# Draft Report
# Groundwater Modeling Report
# Operable Unit Carbon Tetrachloride Plume
# Groundwater Remedial Investigation / Feasibility Study
# Former Fort Ord, California

Prepared for

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# EXECUTIVE SUMMARY

MACTEC was retained by the United States Army Corps of Engineers to conduct the remedial investigation (RI) at the former Fort Ord in Monterey County, California (Study Area). As part of this evaluation, MACTEC developed a three-dimensional numerical groundwater flow model (3-D Model) to simulate hydraulic conditions for the Site, and to evaluate remedial alternatives in the feasibility study (FS) report.

The modeled area (domain) encompasses the OUCTP area and its immediate vicinity, and areas that are hydraulically upgradient and downgradient of this area (Project Area). The model domain boundaries were positioned relatively distant from the planned Project Area so to minimize chances that boundaries affect results within the Project Area itself.

MACTEC developed a groundwater flow model of the Project Area using Groundwater Modeling System™ (GMS), a fully integrated modeling platform that uses the United States Geological Survey (USGS) Modular Three-Dimensional Finite Difference Groundwater Flow Model, version MODFLOW2000®. In addition, mass transport of carbon tetrachloride (CT) plume in the A-Aquifer was simulated using the numerical mass transport model MT3DMS®. The calibrated groundwater flow and the mass transport model were then used to evaluate various remedial options for containing, mitigating, and remediating the A-Aquifer CT-plume. In addition, the calibrated model was also used to evaluate the effectiveness of groundwater extraction in capturing the Upper 180-Foot Aquifer CT-plume.

The objectives of this model were to:

- Accurately represent the conceptual model of groundwater flow beneath the Site by evaluating and illustrating lithologic, aquifer parameter, and groundwater extraction information collated from previous investigations and the remedial investigation program.

- Simulate groundwater elevations in the A-, Upper 180-Foot, and Lower 180-Foot Aquifers.
- Predict and simulate the migration of the carbon tetrachloride (CT) plume from the source area, near what is now Lexington Court, under the prevalent Site flow conditions.
- Evaluate various remedial options and their effectiveness in containing, mitigating, and remediating the CT plume within the OUCTP area.

Lithologic data from all monitoring wells within the model domain were incorporated into the model to construct the model layers. Each aquifer and aquitard was simulated with a single layer. Boundary conditions, aquifer hydraulic properties like hydraulic conductivity, anisotropy, and recharge, and other relevant information like groundwater pumping and source concentrations were also incorporated during the model development process. These parameters were further modified during the calibration process until reasonable correlation between observed and simulated values was achieved. The model was run under quasi-steady state conditions.

The steady state groundwater flow solution generally confirms the aquifer parameters of the A-, Upper 180-Foot, and Lower 180-Foot Aquifers. A reasonable match between predicted and observed water levels was achieved for the model domain monitoring wells for both the calibration and verification simulations. In addition, the orientation of groundwater elevation contour lines within the model domain, determined from model calculated hydraulic heads, was consistent with the orientation of groundwater elevation contour lines determined from actual water level measurements.

The mass transport steady state simulation result was observed to closely mimic the interpreted and predicted A-Aquifer CT plume footprint, and the concentrations at selected target wells

Following completion of the steady state calibration, the verification check, and the sensitivity analysis of the groundwater flow model, and calibration of the mass transport model, a series of predictive simulations were performed to evaluate various remedial alternatives in support of the FS (Volume III).

Based on the evaluation of the three remedial options for mitigating the A-Aquifer CT-plume, the following conclusions can be stated:

- Only the enhanced natural attenuation using a Lactate Recirculation and Injection System (*Scenario 3*) was observed to be effective in containing and mitigating the A-Aquifer CT-plume within a time period of approximately 15 years.

- The groundwater extraction remedial alternative (*Scenario 1*) was observed to provide adequate capture of the CT plume upgradient of extraction well EW-OUCTP-01. In addition, the CT plume in this area could also be remediated in 30 years. However, groundwater downgradient of EW-OUCTP 01 would remain contaminated at concentrations ranging between 0.5 and 5 μg/L because of the inability of well EW-OUCTP-01 to capture the CT mass that is already present downgradient of the capture radius of the well.

- The Permeable Reactive Barrier (PRB) remedial alternative (*Scenario 4*) was observed to remediate the majority of the CT plume upgradient of the PRB in 50 years, with only a small portion (located between the PRB and MW-BW-31-A) of the plume remaining at concentrations ranging from 0.5 to 1.5 μg/L (Plate F17-G). However, groundwater downgradient of the PRB would remain contaminated at concentrations ranging between 0.5 and 5 μg/L due either to the continued migration of CT already present downgradient of the PRB or from residual CT emanating from the PRB.

The result of the Scenario 2 simulation, which simulates the capture of the CT-plume in the Upper 180-Foot aquifer using particle analysis, indicates that extraction of groundwater at a rate of 150 gpm from EW-OU2-07-180 along with the ongoing extraction from the other Upper 180-Foot Aquifer extraction wells sufficiently captures the Upper 180-Foot Aquifer CT plumes, in addition to providing capture to the TCE plume associated with OU2.

The results of this modeling study are dependent on the accuracy of information obtained from the previous investigation reports.

# 1.0 INTRODUCTION

A three-dimensional transient groundwater flow and mass transport model was developed to simulate groundwater flow and mass transport of carbon tetrachloride (CT) in aquifers beneath the former Fort Ord site (Site). The calibrated groundwater flow and mass transport model was used to evaluate the various remedial options proposed in the Remedial Investigation/Feasibility Study (RI/FS) report.

## 1.1 Overview of Modeling Objectives

The primary objective of this report is to simulate the groundwater flow and contaminant mass conditions beneath the operable unit carbon tetrachloride plume (OUCTP) area and to evaluate the various remedial options by introducing potential changes to the simulated hydraulic and/or chemical conditions in the model. Specifically, the objectives of the groundwater flow model included the following:

- Accurately represent the conceptual model of groundwater flow beneath the Site by evaluating and illustrating lithologic, aquifer parameter, and groundwater extraction information collated from previous investigations and the remedial investigation program.

- Simulate groundwater elevations in the A-, Upper 180-Foot, and Lower 180-Foot Aquifers.

- Predict and simulate the migration of the CT plume from the source area, near what is now Lexington Court, under the prevalent Site flow conditions.

- Evaluate various remedial options and their effectiveness in containing, mitigating, and remediating the CT plume within the OUCTP area.

## 1.2 Report Organization

The remainder of this groundwater modeling report is organized as follows:

| | |
|---|---|
| Section 2 | **Data Compilation -** Describes data that were compiled to construct the numerical groundwater flow and mass transport model. |
| Section 3 | **Conceptual Model -** Describes geologic and hydrogeologic characteristics within the model domain. In addition, a discussion of recharge, hydrologic boundaries, and hydraulic properties, and other assumptions is presented in this section. |
| Section 4 | **Numerical Model Development -** Describes the objectives and the development of the numerical flow and mass transport model, including selection of groundwater modeling codes, model domain and configuration, aquifer properties, and boundary conditions. |
| Section 5 | **Groundwater Flow Model Calibration – Steady State -** Describes the calibration of the steady state groundwater flow model, selection of calibration targets for model parameters and variables, and the presentation and discussion of the steady state groundwater flow model calibration results. |
| Section 6 | **Groundwater Flow Model Verification -** Describes the verification of the steady state groundwater flow model. |
| Section 7 | **Sensitivity Analysis -** Describes the sensitivity analysis of the numerical model under ambient (steady state) flow conditions. |
| Section 8 | **Mass Transport Model Calibration and Results -** Describes the calibration of the mass transport model, selection of calibration targets, source area evaluation, and model parameters. In addition, it also includes the presentation and discussion of the mass transport model results. |
| Section 9 | **Remedial Alternative Simulations -** Describes the remedial options and the results of the simulations of the remedial options performed for the Study Area. |
| Section 10 | **Discussion and Conclusions -** Describes the model predictions and provides recommendations for the future. |
| Section 11 | **Limitations -** Describes the limitations of the model and its results. |
| Section 12 | **References** |

# 2.0 DATA COMPILATION

Prior to development of the conceptual and numerical model, existing data were compiled, data needs were evaluated, and data gaps were identified. This section describes the compilation of data required for constructing the numerical model and simulating the steady state calibrated and transient conditions. The section also provides the references used and assumptions applied in compiling the data.

Data that were identified for compilation included the following:

- Ground surface elevation map;
- Stratigraphic data from production, irrigation, and monitoring wells in the form of lithologic logs and associated well construction details along with any geophysical logs from within the model domain boundaries;
- Historic groundwater elevation data from monitoring wells within the model domain boundaries;
- Historic groundwater production data where available or estimated where data are not available;
- Aquifer testing results for the A-Aquifer, Upper and Lower 180-Foot Aquifers; and
- Locations of and operational history of remedial injection and extraction wells and infiltration galleries within the model domain.

Specific data used in the construction of the model and simulation of the groundwater flow conditions were obtained from boring logs, well construction details, reports, and previous aquifer studies discussed in Section 1.2.3. Some of the data obtained from these reports and other sources are as follows:

- Stratigraphic data from borings and well logs; used to allocate the model layers

- Historical groundwater elevation data for wells within the model domain; used during the calibration process
- Historical precipitation data National Oceanic and Atmospheric Administration (NOAA); used to define recharge to the uppermost active layer of the model and were particularly important in calibration of this layer
- Hydraulic conductivity (K) of the model domain soils/aquifers obtained from aquifer tests conducted for the U.S. Army Corps of Engineers (USACE)
- Historic groundwater production data from supply and irrigation wells, where available, and estimated production rates from wells where data were not available (Army, Marina Coast Water District [MCWD])
- Remedial pumping and recharge data for simulation of capture analyses.

Several assumptions were applied in the data compilation task and are as follows:

- Groundwater elevation data are accurate
- Historical precipitation records, obtained from NOAA, are reasonably representative of precipitation within the model domain
- Extraction and injection wells fully penetrate their respective aquifer
- Remedial pumping and recharge data and production well records are accurate
- Estimated pumping rates from now-destroyed production wells are reasonably accurate.

# 3.0 CONCEPTUAL MODEL

Prior to constructing a numerical model, a conceptual model was developed to understand the various factors that would affect groundwater flow within the model domain. This section describes the geologic and hydrogeologic characteristics, and the conceptual movement of groundwater within the model domain. In addition, a discussion of recharge, hydrologic boundaries, hydraulic properties, and other assumptions is also presented.

