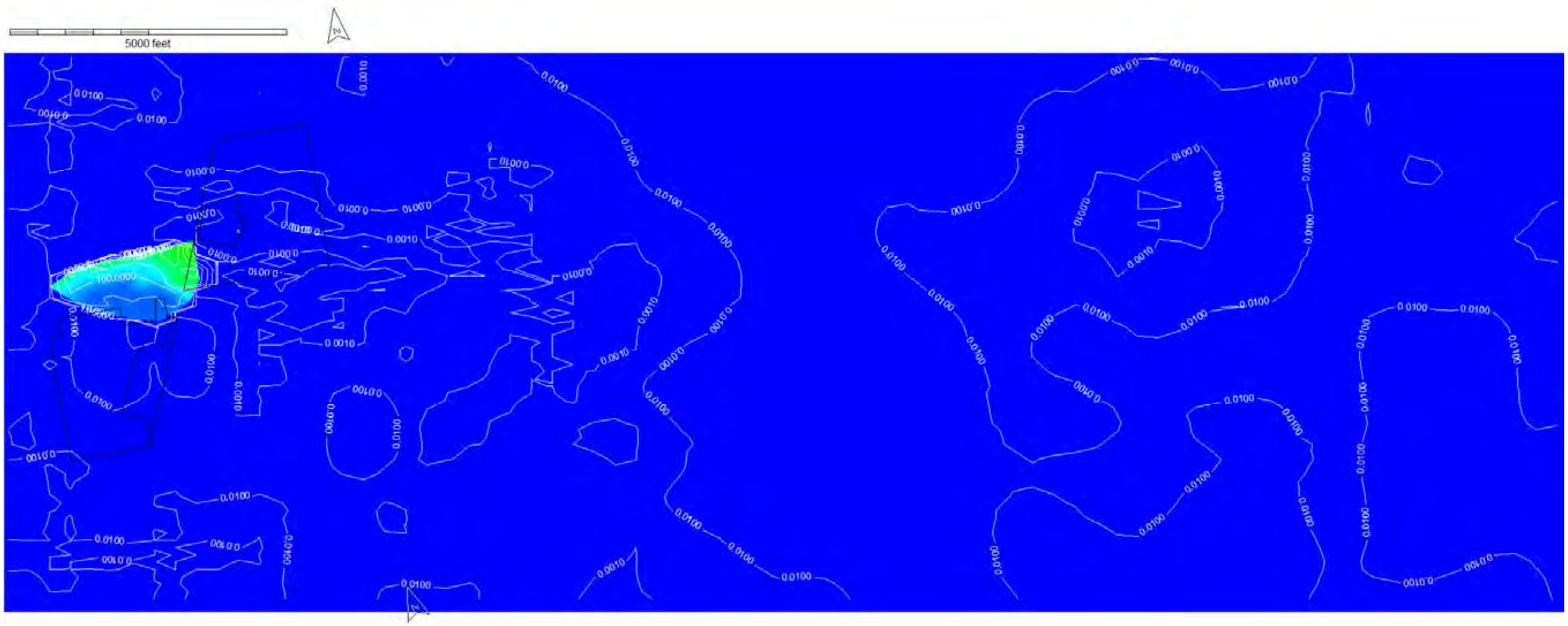


Figure 6.11. Calibrated Hydraulic Conductivities of the Upper Aquitard (ft/d) (model layer 2).

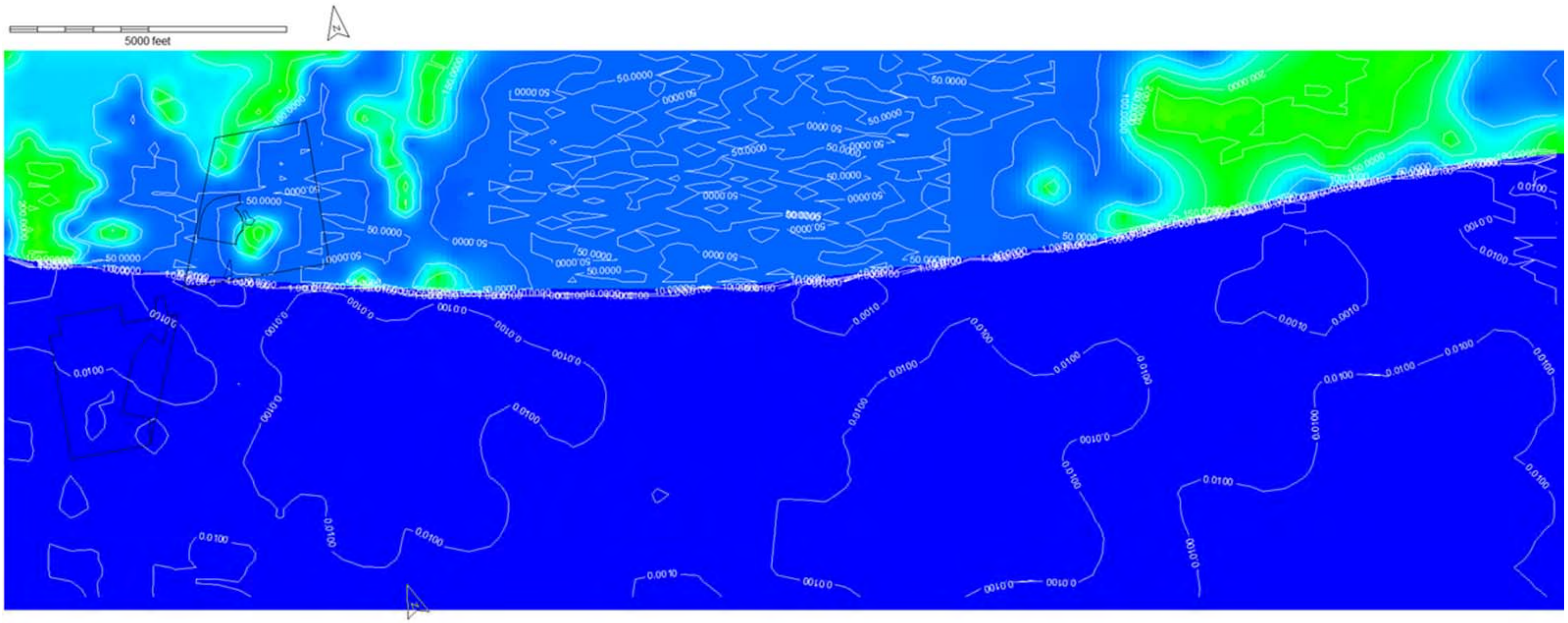


Figure 6.12. Calibrated Hydraulic Conductivities of the Lower Aquitard (ft/d) (model layer 4).