## 3.1 Conceptual Model Objectives

The conceptual model is based on interpretations and assumptions of the geology and hydrogeology and establishes the framework for the numerical model. The purpose of the conceptual model is to identify the major hydrologic and hydrogeologic processes and boundary conditions that qualitatively describe the groundwater flow system so that the system could be modeled numerically. The conceptual model also served to identify potential data gaps, as well as the various assumptions necessary for the development of the numerical model.

## 3.2 Conceptual Model Development

The physiographic region included in the conceptual model included the OUCTP area and its immediate vicinity, and areas that are hydraulically upgradient and downgradient of this area. A description of the OUCTP area geology, hydrogeology, and aquifer properties are discussed in Sections 2.7, 2.8, and 3.6, respectively, and the conceptual model is described in Section 8.4. The following text further discusses the development of the conceptual model as it relates to the numerical advective and mass transport simulation.

### 3.2.1 Domain Extent

The model domain boundaries were positioned to encapsulate the extent of the CT plume in each aquifer and also to include all the wells that are to be used during the remedial option simulations. In addition, the model domain was positioned to minimize boundary affects during the simulation of the remedial options (Plate F1). Lithologic data from all monitoring well logs within the domain were incorporated into the structure of each model layer to represent aquifer/aquitard contacts. Topography was extrapolated from available measurements created a two-foot resolution. Each aquifer and aquitard is represented by a single layer. The vertical extent of the model domain was simulated by the following six layers, comprising a total thickness of approximately 985 feet.

- Layers 1 and 2 define unconfined A-Aquifer that consists of unconsolidated dune sand. The discretization of the A-Aquifer into two layers was designed to afford flexibility, if needed. However, Layer 1 was deactivated during the calibration process as discretization of the A-Aquifer was deemed unnecessary. The A-Aquifer thickness (including both Layers 1 and 2) varies from about 12 feet at MW-BW-42-A to about 32 feet at MW-BW-35-A based on groundwater elevations measured in January 2001 (peak “El Nino” conditions). The aquifer generally thins from the source area (about 30 feet) to areas east of a significant wave-cut terrace (less than 20 feet) in the underlying Fort Ord – Salinas Valley Aquitard (FO-SVA) clay; however, it generally increases west of the wave-cut terrace to a maximum of 44 feet at MW-BW-76-A due to the continual drop in elevation of the underlying FO-SVA.

- Layer 3 extends from the bottom of Layer 2, and consists of the FO-SVA clay. The depth and thickness of this clay unit, which is comprised primarily of materials with a marine origin, is variable. This layer is present throughout the modeled area and is relatively impermeable; however area around the now-abandoned municipal wells may act as vertical conduits.

- Layer 4 defines the Upper 180-Foot Aquifer within the OUCTP area. The layer has an average thickness of about 60 feet and represents a typical consistency of fine to coarse sand that grades to a sand and gravel layer near its base. Layer 4 is present through the modeled area, and varies in thickness from 22 to 139 feet.

- Layer 5 represents the Intermediate 180-Foot Aquitard. Although approximately 50 feet thick near the western extent of the Upper 180-Foot Aquifer, this aquitard feathers out near the southern extent of the model domain. Layer 5 is present through the modeled area, and varies in thickness from 10 to 128 feet.

- Layer 6 defines the Lower 180-Foot aquifer, which underlies the Intermediate 180-Foot aquitard, and represents coarse sand and/or gravel sediments. Layer 6 is present through the modeled area, and has been assigned a uniform thickness of 120 feet (for modeling purposes).

### 3.2.2 Groundwater Flow System

The primary source of groundwater in the area is via the infiltration of precipitation, and from subsurface regional inflow. Groundwater is discharged mainly by pumping from wells or by subsurface outflow through the northwestern and northeastern perimeter for the A-Aquifer, southwestern perimeter for the Upper 180-Foot Aquifer, and eastern perimeter for the Lower 180-Foot Aquifer.

Groundwater flow in the model domain has been monitored for several years, and groundwater gradients and flow in the area have been calculated using static water levels. The depth to the top of the groundwater in the shallowest aquifer (A-Aquifer) varies from as little as 20 feet to as large as 120 feet.

Groundwater flows through the A-Aquifer northwest from the suspected source area to about MW-BW-27-A from which point groundwater flows more to the west and northeast. This could be attributed to the groundwater divide that lies just east of the source area (Section 2.8 in the RI-Volume I). Groundwater gradients in the A-Aquifer across the Study Area vary from 0.005 feet/foot near the suspected source area to 0.008 feet/foot farther downgradient. West of the facies change, the gradient is an order of magnitude less (about 0.0009 feet/foot) which reflects the higher hydraulic conductivity of the beach sand and gravel unit.

Groundwater in the Upper 180-Foot Aquifer throughout the Main Garrison area of Fort Ord generally flows eastward toward Salinas Valley; however, gradients within the OUCTP area reflect a local southeastern flow direction. This local discrepancy reflects discharge to the Lower 180-Foot Aquifer southeast of OUCTP which is consistent with lithologic data that indicate the underlying aquitard is absent beneath the Fredericksburg housing area (in the vicinity of MP-BW-41 and MW-OU2-61-180). Groundwater elevations within this aquifer vary across the site with a small gradient of about 0.001 feet/foot; however, seasonal stresses are significant and result in annual groundwater elevation fluctuations of about eight feet at distal points from the discharge area. The magnitude of these fluctuations decreases with proximity to the western and southern edges of the FO-SVA unit, thus reflecting recharge that probably occurs along the southern extent of the overlying FO-SVA unit.

The static groundwater levels within the Lower 180-Foot Aquifer suggest that groundwater flow is oriented primarily toward the east or southeast direction. In addition, the groundwater gradient does not significantly change over the length of the model domain.

Limited data are available in determining the vertical gradients between the shallow and deep aquifers. Hydraulic communication between the A-Aquifer and the underlying Upper 180-Foot Aquifer is limited to those areas west of the OUCTP where the FO-SVA clay unit pinches out or where it has been penetrated by wells without adequate sanitary seals. However, hydraulic communication is observed between the Upper 180-Foot and Lower 180-Foot Aquifers south of well MP-BW-41 where the Intermediate 180-Foot Aquitard feathers or pinches out, and may not be present (Section 2.8 in the RI-Volume I). Therefore, it can be assumed that a small or negligible vertical gradient is prevalent between the A-Aquifer and the deeper zones. A low vertical gradient between different aquifer zones is indicative of a high flow aquifer system that is dominated by horizontal groundwater movement, as appears is the case in this system.

### 3.2.3 Boundary Conditions

The boundary conditions of the model were selected based on groundwater elevation heads measured as part of the Fort Ord Quarterly Groundwater Monitoring Program since 1992 in each aquifer (Plates F2-F4). Layers 1 and 2 boundary conditions include specified head boundaries that relate to observed groundwater elevations along the domain perimeter in June 2004. Topographic data were also used to control boundary conditions in these layers, particularly in the vicinity of the Salinas River where perched groundwater conditions of the A-Aquifer are relatively shallow. Layers 4 and 6 similarly are bounded by specified head boundaries that derived from observed groundwater elevations. Boundaries in Layers 3 and 5 (aquitards) are represented by no-flow boundary conditions. These boundaries largely define the southern source of groundwater to Layers 1 and 2, the north-south trending groundwater divide in the A-Aquifer, and generally south eastward and eastward flow within Layers 4 and 6, respectively. An oblique view of the three-dimensional grid is illustrated on Plate F5.

### 3.2.4 Hydraulic Conductivity

The initial estimates of horizontal hydraulic conductivity were obtained from available aquifer test data for wells within the model domain. Estimates were also obtained from the evaluation of soil particle sizes in the boring logs, previous investigations at the Site, and predictive literature values for the type of soil underlying the model domain. Most values of hydraulic conductivity estimated from the aquifer pumping tests are generally consistent with the range of values estimated for these kinds of soil materials.

The following is a brief summary of the hydraulic characteristics of the model domain.

Horizontal hydraulic conductivity values of the A-Aquifer and Lower 180-Foot Aquifer were estimated from the aquifer testing activities that were conducted as part of the OUCTP RI. The hydraulic conductivity of the Upper 180-Foot Aquifer was obtained from the examination of lithology from continuous core material, and from results of aquifer tests conducted as part of the OU2 investigations. The horizontal hydraulic conductivity values of the A-Aquifer ranged from about 20 feet/day midway along the A-Aquifer CT plume to as high as 540 feet/day near the toe of the plume (Plate F6). Fine-grained sand observed near the source area suggests values less than 20 feet/day in this area. The horizontal conductivity of the FO-SVA was uniformly simulated at 0.00007 feet/days. The hydraulic conductivity of the Upper 180-Foot Aquifer within the OUCTP area, though not quantified, was considerably higher than that of the A-Aquifer (Plate F7). The intermediate 180-foot Aquitard was simulated with the zones of hydraulic conductivity. The larger of the two where the aquitard is present, has a value of 0.0007 feet/day. The smaller, where the aquitard is absent, has a value of 200 ft/day (Plate F8)Horizontal hydraulic conductivity values for the Lower 180-Foot Aquifer were also observed to be considerably higher than the A-Aquifer values, and were simulated with a uniform value of 700 feet/day.

Limited data were available for the vertical conductivity values. Vertical hydraulic conductivity values of the clay that comprises the FO-SVA were estimated (from permeameter tests) at approximately $10^{-6}$ to $10^{-8}$ cm/sec. However, based on the geologic and hydrogeologic interpretation, and the available regional hydrogeologic literature, the ratio of horizontal to vertical hydraulic conductivity (***K***h/***K***v) was estimated to be approximately 100 for the A-Aquifer and the FO-SVA, and 10 for the Upper 180-Foot and Lower 180-Foot Aquifers.

### 3.2.5 Groundwater Sources and Sinks

#### 3.2.5.1 Groundwater Pumping

Extraction/injection patterns over time from nearby remedial activities (OU2) and pumping from municipal wells over time also represent boundary conditions that apply to each of the aquifer layers (2, 4, and 6). Where available, actual production rate values or average production values were represented in the simulation. Production wells located west of the OUCTP area in the City of Marina generally have no records and, since the use of these wells was terminated prior to the CT plume entering the aquifers within which these wells were screened, production from these wells was not simulated.

#### 3.2.5.2 Surface Water

The only surface waters near the OUCTP area include the Salinas River to the east and a pond associated with Locke Paddon Park to the west. Both of these features interact with the water table of the A-Aquifer and do not interact with groundwater in the 180-Foot Aquifer. However, only the Salinas River lies within the Study Area. The hydrology of the Salinas River and its interaction with the uppermost aquifer at the Study Area is not well defined, with few data reports available. The interaction between the A-Aquifer and the Salinas River is dependent upon the stage of the river, elevation and transmissivity of the river bed, and the groundwater levels in the A-Aquifer. However, because of the limited availability of this data, the Salinas River was simulated as a specified head boundary.

#### 3.2.5.3 Precipitation and Recharge

Recharge represents a significant boundary condition to Layers 1 and 2 and is represented by precipitation records available from NOAA since 1950 (temporal origin of the simulation). Precipitation to the area generally averages 14 inches per year; however, significant fluctuations have occurred as discussed in Section 2.4 of the RI-Volume I. The “El Nino” event, in particular, represented a significant increase in precipitation and resultant increase in storage within the A-Aquifer. However, for the purpose of the steady state modeling simulations, only 33 percent of the total precipitation is assumed to directly infiltrate recharge the groundwater beneath the Study Area. This value represents the net recharge into the system, after taking into account losses due to surface flow and evapotranspiration.

### 3.2.6 OUCTP Source Area

Review of aerial photos indicates that a small facility, allegedly used for storage of CT for cleaning of electronic components, was located at what is now Lexington Court from at least 1949 to 1955. Although the location of the source area has essentially been confirmed, the duration, frequency, and volume of CT use at this facility remain unknown. As discussed in Section 1.2.3.2 of the RI-Volume I, it appears that CT was stored in five-gallon cans and, given the small size of the facility; it appears likely that large volumes were not routinely stored at this location. Assuming that one five-gallon can was used monthly for the six years during which the facility appears to have existed, the approximate volume of CT storage amounts to 360 gallons.

# 4.0 NUMERICAL MODEL DEVELOPMENT

This section describes the development of the numerical groundwater flow model based on the conceptual model discussed in Section 3.0. This section includes a description of the selected groundwater modeling code, the model grid geometry, boundary conditions, and model parameters. In developing the groundwater flow model, simplifying assumptions were made in order to facilitate model construction without significant impact to the validity of the model. A large area outside the Project was included in the model domain to minimize the impact of the imposed boundary conditions on the predictive performance of the model.

## 4.1 Numerical Groundwater Code Description

MODFLOW2000® was selected as the numerical code for performing the groundwater flow simulations. MODFLOW is the industry standard United States Geological Survey (USGS) Modular Three-Dimensional Finite Difference Groundwater Flow Model code. MODFLOW2000® was used because of existing documentation (*USGS, 2003*), which provided quality reference values, and the capabilities of MODFLOW addressed most Project needs as well as satisfied the requirements of American Society for Testing and Materials (ASTM) Standard D6170-97 *Standard Guide for Selecting a Ground-Water Flow Model Code*.

The most recent version of the graphical interface program Groundwater Modeling System (GMS) Version 5.1 was used to assemble and construct the input files for the model. GMS is a pre-processor and post-processor that facilitates data preparation, manipulation, visualization, and presentation of MODFLOW2000® input and output files. This program provides a high degree of automation and flexibility in the development of the model and reduces the time required to construct input files and process output files.

The groundwater flow simulations require the use of different MODFLOW2000® packages depending upon the boundary conditions or the various external stresses that need to be simulated for a given model domain. The following MODFLOW2000® packages were utilized during the groundwater flow simulations:

- .BAS The primary package used for model initialization, layer definition, initial potentiometric conditions, water budget balance, definition of the types of simulations;
- .BCF For layer hydraulic properties and elevation control;
- .RCH To simulate the recharge from Laws operations, canals, ditches, runoff from bedrock outcrops, and mountain-front recharge between tributary streams to the aquifer system;
- .WEL To simulate the groundwater extraction wells;
- .PCG2 For utilization of the Preconditioned Conjugate Gradient matrix equation solver;
- .SIP For utilization of the Simplified Implicit Procedure matrix equation solver, in cases where the PCG2 solver would not converge.

## 4.2 Numerical Mass Transport Code Description

MT3DMS® was used to simulate the three-dimensional mass transport for the site. MT3DMS® is an integral part of the GMS platform. This program uses a modular structure similar to that implemented in the block-centered finite difference flow model, MODFLOW, and is based on the assumption that changes in the concentration field will not affect the flow field measurably. This makes it possible for the program to use information (i.e., hydraulic heads and various flow terms) obtained from a calibrated flow model, to simulate advection, dispersion, sink/source mixing, and chemical reactions of constituents in the groundwater system. Additionally, discrete properties of the aquifer including bulk density, distribution coefficient (Kd), dispersivity, and porosity are used to arrive at the three-dimensional solution for the Study Area. The flow input file used for the mass transport model was created using the MODFLOW program from the GMS platform.

Similar to MODFLOW, MT3DMS® incorporates five different modules to represent the salient transport parameters that either influence or control the rate of movement and concentration of solute in the groundwater, the degree of constituent mixing, and the rate of constituent degradation within the subsurface environment. The five discrete transport modules used for the simulation of mass transport include:

.BTN The primary package used for model initialization, layer definition, specification of the boundary and initial conditions (including constant source cells), determination of the step size, and preparation of mass balance information;

.ADV Solves the concentration changes due to advection using the mixed Euler-Lagrangian algorithms;

.DSP Solves the concentration changes due to dispersion using the explicit finite difference method;

.SSM Solves the concentration change due to fluid sink/source mixing (i.e., wells, recharge, specified head boundaries) using the explicit finite difference method; and

.RCT Solves the concentration changes due to chemical reactions.

## 4.3 Model Geometry and Grid

The area of groundwater modeled (domain) encompasses the OUCTP area (Plate F1). The ground surface in the model domain reflects existing conditions for the calibration runs. The model domain dimensions were positioned relatively distant from potential remedial activity areas to minimize impact of the imposed boundary conditions on the predictive performance of the model. Such distancing is used to reduce the effects of errors from input uncertainties on the model results.

### 4.3.1 Model Grid

In plan view, the model's grid blocks are mutually perpendicular lines that are variably spaced with dimensions ranging from 10 feet to 487.5 feet with several telescopic points where higher resolution is required (e.g., extraction wells). Since the model domain is large (17,945 by 12,935 feet) and there are practical limits to the total number of cells that can be created in the domain, a maximum cell aerial size of 461.9 by 487.5 feet was selected. The result is 142 by 182 cells in six layers for a total of 155,064 cells. However, Layer 1, which had been originally constructed as an upper portion of the A-Aquifer, was deactivated during the calibration process as discretization of the A-Aquifer was deemed unnecessary. Hence, of the 155,064 total cells in the model, only 129,220 cells, which represent all the cells in Layers 2 through 6, were active in the model domain. The greater the number of cells, the greater the computational demands in managing a model. This number of cells was reasonable given the available input data sets and the required resolution of results. Model solution nodes are located at the center of each cell and the model grid is oriented north-south and east-west. Row numbers increase in the southerly direction, column numbers increase in the easterly direction.

The vertical thickness of the OUCTP area aquifers (approximately 900 feet) was represented in the model by six layers of grid cells. Layer numbers increase in the downward direction. Layers 1 and 2 of the model domain are designated as unconfined, whereas the underlying Layers 3 through 6 are fully convertible from confined to unconfined conditions. The flow between the layers is represented by the vertical hydraulic conductivity, except for the bottom most layer. The vertical multi-layer system was derived from the conceptual model, and is assumed to represent five geologically different aquifer units: Layers 1 and 2 represent unconsolidated dune sand of the A-Aquifer, Layer 3 represents marine clay of the FO-SVA, Layer 4 represents sand and gravel of the Upper 180-Foot Aquifer, Layer 5 represents mixed sand and clay of the Intermediate 180-Foot Aquitard, and Layer 6 represents coarse sand and gravel of the Lower 180-Foot Aquifer. However, as stated earlier, Layer 1 was deactivated, and the model therefore simulated the interactions between Layers 2 through 6. Hence, the correlation of the model layers to the stratigraphy can be represented as follows:

| Model Layer | Aquifer/Aquitard Name |
|---|---|
| 1 | Inactive |
| 2 | A-Aquifer |
| 3 | Fort Ord – Salinas Valley Aquitard |
| 4 | Upper 180-Foot Aquifer |
| 5 | Intermediate 180-Foot Aquitard |
| 6 | Lower 180-Foot Aquifer |

### 4.3.2 Layer Elevations

Layer surface and bottom elevations were assigned graphically in GMS using the borehole module and lithologic data from all monitoring and production wells within the domain and simulated in MODFLOW2000® using the .BAS package. Layer/flow zone thicknesses, input as top and bottom elevations for each layer, are required to simulate groundwater flow in the layers. The elevations are used by the model to determine aquifer thicknesses, and subsequently calculate the transmissivity of the aquifer zones based on the thicknesses of each zone.

As stated in the conceptual model, a stratigraphic model was initially created to represent the vertical extent of the model domain. Ground surface elevations were obtained from a high resolution (2-foot) map of the domain area, interpolated to the model grid. This surface represents the top of Layer 1. Elevations for Layers 3, 4, 5, and 6 were also created using the GMS borehole module interface. Lithologic data was interpolated using kriging methods to extend contact elevations throughout the model grid. Confidence of the accuracy of each layer contact decreases with depth as the number of borings extending into the Lower 180-Foot Aquifer (Layer 6) is considerably less than those tapping the top of the FO-SVA (Layer 3). Nonetheless, a reasonable approximation of each layer contact was achieved using this technique and the interpreted surfaces were compared to the hand drawn cross-sections and corrected until a good correlation between the interpreted layers and observed layers was obtained. After completion of the stratigraphic model, the layer surfaces were exported directly to MODFLOW2000® using the GMS interface.

## 4.4 Boundary Conditions

A model's boundary is the interface between the model area and the surrounding environment. The groundwater flow model boundaries are in part selected to correspond to natural hydrogeologic boundaries of the physical groundwater flow system (groundwater divide), and are also used to distinguish the area within the model domain from the adjacent groundwater system or hydrologic features. However, for this model, no specific natural hydrogeologic boundary was observed in the Site groundwater system. Hence, groundwater flow conditions along the perimeter boundary of the model domain were largely defined from existing well data and topographic features.