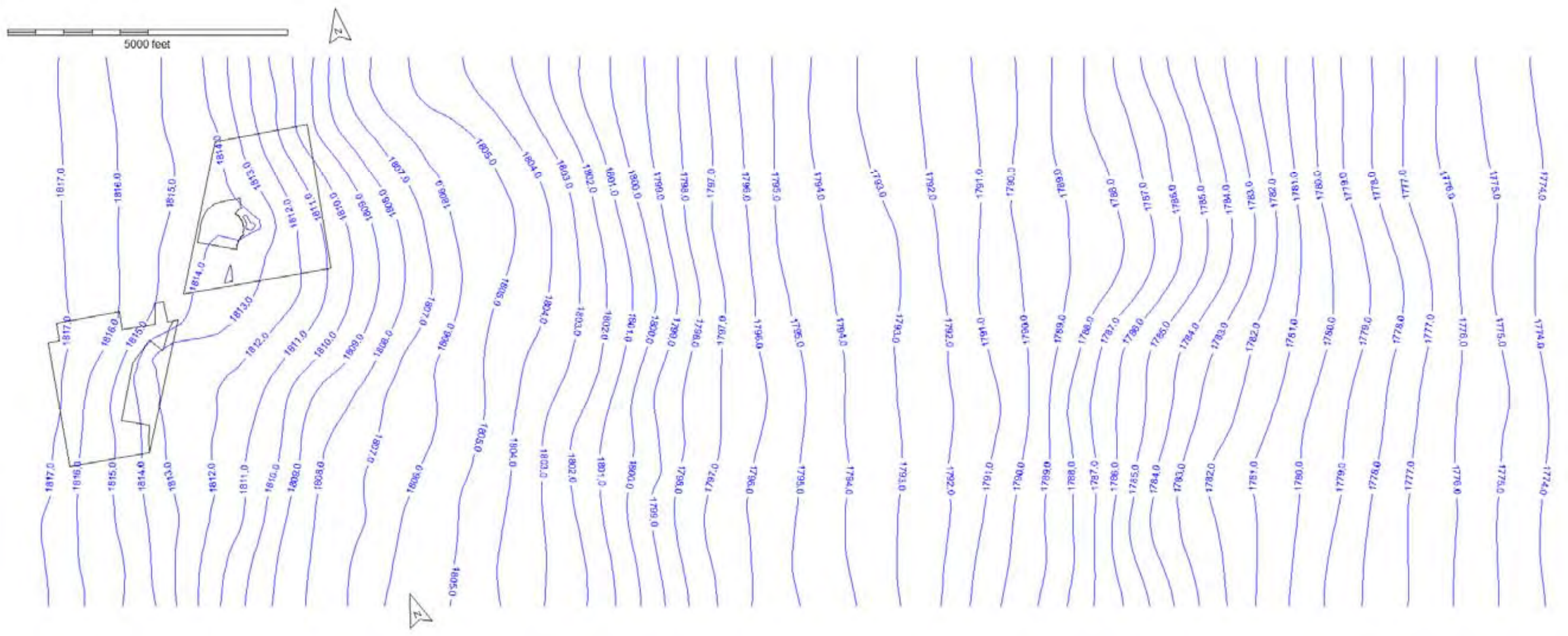


Figure 6.13. Calibrated Potentiometric Surface of the Shallow Aquifer (model layer 1).

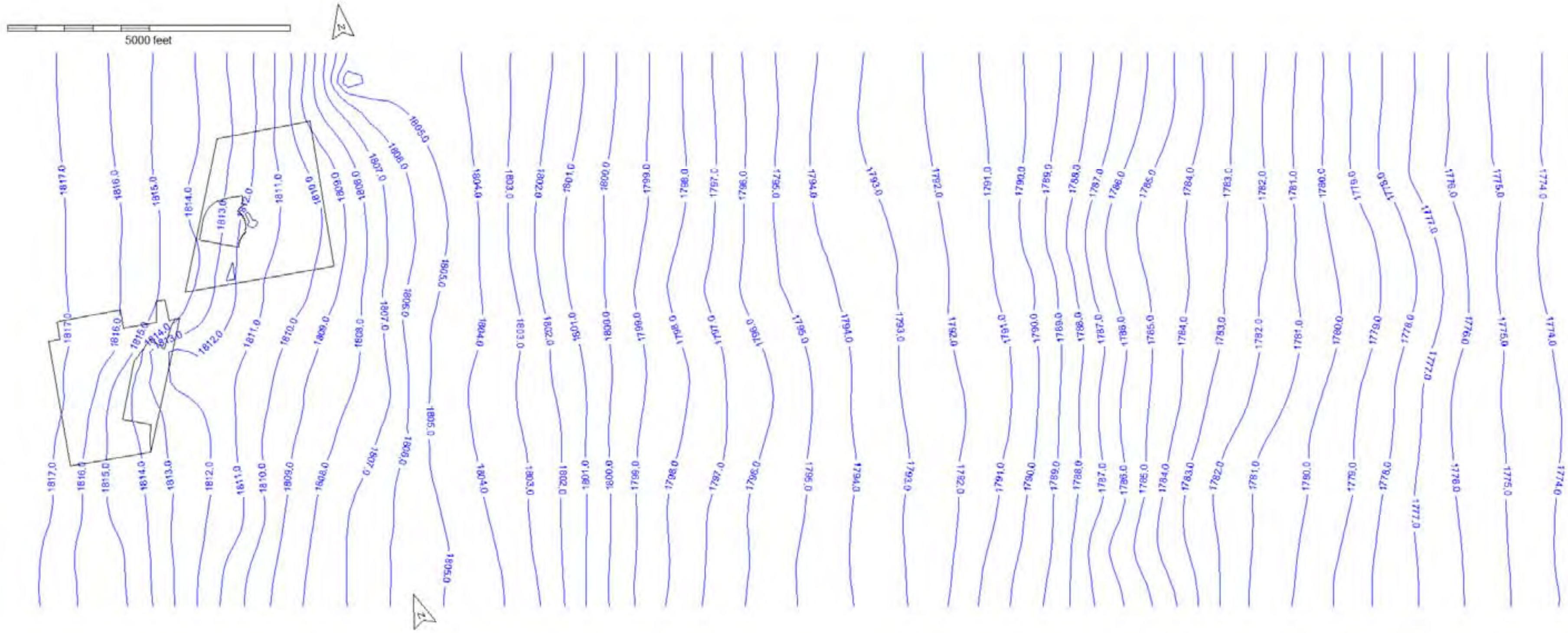


Figure 6.14. Calibrated Potentiometric Surface of the Medial Aquifer (model layer 3).