Data collected from the A-, Upper 180-Foot, and Lower 180-Foot Aquifer wells located along the western and southern Site boundary has allowed definition of the western, southern, and southeastern boundary areas within the model domain. For all other boundary conditions, known hydraulic conditions (i.e. hydraulic head) based on the data of the monitoring events of nearby wells, were extended to regions where data had not been collected. To the extent possible, the boundary conditions were established in areas distant from the location of the Site so that uncertainties in their values would have minimal impact on the simulation results. Plates F2, F3, and F4 depicts the boundary conditions associated with Layers 2 , 4, and 6, respectively, of the model domain.

The perimeter boundary conditions were assigned using a combination of no-flow and specified head boundaries. Specified heads were assigned to boundaries that simulated either inflow to or outflow from the model domain. Hence, specified head boundaries were only assigned to the Layers that represent the A-, Upper 180-Foot, and Lower 180-Foot Aquifers, and not to the two aquitard units, FO-SVA and the Intermediate 180-Foot. This is based on our assumption that minimal inflow and outflow occurs within the two Aquitards. No-flow boundaries were assigned to areas where groundwater flow is interpreted to be parallel to the perimeter of the model domain or where no groundwater flow into the model domain was expected. The following is a description of how these boundary features were simulated within the model domain.

### 4.4.1 No-Flow Boundary

A no-flow boundary is used where negligible groundwater enters or exits the groundwater domain, such as where groundwater flow was parallel to the border, a localized groundwater divide may reside, or a geologic fault was present. All boundaries for Layers 3 and 5, which represent the FO-SVA and the Intermediate 180-Foot Aquitards, were designated as no-flow boundaries. Layers 2 and 4, which represent the A- and the Upper 180-Foot Aquifers, respectively, did not have any no-flow boundaries assigned to it. However, the northern and the southeastern boundaries (except for the northeast edge of the model domain) of Layer 6 (Lower 180-Foot) were designated as no-flow boundaries.

### 4.4.2 Specified Head Boundary Conditions

The .BAS package of MODFLOW was used to simulate the specified head boundaries within the model domain. Generally, specified head nodes are useful to simulate the flow of water across the edge of the model (in or out of the model) and to help stabilize the iterative solution process. Specified head boundaries were assigned to the cells in Layers 2, 4, and 6 as follows:

- Along the southern border to set the upgradient heads in Layer 2 (simulating inflow to the A-Aquifer) and the eastern, western, and northern border to set the downgradient head (simulating outflow from the A-Aquifer) (Plate F2).

- Along the western, northern, and southwestern border to set the upgradient heads in Layer 4 (simulating inflow to the Upper 180-Foot Aquifer) and the south-eastern border to set the downgradient head (simulating outflow from the Upper 180-Foot Aquifer) (Plate F3).

- Along the western and southeastern border to set the upgradient heads in Layer 6 (simulating inflow to the Lower 180-Foot Aquifer) and the northeastern border to set the downgradient head (simulating outflow from the Lower 180-Foot Aquifer) (Plate F4).

In addition to the boundary conditions stated above, the Salinas River, which lies in the eastern portion of the OUCTP area and is observed to interact with the water table of the A-Aquifer, was also simulated in the model domain. Normally, the Salinas River would have been simulated using the River Boundary Condition; however, the hydrology of the Salinas River and its interaction with the A-Aquifer within the model domain is not well defined, with few data reports available. Also, the parameters that are necessary to define the River Boundary condition have not been determined for the Salinas River within the model domain. Therefore, the Salinas River was simulated as an outflow boundary using the specified head boundary.

The initial specified head boundary node elevations were estimated by primarily using the groundwater elevations in observations wells near the boundary. In areas where no observation wells were available, the specified head boundary nodes were estimated by projecting the inferred groundwater elevations in the central portion of the model domain to the edges of the model boundaries. Head values for cells along the boundaries between these nodes are linearly extrapolated by the model. However, specified head boundaries were modified during the calibration process.

## 4.5 Aquifer Properties

Discrete aquifer properties for MODFLOW include hydraulic conductivity, anisotropy, specific yield, specific storage, and porosity. However, specific yield and specific storage values are required only during transient simulation runs. As all our simulations were assumed to be steady state, specific yield and storage values have not been provided. The .BCF package of MODFLOW2000® was used to simulate the remaining aquifer properties within the model domain.

### 4.5.1 Horizontal Hydraulic Conductivity

Horizontal hydraulic conductivity ($K_h$) values were assigned to each model cell to simulate flow within the hydrostratigraphic layers of the model (Plates F6 through F8). The initial $K_h$ values in the three aquifers of the model domain were estimated from the limited aquifer test data and June 2004 groundwater elevations. This data was initially used in concert with a parameter estimation tool (PEST) to develop the initial distribution of hydraulic conductivity values throughout the model domain of each aquifer. Subsequent calibration of the model resulted in variations, including parameterization, of $K_h$ values; however, PEST-solved hydraulic conductivity distributions were useful in gaining insight to mechanisms of groundwater flow within the study area.

Initial hydraulic conductivity values for the model layers were further refined by incorporating additional zones of $K_h$, based on the observed lithologies in boring logs and various heterogeneities in the geologic materials comprising the model layers. $K_h$ values in outlying areas, not influenced by aquifer tests, were assigned based on boring log data and published estimates for aquifer materials. In addition, to provide a complete coverage of the model domain, interpreted conductivity values were extended to areas of the model domain where little or no data was available. Based on the $K_h$ data, different conductivity zones were allocated to different areas of the model domain.

During calibration, the assigned hydraulic conductivity for the various zones in the model Layers was refined in GMS in order to obtain an acceptable agreement to the calibration targets.

### 4.5.2 Vertical Hydraulic Conductivity / Vertical Anisotropy

The hydraulic communication between flow zones can be simulated using either vertical hydraulic conductivity ($K_v$) or vertical anisotropy ($K_h/K_v$). There is no vertical hydraulic conductivity ($K_v$) data available for the model domain beyond those estimated for the FO-SVA clay from brass tube samples collected from continuous core during well installation activities. Because field measurements of vertical hydraulic conductivity are rarely available typically, hydrogeologic studies commonly use typical ratios of horizontal-to-vertical hydraulic conductivity as a means of estimating and distributing values of vertical hydraulic conductivity. Based on the conceptual model of groundwater flow and the assumption that horizontal flow is dominant, the vertical conductivity values for a given cell in all the model Layers were assumed to be approximately one order of magnitude lower than the horizontal conductivity for that cell for Layers 4, 5, and 6 and two orders of magnitude for Layers 2 and 3. However, the hydraulic communication between the different flow zones was simulated using vertical anisotropy ($K_h/K_v$) for each Layer. A $K_h/K_v$ value of 100 was assigned to Layers 2 and 3, and a value of 10 to Layers 4, 5, and 6.

### 4.5.3 Horizontal Anisotropy

As stated in Section 2.8.2.1 of the RI – Volume I, the A-Aquifer is comprised of dune sand overlying a gently dipping marine clay unit (FO-SVA) that generally controls the direction of groundwater flow in this aquifer. The conceptual model implies that these dune faces and associated paleosols were more developed inland, which resulted in a slight northward anisotropy in the A-Aquifer. This was further confirmed by the groundwater flow direction and the migration of the CT plume in the A-Aquifer. Hence, to simulate this apparent migration of the CT plume in the A-Aquifer (Layer 2), horizontal anisotropy values have also been included in the model. An initial anisotropy value of 1.25 (25 percent northward anisotropy) was assigned to the portions east of the wave cut terrace in Layer 2 (A-Aquifer). Homogenous conditions (no horizontal anisotropy) were simulated in the wave cut terraces portions of the A-, Upper 180-Foot, and Lower 180-Foot Aquifers. During calibration, the assigned horizontal anisotropy in model Layer 2 was refined in GMS in order to obtain an acceptable agreement to the calibration targets. Final values range from 1.0 below the City of Marina (west of MW-BW-31-A) to 1.5 further east beneath the former Fort Ord, which is consistent with the conceptual model.

### 4.5.4 Effective Porosity

An effective porosity value of 0.30 was assigned to all the cells within the model domain. This value lies within the range of values specified for the soil within the area.

## 4.6 Recharge

Recharge to the model domain was simulated in MODFLOW2000® using the .RCH package. As stated previously in the conceptual model, net aerial recharge from precipitation (defined as the total recharge from precipitation that is available to the water table after taking into account loses from surface water runoff and evapotranspiration) was simulated as inflow to the model, and assigned to the uppermost active node within each vertical column of cells in the model domain.

Recharge was applied to the model in two zones, the largest being applied to the former Fort Ord area and a smaller zone covering the most developed portion of the City of Marina. The second zone was included on the basis that storm water within the city is more effectively captured and removed from the groundwater system within the model domain. Storm water in other areas of the model is collected in many small retention ponds and ultimately allowed to enter the groundwater system. The concentration of storm water at these retention ponds does not appear to be significant enough to warrant their specific simulation and hence recharge is simulated over the entire area as if they were not present.

For the steady state model simulation, a net areal recharge, which is used to account for the potential contribution of precipitation, of 0.001 feet per day [f/d] (4.4 inches/year) was provided at each cell along the east end of the model domain.

## 4.7 Groundwater Extraction/Injection

Groundwater pumping within the model domain was simulated in MODFLOW2000® using the WEL package. As stated in the conceptual model, ongoing pumping within the model domain occurs at ten OU2 extraction wells within the A-Aquifer, five OU2 extraction wells within the Upper 180-Foot Aquifer, and three active drinking water wells within the Lower 180-Foot Aquifer. However, injection of treated water to the A-Aquifer, which occurred from 1995 to 2000, was not simulated as the steady state simulation was calibrated to the June 2004 data, when no injection was occurring. The average simulated extraction rate for the OU2 extraction wells within the A-Aquifer ranged from 15 gallons per minute (gpm) in extraction wells EW-OU2-12-A and EW-OU2-15-A to 29 gpm in extraction well EW-OU2-13-A. In the Upper-180 Foot Aquifer, the average simulated extraction rate for the OU2 extraction wells ranged from 125 gpm in extraction wells EW-OU2-05-180 and EW-OU2-06-180 to

150 gpm in extraction well EW-OU2-03-180.  In the Lower-180 Foot Aquifer, the average simulated extraction rate for drinking wells MCWD-29, MCWD-30, and MCWD-31 were 767 gpm, 725 gpm, and 490 gpm, respectively.

## 4.8 Solute Transport Parameters

The construction of the mass transport model involved discretization of the solute transport parameters including bulk density, distribution coefficient (Kd), dispersivity and porosity.  The discretization of these parameters is described in Section 8.0 of this report.

# 5.0 GROUNDWATER FLOW MODEL CALIBRATION

This section presents the calibration of the steady state groundwater flow model performed to assess the model parameters. Calibration is the process by which model parameters, such as hydraulic conductivity, recharge, and boundary conditions, are adjusted within typical model criteria ranges and until the difference between observed and simulated hydraulic head values are within limits of acceptability. The model calibration was conducted in general accordance with the procedures presented in the ASTM Standard D 5981-96 (re-approved 2002) *Standard Guide for Calibrating a Ground-Water Flow Model Application*.

Before a groundwater flow model can be used for predictive simulations, it is necessary to obtain a reasonable correlation between the simulated and observed hydraulic head conditions under natural flow conditions. Because of the complexity of hydrogeologic systems, initial estimates of model parameters generally do not produce results that are consistent with observed field conditions. Hence a calibration process is performed, in which estimated model parameters defining the modeled system are adjusted, until an acceptable match between the modeled and observed values is achieved. The following model variables were modified during the calibration of the model: hydraulic conductivity, anisotropy, and the hydraulic head assigned to the boundary cells.

The following sections describe the calibration to target water elevations, the procedures that were followed during the calibration of the groundwater flow model, the resulting calibrated parameters and boundary conditions, and the quality of the calibration.

## 5.1 Calibration to Target Groundwater Elevations

The groundwater flow model was calibrated until a reasonable correlation between the observed water elevation data and the simulated model heads was achieved. The groundwater elevation data collected from a relatively complete data set of monitoring wells were used as the primary set of calibration targets.

MACTEC calibrated steady state groundwater conditions to the June 2004 groundwater data. Pumping from the extraction wells and recharging from Fort Ord operations within the model domain were also incorporated during the calibration process.

## 5.2 Calibration Procedures

The model was calibrated consistent with the procedures presented in ASTM Standard D 5981-96 (re-approved 2002). Model parameters and boundary conditions were adjusted in a systematic manner until a reasonable fit was obtained between the model solution and the target water elevation data. Plates F9 through F11 depict the observed and simulated potentiometric surface contours associated with the *steady state condition* for the A-, Upper 180-Foot, and Lower 180-Foot Aquifers, respectively. Linear plots of computed versus observed needs are illustrated in Plates 13A, 13B, and 13C, for the A-Aquifer, Upper 180-Foot Aquifer, and Lower 180-Foot Aquifer, respectively,

Initial model parameters and boundary conditions were taken primarily from information published in the previous Site Investigation reports; and, from groundwater extraction and groundwater level data obtained from monitoring reports and from existing operations. Data from other sources were used to supplement the data from the above reports to arrive at a more localized representation of the model domain-specific parameter values and boundary conditions. Using these initial values, the *steady state* simulation was performed, and groundwater head results of the *steady state* simulation were compared to those observed.

As is typical of such modeling, the initial *steady state* simulation did not adequately mimic observed heads for the *steady state condition*. Where deviation from expected values occurred, consideration was given to changing boundary and initial conditions, and grid cell characteristics. Small changes were made in general head elevations at the boundaries. Substantial changes were made to hydraulic conductivity during the calibration process. Data were evaluated repeatedly to realistic values and resulted in simulated groundwater elevations that approached observed groundwater elevations.

### 5.3 Calibration Quality

A qualitative evaluation of the calibration can be made by comparing the observed potentiometric surface for the *steady state condition* with the simulated potentiometric surface. It is apparent from a comparison of the observed and the model simulated potentiometric surface maps, that the calibrated model is generally capturing the major features of the groundwater flow system. The elevation, shape, magnitude, gradient, and position of the potentiometric surface are accurately simulated by the calibrated model.

The quality of the calibration can be measured more objectively in the following two ways: 1) by the model convergence statistics, and 2) by the target water level residual statistics. The model convergence statistics are a measure of the quality of the iterative solution of the model. A target water level residual is defined as:

Residual = (Target Value - Model Predicted Value)

For the model, the residuals are in units of feet. The closer the residual is to zero (0), the better the fit at a given target location.

#### 5.3.1 Convergence Statistics

The quality of the iterative solution of the model is measured by a number of convergence statistics. These parameters include the maximum head change for all model cells between iterations (head change), and the percent discrepancy between the total flow into and out of the model (volumetric flow budget discrepancy). Generally, the head change should be small (less than approximately 0.1 foot for the model), but may be affected by a single “problem” cell within the model domain. The most important convergence statistic is the volumetric flow budget discrepancy, and it should be close to, or less than, 5%. The convergence statistics (absolute values) for the final calibrated model are as follows: -0.01 foot head change and 0% volumetric flow budget discrepancy for the *steady state* simulation. These statistics indicate acceptable model convergence.

### 5.3.2 Residual Statistics

The residual statistics were evaluated by the following: 1) by traditional statistics, 2) by the spatial distribution of the residuals, and 3) by a graphical presentation of the observed target heads *versus* the model predicted heads. During calibration, the primary statistical methods (residual mean error, absolute residual mean error, and root mean squared [RMS] residual error) were obtained for comparing observed and simulated hydraulic heads at selected calibration targets within the model domain. The goal of the calibration was to obtain a residual mean as close to zero as possible and to minimize the sum of the squared residuals.

A qualitative analysis of the similarity between the interpreted and predicted hydraulic head values indicates a close correlation between the heads at the groundwater monitoring wells. Table 1 presents the residuals for each target location for the steady state groundwater condition. Positive residuals indicate targets where simulated heads are less than observed water levels, while negative residuals indicate targets where simulated heads are greater than observed water levels.

The evaluation of the residual statistics for the *steady state* simulation indicates an acceptable model calibration since the residual mean value is close to zero (Table 1). The mean residual was 0.856, 0.018, and 0.336 for the A-, Upper 180-Foot, and Lower 180-Foot Aquifers, respectively. The RMS residual error was 3.967, 0.811, and 1.296 $ft^2$ for the A-, Upper 180-Foot, and Lower 180-Foot Aquifers, respectively. From Table 1, it is observed that the *steady state* simulation residuals for all the calibration targets were within a range of -11.57 feet to 13.03 feet, -1.951 to 1.862 feet, and -3.853 to 3.524 for the A-, Upper 180-Foot, and Lower 180-Foot Aquifers, respectively. The large discrepancy range of residuals in the A-Aquifer is attributed to only a few of the calibration targets which are located primarily near the boundaries. In addition, discrepancies in residuals could be attributed to surface control of recharge, localized variations in aquifer characteristics, and the inherent limitations of the model discretization

In general, the sign and magnitude of the residuals were randomly distributed within the model domain, as was desired. Plates F13-A, F13-B, and F13-C show the plot of the observed heads *versus* the simulated heads for the *steady state* simulation for the A-, Upper 180-Foot, and Lower 180-Foot Aquifers, respectively. For an ideal model calibration, the data should plot on a 45 degree line as shown. Based on Plates F13-A, F13-B, and F13-C, the calibration is acceptable.

## 5.4 Water Budget

The water budget for the calibrated *steady state* model can be summarized by the following contributions to inflow and outflow of the model.

For the *steady state simulation*, the inflows to the calibrated model consisted of 192,284 cubic feet per day ($ft^3$/d) from recharge and 854,421 $ft^3$/d from the upgradient specified heads (as inflow). The outflows from the calibrated model consisted of approximately 521,057 $ft^3$/d from the extraction wells, and 525,648 $ft^3$/d from the downgradient specified heads located along the specified boundaries of each model layer. There was an no discrepancy between the inflow and outflow of the calibrated model. The ASTM Guide considers a water budget discrepancy of less than 5% adequate.

# 6.0 MODEL VERIFICATION

Model verification is a critical step in the modeling process that provides an opportunity to test the model's predictive capability. If model verification simulations indicate that the model is not capable of simulating the field observations or the correlation between the predicted and observed responses is insufficient, then the model calibration must be revisited. This is done by adjusting the model input parameters until a good correlation is obtained. Once the results of the model calibration and verification simulations are acceptable, then the model is ready for making predictive simulations.

A groundwater flow model is typically verified to evaluate whether the groundwater flow model is capable of reliably predicting responses to aquifer stresses such as an aquifer pump test or duplicating the observed water levels for a non-calibration period. Following model calibration, the groundwater flow model was verified by simulating the MW-BW-14A and MW-BW-44A constant rate discharge tests for the A-Aquifer, and comparing predicted and observed drawdown values. In addition, model verification was also performed by simulating the MW-OU2-49-180, MW-OU2-51-180, and MW-OU2-53-180 constant rate discharge tests for the Upper 180-Foot Aquifer, and comparing predicted and observed drawdown values. Transient model runs were performed using the hydraulic head data from the final steady state calibration run as the initial conditions. Pumping test A-Aquifer wells MW-BW-14A and MW-BW-44A, and Upper 180-Foot Aquifer wells MW-OU2-49-180, MW-OU2-51-180, and MW-OU2-53-180 were simulated operating at 7, 6.5, 125, 150, and 175 gpm for a period of 1, 0.4, 3, 2.2, and 3 days, respectively. Predicted drawdown values were calculated for each observation well, and were compared to observed drawdown values.

Table 2 summarizes the results of the model verification runs. Based on the simulated drawdowns, the model adequately predicted the behavior of the observed drawdown during the tests. Any discrepancies between the observed and predicted drawdown for the tests can potentially be attributed to the "coarse" discretization of the model grid and the larger diameter model representation of the pumping well (10 feet by 10 feet cell) compared to the actual well (completed in a 10-inch diameter borehole).

# 7.0 SENSITIVITY ANALYSIS

This section presents the results of sensitivity analysis simulations performed on the steady state calibrated model. After the model was calibrated (Section 5.0) and predictive simulations were run (Section 6.0), a sensitivity analysis was performed to identify which model input parameters have the most impact on the degree of calibration. The model sensitivity analysis was conducted in general accordance with the procedures presented in ASTM Standard D 5447 *Application of a Ground-Water Flow Model to a Site-Specific Problem* (*ASTM, 1994*).