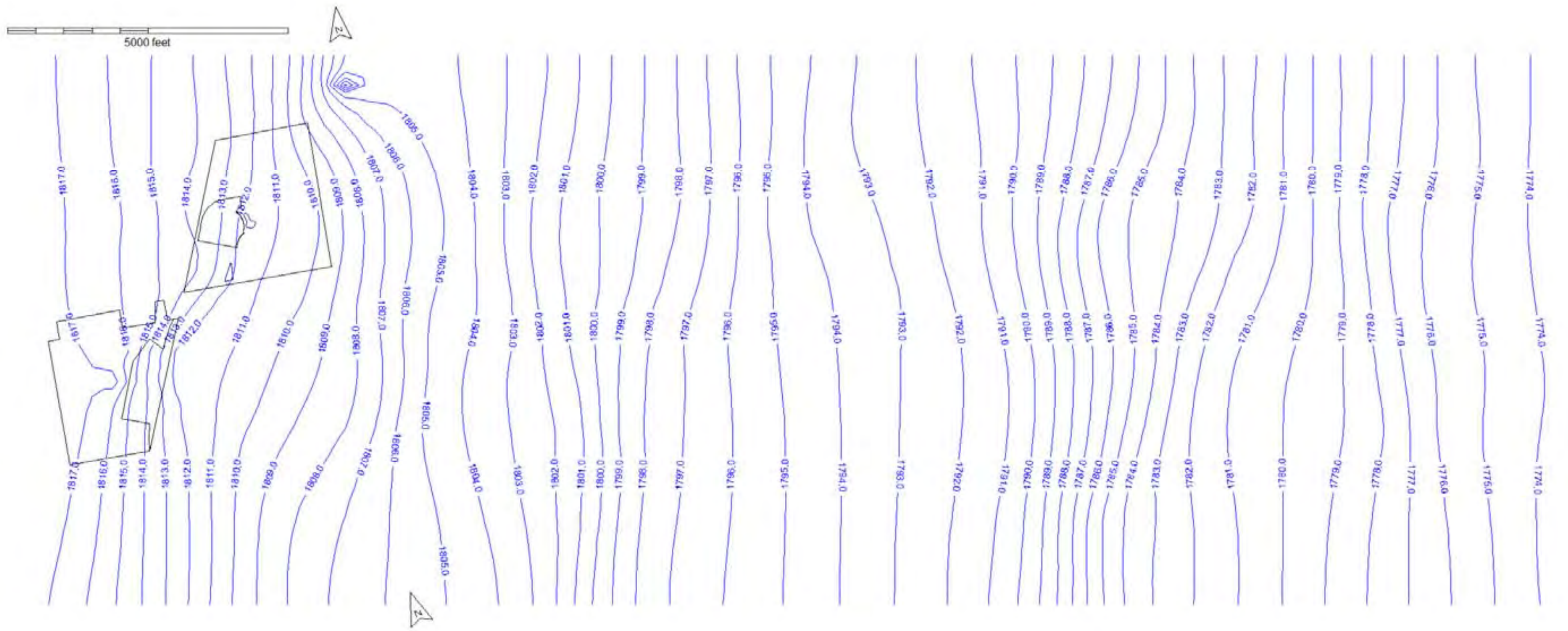


Figure 6.15. Calibrated Potentiometric Surface of the Lower Aquifer (model layer 5).

Figure 6.16. Particle Tracking Analysis to Estimate Travel Time.

Figure 7.1. Initial Concentrations for Alternative SG3.

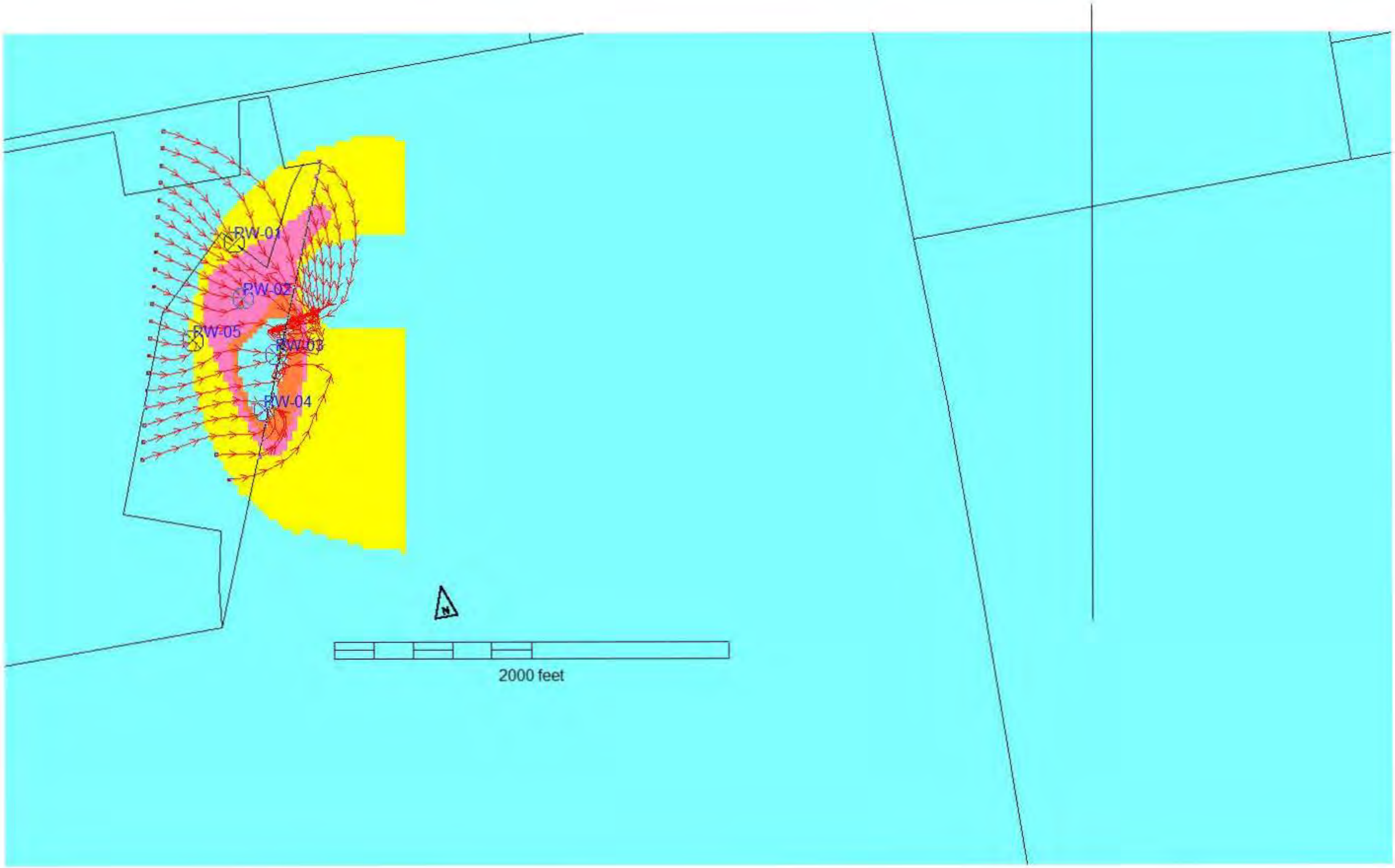


Figure 7.2. Capture Zone Analysis in the Shallow Aquifer for Alternative SG3.

Figure 7.3. Capture Zone Analysis in the Medial Aquifer for Alternative SG3.

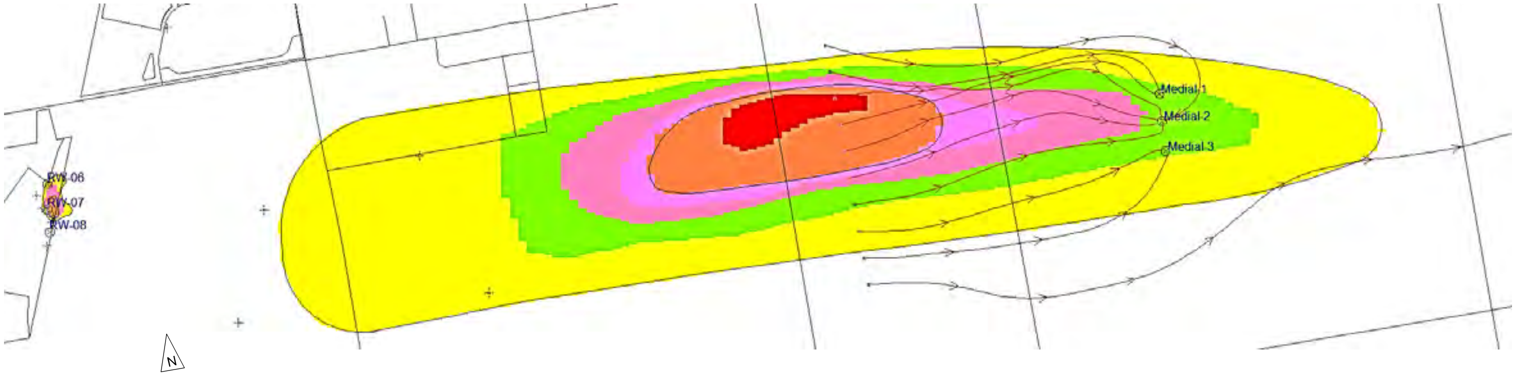


Figure 7.4. Alternative G2-Proposed Recovery Wells Medial Aquifer.

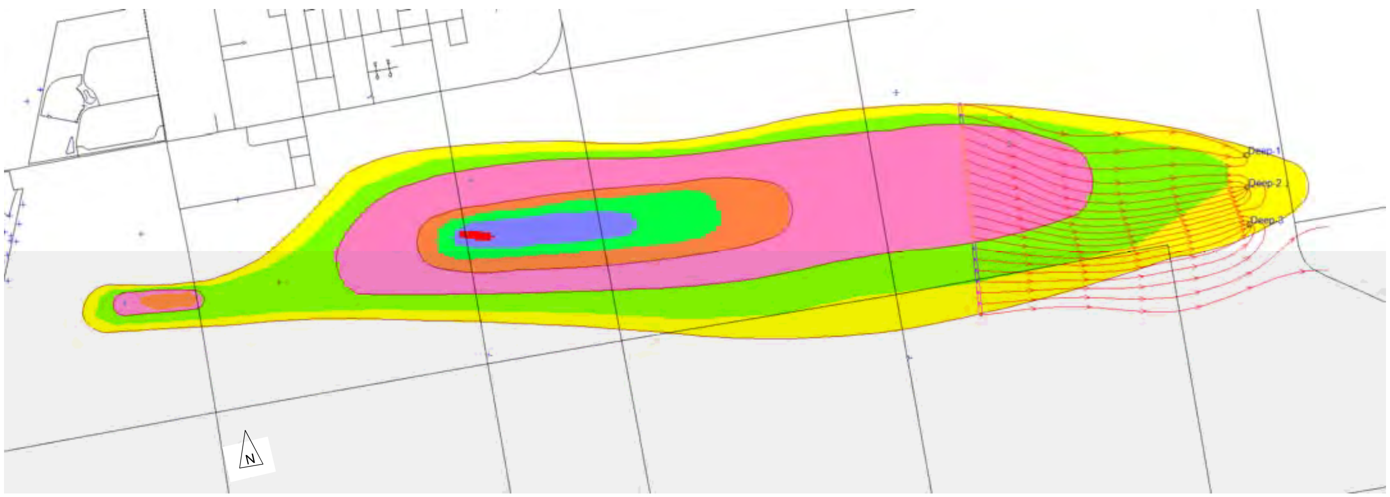
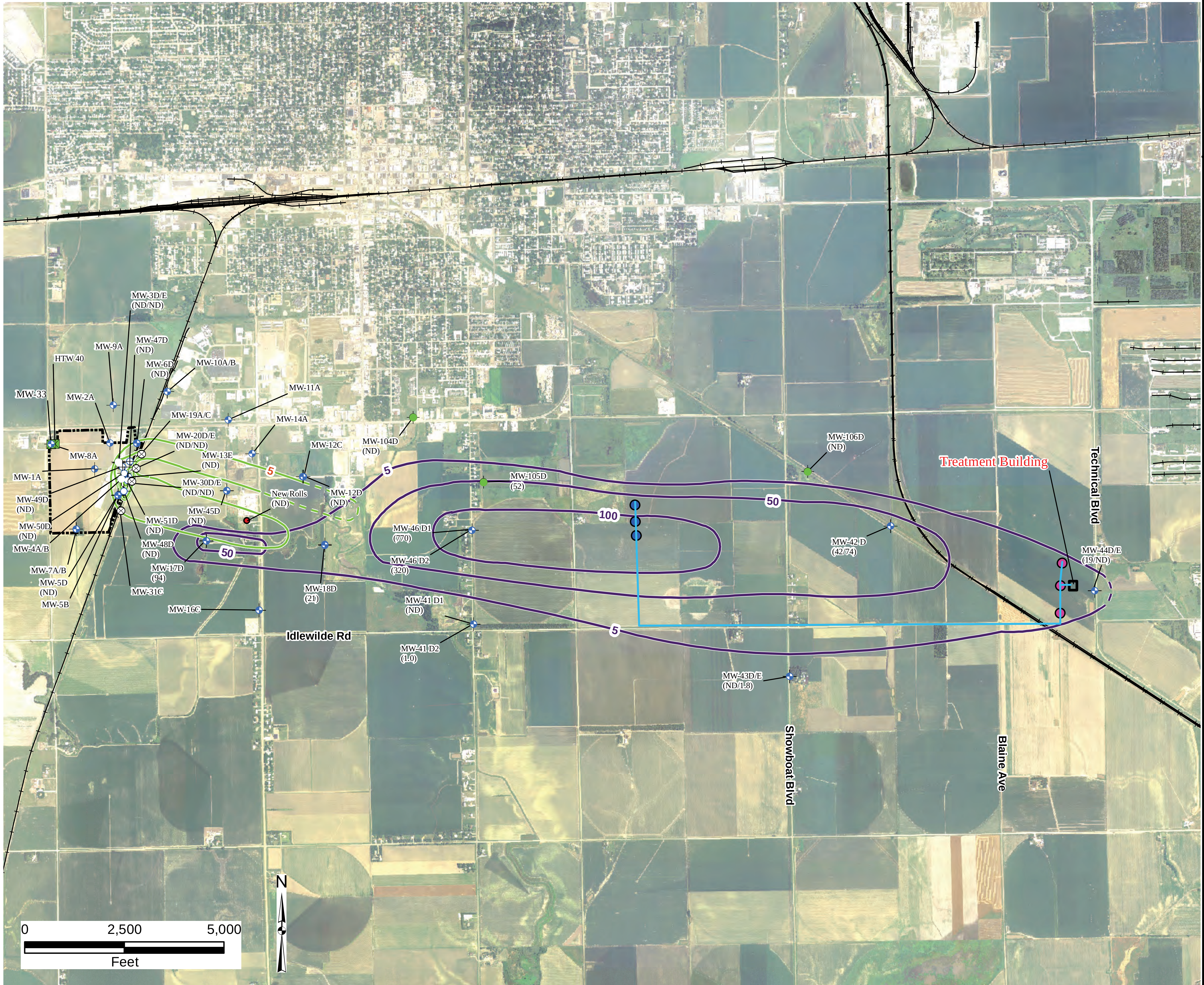