The sensitivity analyses conducted generally were limited to those model parameters found to have significant effect on results during calibration and during the ambient condition predictive simulations. The implications of the sensitivity analysis are dependent on the accuracy of the input data, as is the case with any model results. A general, qualitative, sensitivity analysis of the model was performed during the initial stages of the model calibration to determine which parameters most affect the calibration process. Based upon this analysis, it was found that horizontal hydraulic conductivity ($K_h$), and anisotropy in Layer 1 were the most sensitive model parameters (given the anticipated range of each model parameter) for the steady state (calibrated) condition. Also during calibration, other poorly constrained model parameters, such as natural and artificial boundary conditions which represented upgradient inflow and downgradient outflow conditions, and vertical hydraulic conductivity in Layers 4 through 6 were found to affect the calibration only in a limited way. Hence, sensitivity analysis of these parameters was not conducted as changes in these values did not have that great an impact at the Site area similar to that observed for the $K_h$ and S parameters.

During the sensitivity analysis, the least constrained model parameters, such as natural and artificial boundary conditions, unverified pumping rates, and/or poorly constrained aquifer parameters were increased or decreased in a systematic way. This approach assesses the sensitivity of model results to individual parameters, the uncertainty of model predictions, and the potential need for addressing parameter uncertainty in the future. Generally, changing a value of an input parameter in a single zone or layer will not significantly affect the results. Therefore, the selected model inputs upon which the sensitivity analysis was performed were modified as a group. Model sensitivity was examined by observing changes in the mean absolute error and bias of the resulting simulated water levels.

Sensitivity analysis of $K_h$ was performed by decreasing and increasing the calibrated value by an order-of-magnitude, while values of the remaining parameters were held constant. The ratio between the horizontal and vertical hydraulic conductivity was preserved for these simulations. Results of the sensitivity analysis for the variation of $K_h$ in the steady state indicated that changes in the calibrated $K_h$ had significant effects on the overall calibration of groundwater flow within the model domain, and the quantity of underflow into the system. Increasing the $K_h$ by an order of magnitude resulted in increasing the transmissivity of the model layers, which resulted in a significant variation in the heads of the calibration targets, and a significant increase in the quantity of underflow into the groundwater system. Decreasing the $K_h$ by an order of magnitude resulted in decreasing the transmissivity of the model layers, which resulted in moderate changes in groundwater flow direction, and a significant decrease in the quantity of underflow into the groundwater system.

Similar analysis of the sensitivity of the model to variations in the horizontal anisotropy in Layer 1 also indicated variations in the overall calibration of groundwater flow within Layer 1 (A-Aquifer) in the model domain. However, the variations in the overall calibration were not as significant as those observed during changes of $K_h$.

In summary, the model is found to be most sensitive to variations in hydraulic conductivity of the soil materials underlying the model domain, and mildly sensitive to variations in the anisotropy in Layer 1.

# 8.0 MASS TRANSPORT MODEL SIMULATION

The primary objectives of the mass transport modeling activities were to evaluate various remedial alternatives. Prior to simulating remedial alternative scenarios, it was necessary to calibrate the final solute transport parameters. To achieve these objectives, and following calibration of the steady state groundwater flow model, mass transport of CT in the A-Aquifer was simulated using the numerical mass transport model MT3DMS® (*Zheng, 1999*). Simulation of mass transport of CT was limited to the A-Aquifer due to complexity associated with historical pumping and vertical conduits (both their location and time of construction). In addition, remedial alternatives requiring the simulation of mass transport were only considered for CT within the A-Aquifer. The MT3DMS® model was calibrated to CT groundwater concentrations from 1995 through 2004. Based on the operational history of the site, an assumed release date of 1950, and the assumption that the former drum storage area was the primary source of impact at the site, a 55-year steady state calibration run was conducted to simulate the distribution of CT. This simulation was performed to obtain the final transport parameters, before utilizing the model to evaluate the remedial alternatives identified in the GCMP. The discrete solute transport parameters of the aquifer including bulk density, distribution coefficient (Kd), dispersivity and porosity, are used to simulate advection, dispersion, and chemical reactions of constituents in groundwater. Each of these transport parameters have been defined in the transport modules discussed below.

## 8.1 Solute Transport Model Construction

The discrete solute transport parameters of the aquifer used to simulate advection, dispersion, and chemical reactions of constituents in groundwater are adjusted to arrive at the calibrated three-dimensional mass transport solution for the Study Area. These solute transport parameters were defined in the transport modules discussed below.

### 8.1.1 Basic Transport Package (BTN)

The BTN package is used for definition of the transport problem, specification of boundary and initial conditions, and preparation of mass balance information. The BTN package provides the same function in MT3DMS® as the BAS package provides in MODFLOW2000®. It contains the grid configuration, the layer types being modeled, the layer thicknesses, the effective porosity of the aquifer material, the initial boundary conditions, and the type and length of simulation being performed. The grid mesh configuration was similar to the one used for the groundwater flow model.

### 8.1.2 Advection Package (ADV)

Advection describes the transport of miscible constituents at the same velocity as the groundwater. The ADV package uses a hybrid particle tracking algorithm that performs particle tracking, calculates the concentrations at arbitrary points within the model domain, and computes the mass flux into or out of a given cell. The Hybrid Method of Characteristics / Modified Method of Characteristics (HMOC) solution scheme with the combination Euler and Fourth Order Runge-Kutta particle tracking algorithm was adopted as the advection module type.

### 8.1.3 Dispersion Package (DSP)

The DSP package calculates the components of the hydrodynamic dispersion coefficient for the aquifer. Hydrodynamic dispersion refers to the spreading of a miscible contaminant over a region greater than that predicted solely from the advective mechanism. Hydrodynamic dispersion is comprised of molecular diffusion, which is a result of variations in concentrations, and mechanical dispersion, which is a result of deviations of the actual groundwater velocity from the average velocity. Molecular diffusion effects are deemed negligible when compared to mechanical dispersion effects for aquifers having highly conductive materials. The molecular diffusion was assumed to be negligible for the purpose of our model. A longitudinal dispersivity value of 100-feet was used to represent the initial dispersivity within each of the layers in the model domain. These initial values were obtained from empirical values from literature pertaining to similar lithologies.

Transverse dispersivity values are typically found to be an order of magnitude less than the longitudinal dispersivity values, while vertical dispersivity values are typically found to be two orders of magnitude lower than the longitudinal dispersivity values. These ratios are again based on empirical relationships available in literature for similar lithologies. The dispersivity values and ratios were further modified during the initial calibration process. The dispersivity values were utilized to simulate the effects of horizontal and vertical movement of the CT plume in the Study Area. This was essential to obtain a good correlation between observed and simulated CT values, and also explain the movement of the CT due to anisotropy and pumping.

### 8.1.4 Sink and Source Package (SSM)

This SSM represents the solute mass entering or leaving the simulated domain through sources and sinks, respectively. This package is primarily used to identify areas or points of solute / mass injection or removal through wells, drains, rivers, recharge and evapotranspiration. At present, only the point source/sink option of this package, which is represented by wells and mass loading points, is used to simulate the extraction wells and the source areas, respectively. For the steady state simulation, the mass loading that represents the source distribution, is discussed in Section 8.1.6.

### 8.1.5 Chemical Reaction Package (RCT)

The RCT package represents the equilibrium controlled linear sorption and first order irreversible rate reactions (radioactive decay or biodegradation) that affect the solute transport in groundwater. Also, this package simulates the decay in the source term due to biodegradation or the use of remedial technologies. Sorption is the process that causes the slower migration of solute with respect to groundwater. Sorption can be defined as the mass transfer process between the constituents dissolved in the solution phase and the constituents adsorbed on the solid phase. The partitioning between these two phases is called the distribution coefficient ($K_d$). Sorption is generally incorporated into a transport model through the use of the retardation factor, which is related to the distribution coefficient by the following formula:

$$R = 1 + K_d\ (\rho/n)$$

where,

| | | |
|---|---|---|
| R | = | retardation factor for a water quality constituent |
| $K_d$ | = | distribution coefficient |
| $\rho$ | = | bulk density of the aquifer sediments |
| n | = | effective porosity of the aquifer sediments |

Organic compounds such as CT are hydrophobic and are sorbed by weak forces. The sorption of these compounds is related to the amount of organic carbon in the aquifer materials. Kd can be determined from the organic carbon content by the following equation:

$$K_d = f_{oc}\ \text{x}\ K_{oc}$$

where,

| | | |
|---|---|---|
| $f_{oc}$ | = | fractional organic carbon concentration in the aquifer sediments |
| $K_{oc}$ | = | distribution coefficient of the organic compound in water and 100 percent fraction organic carbon |

This implies that the retardation factor is dependent upon the percentage of organic carbon contained within the aquifer. A value of $5.37e^{-11}$ $ft^3$/mg was used to represent the initial value of $K_d$ for CT. In addition, a value of 45,000,000 mg/$ft^3$ was used to represent the average bulk density of the aquifer. Both the '$K_d$' and the '$\rho$' values used in the initial calibration runs were based on the results obtained from the previous modeling conducted at the Study Area. Based on these values, a single retardation factor for CT of 1.01 was assigned to each active cell within the three layers of the model domain for the initial calibration runs. This uniform value was selected based on available data from previous modeling studies conducted for the site. These initial values were modified, as necessary, during the calibration processes of the transport model.

A first order irreversible process that would represent radioactive decay or biodegradation was also included for the initial solute transport run of the model. However, based on simulation runs during the calibration process, the effect of solute decay was deemed negligible, and hence not simulated.

### 8.1.6 Source Term Distribution

The performance of a solute transport simulation requires the assignment of source concentrations to various cells within the model. The following sections discuss the assignment of the source term in the Steady State Simulation and the use of the Steady State Simulation output to establish the source term for the remedial simulations.

The Steady State Simulation modeled the migration of the CT plume from its assumed origin in 1950 to the present time of 2004. As stated in the Section 3.2.4, a small facility, allegedly used for storage of CT for cleaning of electronic components, was located at what is now Lexington Court from at least 1949 to 1955. Assuming that one five-gallon can was used monthly for the six years during which the facility appears to have existed, the approximate volume of CT storage amounts to 360 gallons. Because the model only simulates groundwater flow and not unsaturated flow or the potential for mass storage within the vadose zone, CT mass from the source area was applied from 1950 to present with an exponential decay, simulating the initially rapid mass transfer from the vadose zone to the A-Aquifer with progressively slower mass transfer until concentration within the vadose zone resembled residual conditions observed in 2004. Calibration of the mass transport model was initiated with source terms equaling this mass. This effect was simulated using the variable mass loading option, with CT mass estimated at initial rates of approximately 503,000 mg/day, tapering off to a flux of 5,000 mg/day. Therefore, for the purpose of the Steady State Simulation and to adequately calibrate the model, three source nodes were incorporated into the model Layer 1 cell nodes (74,98), (74,99), and (74,100). The extent of the source and its concentrations were modified during the calibration runs, until a final source concentration that provided the best-fit results was obtained.