Figure 7.5. Alternative G2- Proposed Recovery Wells Lower Aquifer.

Figure 7.6
Preliminary Locations for Leading Edge Recovery Wells and Groundwater Treatment Building-Alternative G2



Legend

Garvey Property Boundary

Railroad

Monitoring Well Location

Multilevel Well

Hydraulic Conductivity Well

West Highway 6 & Highway 281 Site Monitoring Well

(190) Carbon Tetrachloride Concentration in micrograms per liter (µg/L)

(5) Carbon Tetrachloride Isoconcentration Contour (Lower Aquifer) (µg/L) (Dashed Lines are Estimated)

Domestic / Irrigation Water Wells

(5) Carbon Tetrachloride Isoconcentration Contour (Upper Aquifer) (µg/L) (Dashed Lines are Estimated)

Recovery Wells (Medial)

Recovery Wells (Deep)

Recovery Well Piping

Treatment Building

Notes:
(ND) Nondetect

Filename: X:/EPA009/Garvey/GW_Flow_Tech_Memo/Carbon_TetChl_LoweR_Aquifer_D.mxd
Project: EP9034.01.22.02.02
Revised: 06/13/12 ST
Source: ENSR GDB 2008, DNR

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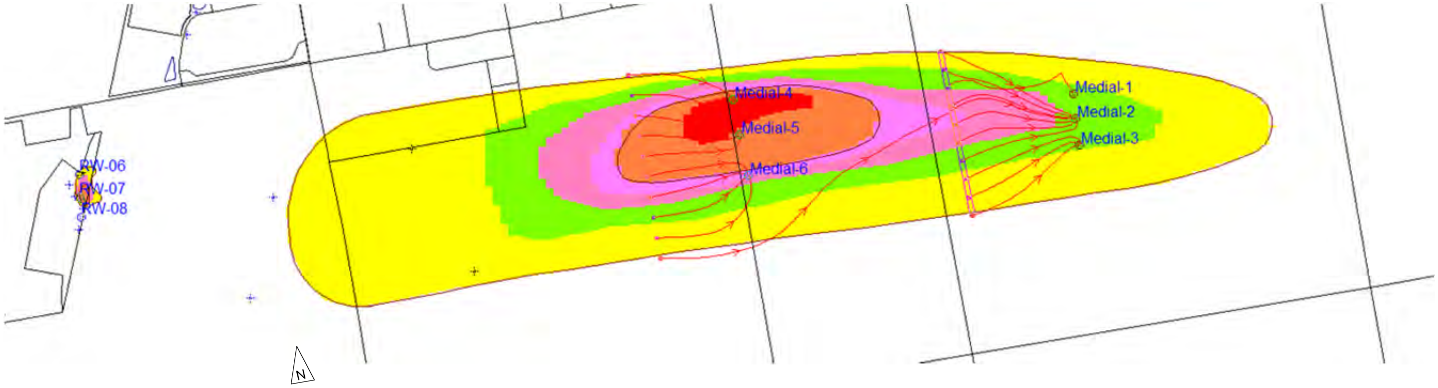


Figure 7.7. Alternative G3a,b-Proposed Recovery Wells Medial Aquifer.