The best fit to the current plume footprint and CT concentrations in the A-Aquifer were attained with a cumulative mass of 162 gallons of CT applied over a 50-year period of time as described above. However, cumulative mass that had historically or currently exists in the Upper and Lower 180-Foot Aquifers or mass removed via historical pumping at previously used municipal wells has not been simulated. Therefore, the actual amount of CT released circa 1950 has not been completely accounted for in this simulation. Given our knowledge of the small storage facility and the use of CT as a cleaning solvent from the 1940's until its phase-out in the late 1950's, it is reasonable to assume that initial estimates of approximately 360 gallons to perhaps 1,000 gallons of CT had been released at the source area over perhaps as many as 15 years; however, no records have been located to corroborate these estimates.

The SVE pilot study effectively removed residual mass (totaling about one pound of CT) from the vadose zone, thus halting the potential for future mass transferal to A-Aquifer groundwater. Therefore, predictive remedial simulations did not simulate any mass flux from the source area.

## 8.2 Model Calibration and Results (Steady State Simulation)

Before a transport model can be used for evaluating various remedial alternatives, it is necessary to obtain a reasonable correlation between the simulated and observed CT concentrations under natural flow conditions. Because of the complexity of hydrogeologic systems in general, initial estimates of model transport parameters generally do not produce results that are consistent with observed field conditions. Hence, a calibration process, in which estimated model transport parameters that define the modeled system are adjusted, is performed until an acceptable match between the simulated and observed CT concentration values is achieved. Also, the iterative process aids in identifying potential data gaps associated with the transport parameter values in the model domain.

Initial calibration of the model was conducted by performing multiple simulations, while modifying transport parameters such as dispersivity, chemical reaction terms, and source location and concentrations until model target concentrations were obtained. These initial calibration simulations were used to modify and finally obtain the calibrated transport parameters. The following subsections describe the calibration target concentration levels, the procedures that were followed during the calibration of the mass transport model, the resulting calibrated transport parameters and boundary conditions, and the quality of the calibration. Throughout this section, Figures are used to illustrate the simulated plume and capture zones.

### 8.2.1 Calibration Target Concentration Levels

The initial calibration process implemented was an iterative exchange in which the solute transport parameters were simultaneously modified and estimated until an optimal calibration corresponding to the average CT concentration data and the CT plume in June 2004 was achieved. In order to effectively simulate the mass transport conditions, it was necessary to calibrate the mass transport model to steady state conditions.

### 8.2.2 Calibration Procedures

The model was calibrated for CT consistent with the procedures presented in ASTM standard D5447 (*ASTM, 1994*). Model transport parameters and boundary conditions were adjusted in a systematic manner until an acceptable fit was obtained between the model solution and the target concentration data. This initial calibration was conducted according to the following approach:

1. Calibrating the source concentration to match CT concentrations observed in nearby target wells without modifying the dispersivity and chemical reaction terms.

2. After achieving initial calibration of the source concentration and nearby target well concentrations, the dispersivity values are modified to match the lateral and vertical extent of the plume to target well data.

3. Keeping the dispersivity and chemical reaction terms constant, recalibrating the source concentration to simulate the lateral extent of the CT plume to match observed CT plume footprints from 1995 through 2004.

### 8.2.3 Calibration Results

A qualitative analysis of the similarity between the interpreted and predicted CT plume footprint, and the concentrations at selected target wells, indicate a close correlation between the observed and simulated CT plume within the Study Area. Some degree of discrepancy between simulated and observed CT concentrations at certain calibration locations should be expected and are generally attributed to localized variations in the aquifer characteristics and variation in the pumping of the aquifer. In addition, the modeled concentrations represent average concentrations across the entire cell where the observed concentrations are derived from specific samples which are subject to variability due to sampling technique, seasonal variation, and other external influences that cannot be simulated by the model.

Plate F13 depicts the observed and simulated CT Plume footprint in the A-Aquifer in June 2004. In 1992, a CT concentration of approximately 6 μg/L had been detected in MW-B-14-A, but was not detected at MW-B-12-A (with a reporting limit of 5 μg/L). The mass transport simulation results are consistent with these data as the simulation illustrates CT concentrations of approximately 5 μg/L had reached MW-B-14-A in 1992, but had not reached MW-B-12-A. Subsequent migration to the west has also been simulated consistent with the progressive delineation of the CT plume in the A-Aquifer. However, simulated results for 2004 indicate an acceptably larger plume footprint in the toe area, which provides slightly conservative starting conditions for predictive analyses used to evaluate remedial alternatives.

### 8.2.4 Calibrated Transport Parameters

The final calibrated solute transport parameters established by the Steady State Simulation consisted of the following:

- A uniform longitudinal dispersivity value of 40 feet was found to be applicable for the A-Aquifer. Based on the simulated results, a transverse to longitudinal dispersivity ratio of 0.0002, and a vertical to longitudinal dispersivity ratio of 0.00001 were assigned to the model layers. These low ratios indicate that the CT plume in the A-Aquifer is governed by advective flow in the longitudinal direction, and that there is minimal transfer of CT mass from the A-Aquifer to the FO-SVA aquitard.

- The calibrated source concentration was estimated have an initial rate of approximately 246,000 mg/day per cell, tapering off to a flux of 5,000 mg/day. The total mass applied over the period of simulation (1950 through 2004), over the area represented by three model cells located at Lexington Court, approximates 162 gallons; however, the mass does not account for CT in the Upper and Lower 180-foot Aquifers or CT that had been removed historically by pumping from previously used municipal wells.

## 9.0 PREDICTIVE SIMULATIONS

Following completion of the steady state calibration, the verification check, and the sensitivity analysis of the groundwater flow model, and calibration of the mass transport model, a series of predictive simulations were performed to evaluate various remedial alternatives in support of the FS (Volume III). This section presents the design procedures, predictive simulations, and results of the proposed remedial alternatives for containment and clean-up of the A-Aquifer and Upper 180-Foot Aquifer CT plumes. The simulations were performed using the steady state calibrated groundwater flow and mass transport model.

The main objective of numerically simulating the proposed remedial alternatives is to evaluate the effectiveness of each remedial alternative in containing and mitigating the CT plume. Based on the evaluation of the various factors and the main objective, four remedial alternatives were evaluated. The salient features of each scenario are as follows:

- ***Scenario 1 - Advective Capture and Transient Mass Removal of the A-Aquifer CT plume via Groundwater Extraction/Injection***: This scenario uses transient groundwater flow conditions with particle traces to predict the direction of flow under pumping conditions from A-Aquifer extraction/injection wells. Backward particles are simulated from each extraction well to illustrate capture solely from advective processes. It then uses results from the steady state advective simulation in combination with the transient simulation of A-Aquifer CT mass transport to predict the rate of mass removal. The goal is to optimize the location, number, and extraction rates of the extraction wells that may be necessary to capture the A-Aquifer CT plume.

- ***Scenario 2 - Advective Capture of the Upper 180-Foot Aquifer CT plume via Groundwater Extraction (Transient Particle Analysis of Upper 180-Foot Aquifer)***: This scenario is similar to Scenario 1 except that particles will originate from the newly installed extraction Well EW-OU2-07-180 (part of the expanded OU2 GWTS) to predict capture at various pumping rates.

Forward particle analysis will also be accomplished with particles originating at each of the two suspected vertical conduits and observing capture afforded by the OU2 extraction wells.

- ***Scenario 3 - Enhanced Natural Attenuation of A-Aquifer:*** This scenario simulates the dechlorination of CT under favorable chemical conditions induced by the addition of an electron donor such as lactate in sufficient quantity and number of locations to remediate the A-Aquifer CT plume.

- ***Scenario 4 - Use of a Permeable Reactive Barrier (PRB)*****:** This scenario simulates dechlorination with the use of a PRB to passively remove CT from the A-Aquifer near MW-BW-42-A.

The initial contaminant mass condition selected for the remedial alternative simulations included using the CT plume footprint that was obtained from the Steady State simulation in 2004. A 30-year treatment life was assumed for evaluation purposes. However, in Scenarios where more than 30-years were required to evaluate the effectiveness of the proposed remedial alternative, the simulation was performed for a longer duration of time, up to a maximum of 50 years.

Prediction of mass transport of CT was limited to the A-Aquifer because (1) remedial alternatives requiring the simulation of mass transport were only considered for CT within the A-Aquifer, (2) mass transport through the two suspected vertical conduits is extremely subjective of numerous assumptions not provable with this model and, hence, predictive analysis would be of limited use.

The injection of simulated extracted water from Scenario 1 was designed to facilitate capture and expedite removal of mass from the A-Aquifer; however, simulation of the eastward migration of the A-Aquifer CT plume in response to injection of treated water associated with the OU2 GWTS, which lies west of the OUCTP plume, is not simulated under these conditions. Also, injection was not simulated as part of Scenario 2 as it is assumed that existing injection wells located outside the model domain will be used. If, in fact, IW-OU2-03-180, located just west of the OUCTP Upper 180-Foot Aquifer, is reactivated, Scenario 2 will require appropriate revisions to evaluate the effectiveness of this alternative.

The following sub-sections summarize the design procedures, assumptions, and predicted CT concentrations for the four remedial alternative simulations.

## 9.1 Scenario 1

The primary objective of this model evaluation phase was to simulate and evaluate the capture of the A-Aquifer CT footprint by groundwater extraction in conjunction with mass removal of CT. This simulation provides an accurate assessment of the remedial operation period required to remediate the A-Aquifer plume via groundwater extraction. These results are then used to estimate costs as part of the FS (Volume III) in comparison to other alternatives. The following sections describe the design procedures and the results for the remedial alternative Scenario 1 simulation.

***Design Procedures***

The proposed extraction wells EW-OUCTP-01 through EW-OUCTP-05 were simulated in the model domain by using the .WEL package of MODFLOW2000®.