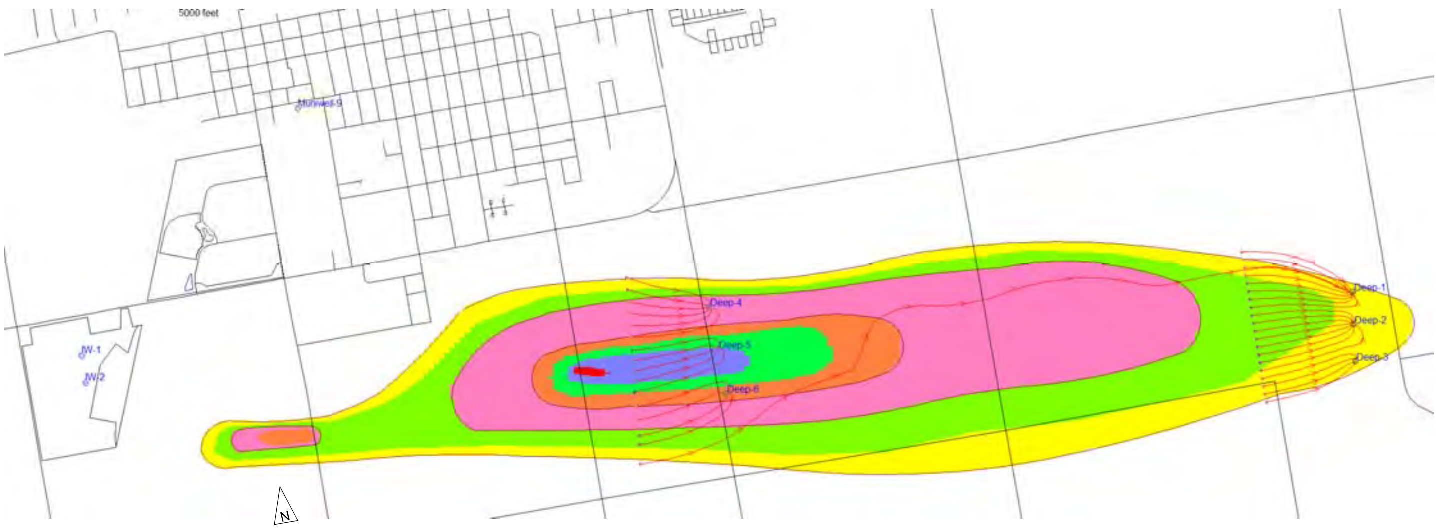
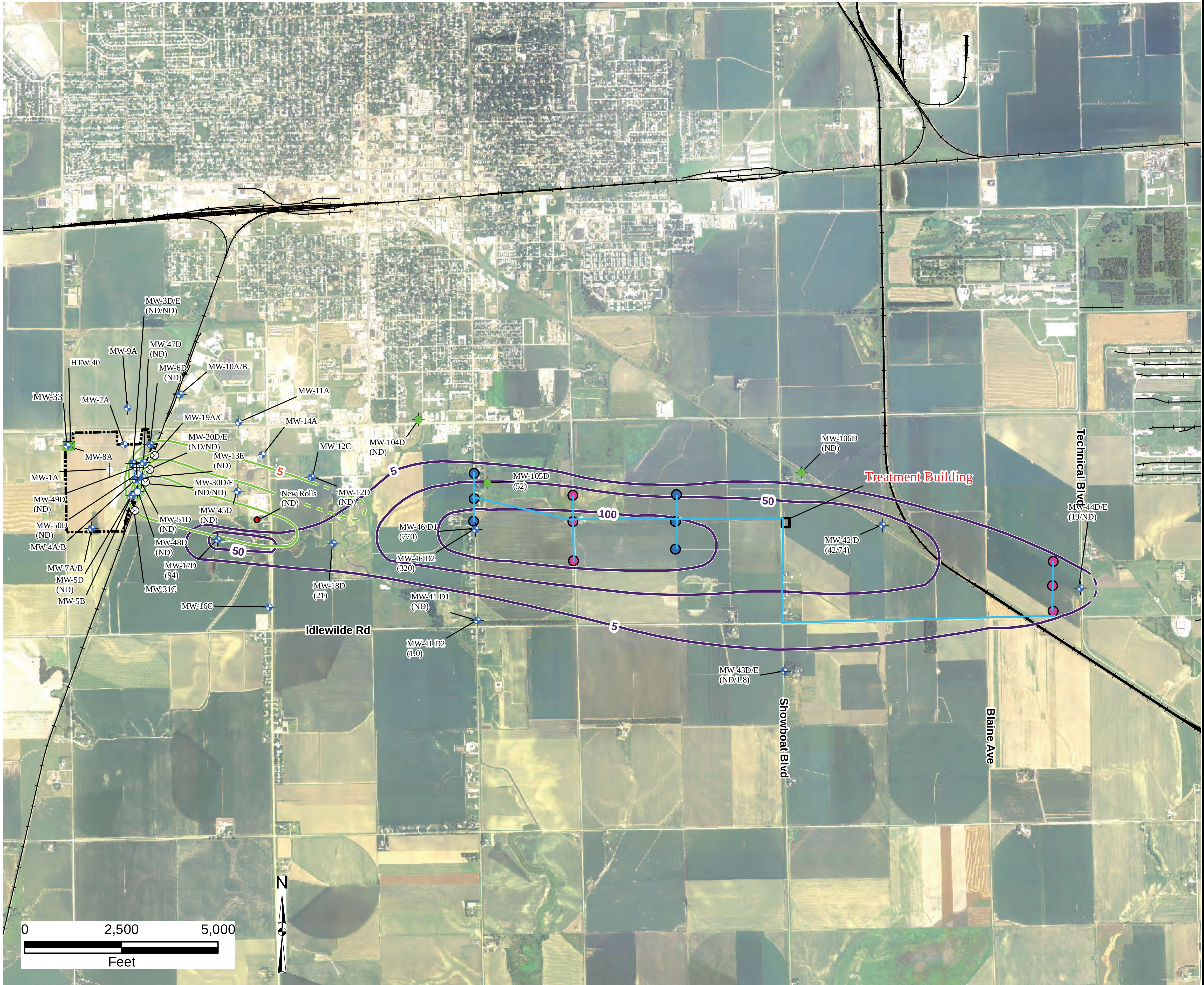


Figure 7.8. Alternative G3a- Proposed Recovery Wells Lower Aquifer.

Figure 7.9
Preliminary Locations for Mid-Plume and Leading Edge Recovery Wells and Groundwater Treatment Building-Alternative G3



Legend

- Garvey Property Boundary
- Railroad
- Monitoring Well Location
- Multilevel Well
- Hydraulic Conductivity Well
- West Highway 6 & Highway 281 Site Monitoring Well
- (190) Carbon Tetrachloride Concentration in micrograms per liter (µg/L)
- (5) Carbon Tetrachloride Isoconcentration Contour (Lower Aquifer) (µg/L) (Dashed Lines are Estimated)
- Domestic / Irrigation Water Wells
- (5) Carbon Tetrachloride Isoconcentration Contour (Upper Aquifer) (µg/L) (Dashed Lines are Estimated)
- Recovery Wells (Medial)
- Recovery Wells (Deep)
- Recovery Well Piping
- Treatment Building

Notes:
(ND) Nondetect

Filename: X:/EPA009/Garvey/GW_Flow_Tech_Memo/ Mid-Plume_Prelim_Loc
Project: EP9034.01.22.02.02
Revised: 06/13/12 RL
Source: ENSR GDB 2008, DNR

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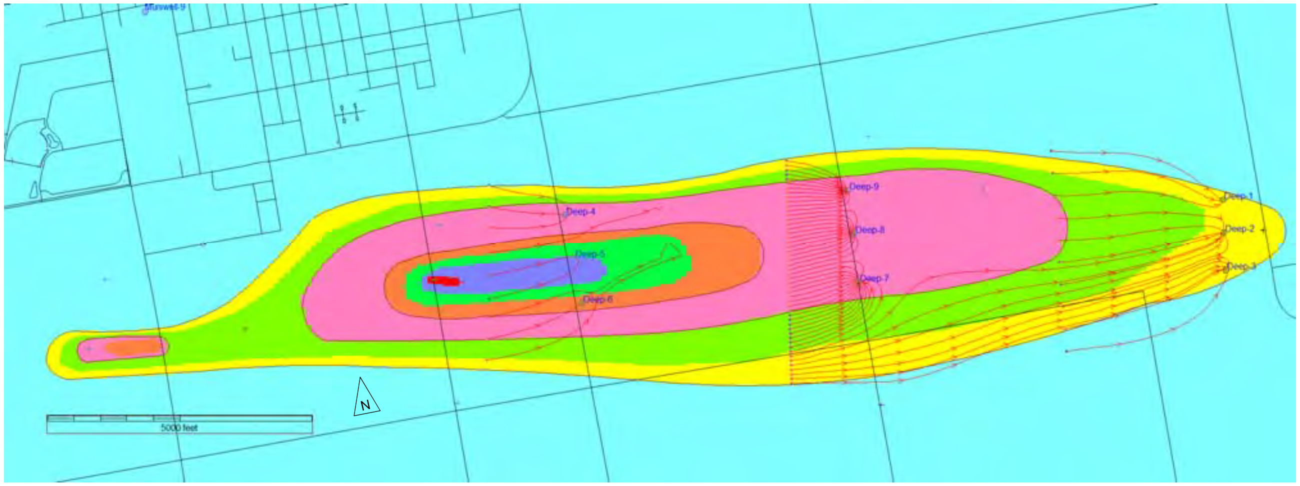

Figure 7.10. Alternative G3b-Proposed Recovery Wells Lower Aquifer.

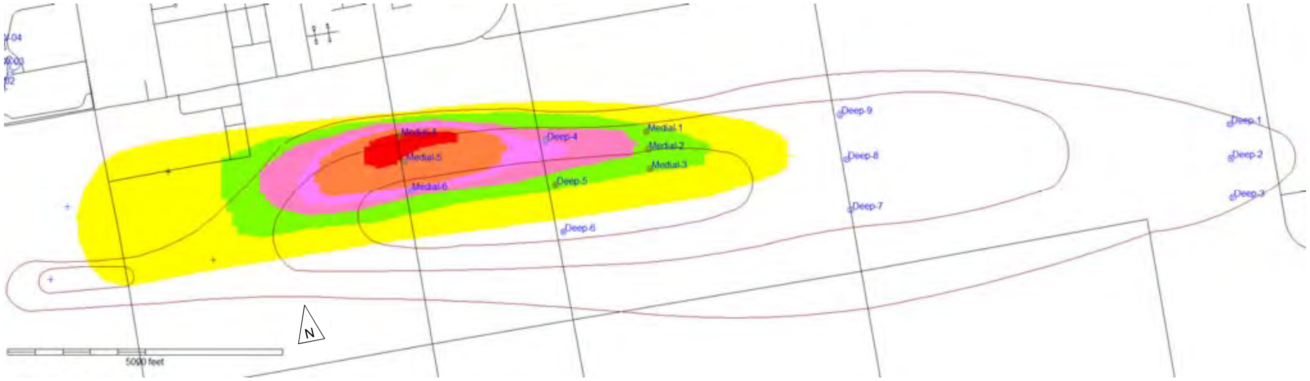

Figure 7.11. Alternative G3b-Relative Positions of Proposed Recovery Wells Medial and Lower Aquifers.

Figure 7.12. Alternative G4a-Proposed Treatment Curtain and Recovery Wells Lower Aquifer.

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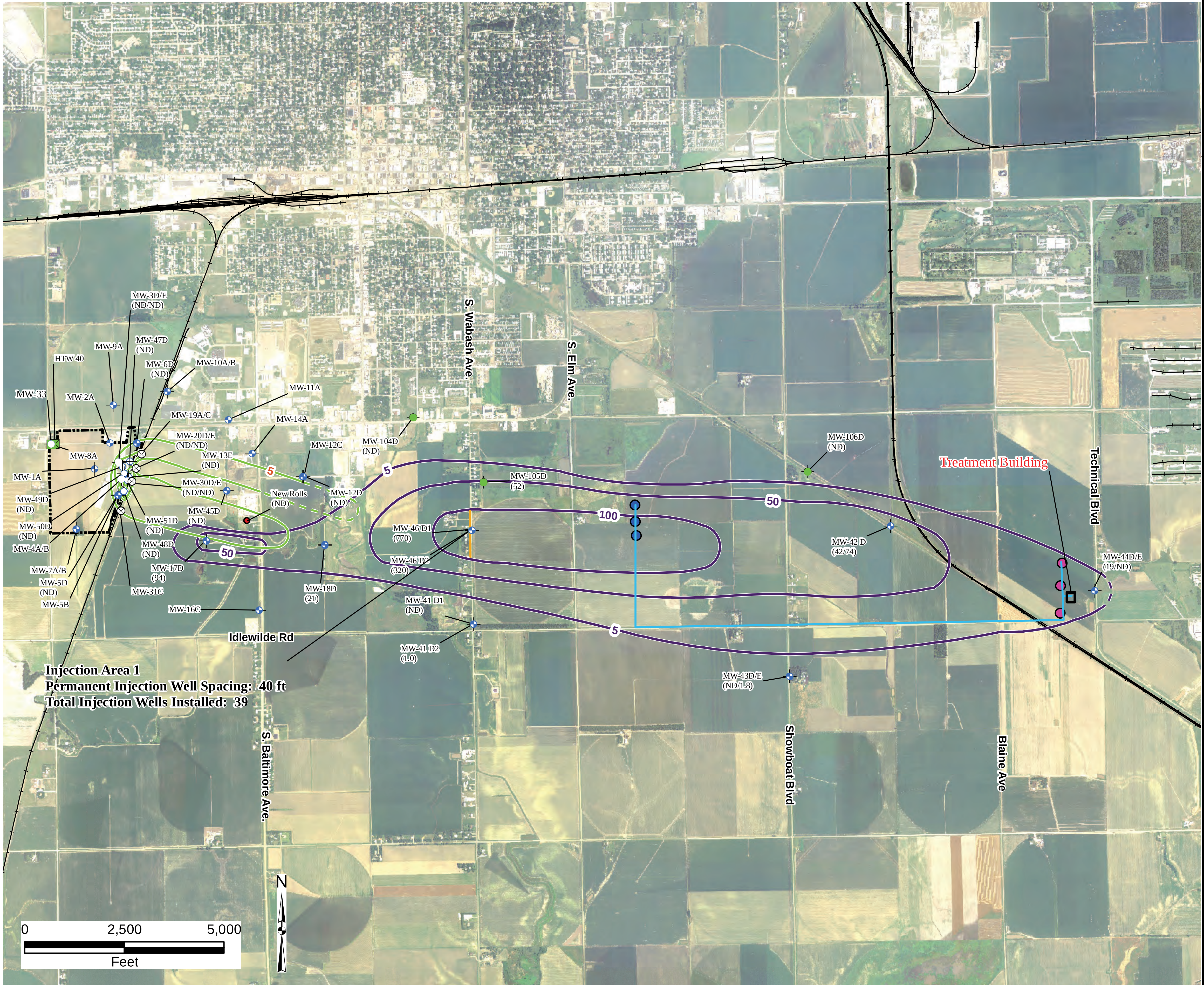
Figure 7.13
Preliminary Locations for Mid-Plume Injection Wells, Leading Edge Recovery Wells, and Groundwater Treatment Building -Alternative G4



Legend

- Garvey Property Boundary
- Railroad
- Monitoring Well Location
- Multilevel Well
- Hydraulic Conductivity Well
- West Highway 6 & Highway 281 Site Monitoring Well
- (190) Carbon Tetrachloride Concentration in micrograms per liter (µg/L)
- (5) Carbon Tetrachloride Isoconcentration Contour (Lower Aquifer) (µg/L) (Dashed Lines are Estimated)
- Domestic / Irrigation Water Wells
- (5) Carbon Tetrachloride Isoconcentration Contour (Upper Aquifer) (µg/L) (Dashed Lines are Estimated)
- Recovery Wells (Medial)
- Recovery Wells (Deep)
- Recovery Well Piping
- Injection Area (40 ft spacing between the wells)
- Treatment Building

Notes:
(ND) Nondetect

Filename: X:/EPA009/Garvey/GW_Flow_Tech_Memo/ G4_Prelim_Loc_Inj_Area.mxd
Project: EP9034.01.22.02.02
Revised: 06/13/12 RL
Source: ENSR GDB 2008, DNR

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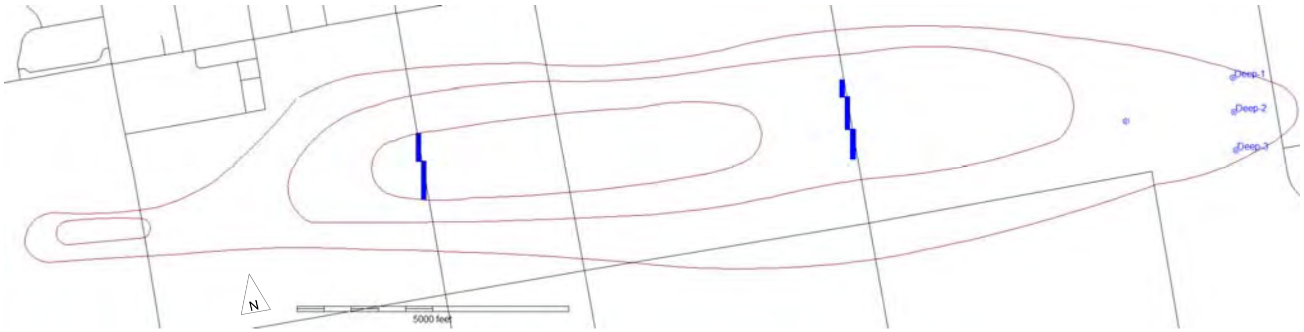

Figure 7.14. Alternative G4b-Proposed Treatment Curtains and Recovery Wells Lower Aquifer.

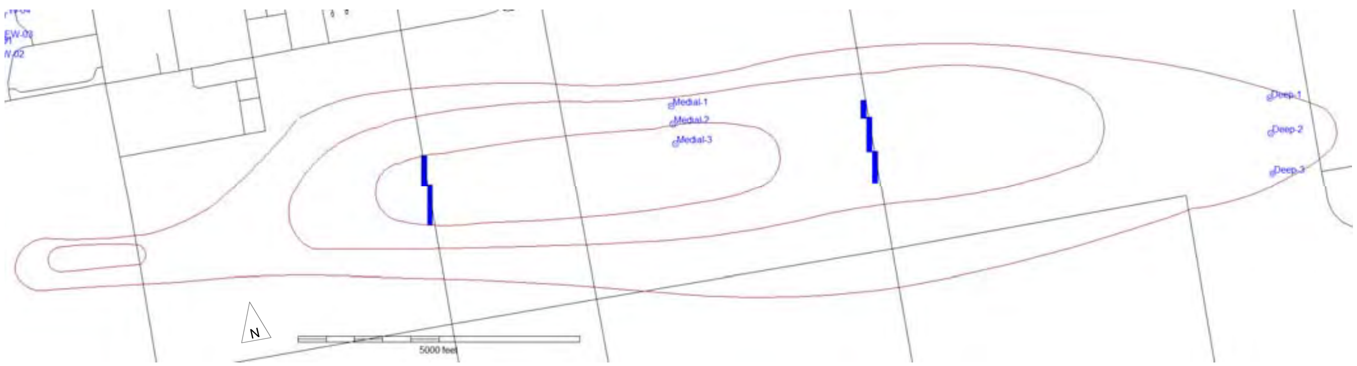

Figure 7.15. Alternative G4b-Relative Positions of Proposed Recovery Wells and Treatment Curtains.