During the simulation of this remedial alternative, several configurations of the extraction well locations and their pumping rates were simulated. This was done to estimate the optimum locations and extraction rates while maintaining capture of the CT plume. Based on these optimization simulations, five extraction wells located within the A-Aquifer CT plume footprint were determined to be capable of providing adequate capture. The extraction wells pump at 50 gallons per minutes (gpm), 40 gpm, 30 gpm, 35 gpm, and 10 gpm from EW-OUCTP-01-A, EW-OUCTP-02-A, EW-OUCTP-03A, EW-OUCTP-04A, and EW-OUCTP-05-A, respectively.

The simulation was initiated with current (2004) concentrations resulting from the steady state mass transport simulation. Steady state condition was simulated in the interest of minimizing computing time and under the realization that, despite significant groundwater elevation change in response to the 1997/98 El Nino precipitation event, the direction of groundwater flow within the A-Aquifer did not change significantly. However, simulation of the eastward migration of the A-Aquifer plume in response to injection of treated water associated with the OU2 GWTS west of the OUCTP plume is not simulated under these conditions. The discrepancy between observed and simulated conditions in this respect is thus easily explained and, given the low probability that this mass will continue to migrate eastward, its omission from this simulation is acceptable. In addition, no information exists regarding the use or disposal of CT at the source area, and results of the steady state simulation reasonably represent observed conditions and plausible conditions not observed (i.e., where monitoring wells have not been installed). Thus, results of this simulation, under steady state conditions, are considered to be conservative.

***Scenario 1 Results***

Plates F14-A through F14-G illustrate the results of the Scenario 1 simulations. As illustrated in Plates F14-A through F-14G, the five extraction wells located within the A-Aquifer CT plume footprint are capable of providing adequate capture of the majority of the CT plume upgradient of EW-OUCTP-01, and the CT plume in this area could be remediated in 30 years. However, groundwater downgradient of EW-OUCTP-01 would remain contaminated at concentrations ranging between 0.5 and 5 μg/L because of the inability of well EW-OUCTP-01 to capture the CT mass that is already present downgradient of the capture radius of the well. Any increase in the pumping rate in well EW-OUCTP-01 results in drying out the model cell. This indicates that not enough water is available to support an increase in the pumping rates.

## 9.2 Scenario 2

The primary objective of this model evaluation phase was to simulate and evaluate capture deriving from the operation of extraction well EW-OU2-07-180, associated with the OU2 GWTS, located near the area where the OUCTP and OU2 plumes merge in the Upper 180-Foot Aquifer prior to entering the Lower

180-Foot Aquifer. This simulation provides an estimate of the cumulative volume of water requiring treatment and amount of time necessary to provide capture within the Upper 180-Foot Aquifer. The results are used to estimate costs as part of the FS (Volume III) in comparison to other alternatives. The following sections describe the design procedures and the results for the remedial alternative Scenario 2 simulation.

***Design Procedures***

The proposed extraction from well EW-OU2-07-180, and the other OU2 GWTS wells, was simulated in the model domain by using the .WEL package of MODFLOW2000®. This simulation also includes the simulation of pumping from the A-Aquifer and the Lower 180-Foot Aquifer extraction wells. The extraction rates adopted for the existing extraction wells were the average extraction rates observed and calculated during the operation of the ongoing system.

In this Scenario, the existing Upper 180-Foot Aquifer groundwater extraction was enhanced by extracting groundwater at an initial rate of 150 gpm from an additional extraction well EW-OU2-07-180. In addition, several combinations of the pumping rates of the Lower 180-Foot Aquifer extraction wells were simulated to estimate their optimum extraction rates while maintaining capture of the CT plume.

This simulation was also performed under a steady state condition so as to minimize computing time. As in the previous simulations, the results of this simulation, under steady state conditions, are considered to be conservative.

***Scenario 2 Results***

Plate 15 illustrates the result of the Scenario 2 simulation. For this Scenario, backward particle tracking simulated at each extraction well was used as an indicator of groundwater capture. Extraction of groundwater at a rate of 150 gpm from EW-OU2-07-180 along with the ongoing extraction from the other Upper 180-Foot Aquifer extraction wells sufficiently captures the Upper 180-Foot Aquifer CT plumes, in addition to providing capture to the TCE plume associated with OU2. However, optimization procedures must be employed to maintain capture within the Upper 180-Foot Aquifer so as to comply with the treatment capacity limitations of the OU2 GWTS (approximately 600 gpm).

## 9.3 Scenario 3

This scenario consists of remediation of the CT plume in the A-Aquifer using a Lactate Recirculation and Injection System throughout the length of the CT plume. Enhanced natural attenuation was field tested with the addition of lactate to the A-Aquifer (Section 3.9), which resulted in the immediate decrease in CT concentrations in monitoring wells located approximately 20 feet from the recirculation well. This simulation builds from the same steady state conditions used to construct Scenario 1, but does not include the extraction or injection of groundwater beyond those associated with the OU2 GWTS. Steady state conditions are permissible because, as shown during the field-scale pilot study, groundwater elevations remained unchanged during the recirculation of lactate into the A-Aquifer. The following section describes the design procedures and the results for the remedial alternative Scenario 3 simulations.

***Design Procedures***

This Scenario 3 remedial simulation was performed by simulating a line of cells having higher degradation rates (lower contaminant half-lifes) at 10 locations along the plume length. Each of these locations was represented by a line of lactate injection points located in a direction perpendicular to groundwater flow. The degradation rate for CT was obtained from the Bio-treatability Field-scale Pilot Study (Section 3.9 of the RI-Volume I). The pilot study successfully demonstrated that CT concentrations could be reduced within a 20-foot radius of a recirculation well, with the addition of 250 gallons of sodium-lactate (60 percent solution). Based on the results of the Study, first order rate constants of CT were estimated, and a decay constant equating a 21-day half-life was used to simulate the enhanced degradation of CT in the A-Aquifer.

The dechlorination of CT in the A-Aquifer is accounted for by using the .RCT package of MT3DMS®. The location and number of recirculation wells were derived from results of the field-scale pilot study (20-foot radius for a given volume of lactate). Actual performance and radius of influence of an electron donor will necessarily vary upon unknown conditions not able to be simulated at this time. Heterogeneities within the A-Aquifer have been accounted for as part of the advective model calibration and, hence, results are useful for comparison purposes to other remedial alternatives.

The simulation was initiated with current (2004) concentrations resulting from the steady state mass transport simulation. Steady state conditions are permissible because, as shown during the field-scale pilot study, groundwater elevations remained unchanged during the recirculation of lactate into the A-Aquifer. Because no information exists regarding the use or disposal of CT at the source area, results of this steady state simulation reasonably represent observed conditions and plausible conditions not observed (i.e., where monitoring wells have not been installed). Thus, results of this simulation are considered to be conservative.

The 10 model locations used to simulate the injection points were as follows:

- Injection Point location 1, which lies between wells MW-BW-23-A and MW-BW-53-A, was simulated by 6 model cells located at model cell addresses of 70,95 through 70,100. The total length of the model cells in the direction perpendicular to groundwater flow was approximately 350 feet. Based on the 40 feet zone of influence observed for each recirculation well during the Pilot Study, this length equates to 10 injection points at this location.

- Injection Point location 2, which lies between wells MW-BW-24-A and MW-BW-17-A, was simulated by 18 model cells located at model cell addresses of 62,81 through 62,98. The total length of the model cells in the direction perpendicular to groundwater flow was approximately 480 feet. This equates to 13 injection points at this location.

- Injection Point location 3, which lies along the CT plume axis upgradient of well MW-BW-27-A, was simulated by 8 model cells located at model cell addresses of 33,79 through 40,72. The total length of the model cells in the direction perpendicular to groundwater flow was approximately 720 feet. This equates to 19 injection points at this location.

- Injection Point location 4, which lies along the CT plume axis upgradient of well MW-BW-31-A, was simulated by 10 model cells located at model cell addresses of 15,76 through 24,67. The total length of the model cells in the direction perpendicular to groundwater flow was approximately 940 feet. This equates to 24 injection points at this location.

- Injection Point location 5, which lies along the CT plume axis downgradient of well MW-BW-31-A, was simulated by 8 model cells located at model cell addresses of 12,69 through 19,62. The total length of the model cells in the direction perpendicular to groundwater flow was approximately 390 feet. This equates to 10 injection points at this location.

- Injection Point location 6, which lies along the CT plume axis downgradient between wells MW-BW-34-A and MW-BW-36-A, was simulated by 5 model cells located at model cell addresses of 11,51, 12,50, 13,49, 14, 48, and 15,47. The total length of the model cells in the direction perpendicular to groundwater flow was approximately 800 feet. This equates to 21 injection points at this location.

- Injection Point location 7, which lies along the CT plume axis downgradient of well MW-BW-12-A, was simulated by 4 model cells located at model cell addresses of 8,42, 9,41, 10,40, and 11,39. The total length of the model cells in the direction perpendicular to groundwater flow was approximately 1,190 feet. This equates to 30 injection points at this location.

- Injection Point location 8, which lies along the CT plume axis between monitoring wells MW-BW-43-A and MW-BW-44-A, east (upgradient) of the higher hydraulic conductivity zone coincident with the wave-cut terrace in the underlying FO-SVA, was simulated by 4 model cells located at model cell addresses of 7,34, 8,33, 9,32, and 10,32. The total length of the model cells in the direction perpendicular to groundwater flow was approximately 1,400 feet. This equates to 36 injection points at this location.

- Injection Point location 9, which lies along the downgradient edge of the current CT plume east of wells MW-BW-44-A and MW-BW-45-A, was simulated by 3 model cells located at model cell addresses of 6,12, 7,11, and 8,10. The total length of the model cells in the direction perpendicular to groundwater flow was approximately 1,330 feet. This equates to 34 injection points at this location.

- Injection Point location 10, which lies along the downgradient edge of the current CT plume west of wells MW-BW-48-A and MW-BW-49-A, was simulated by 6 model cells that are located at model cell addresses of 3,5, 4,4, 5,3, 6,3, 7,3, and 8,4. The total length of the model cells in the direction perpendicular to groundwater flow was approximately 2,600 feet. This equates to 66 injection points at this location.

Given that the field-scale pilot study effectively changed the chemical environment of the A-Aquifer within a 20-foot radius with the application of 250 gallons of lactate, a total of approximately 65,750 gallons of lactate would need to be applied once at the 263 A-Aquifer injection points to match the simulated areas.

The effective duration of lactate applied to the A-Aquifer has not yet been determined, and thus the need for re-application of lactate to these areas over time cannot yet be determined. However, it is reasonable to assume that 250 gallons of lactate will maintain desirable conditions within the A-Aquifer for approximately one year, based on the fact that the dissolved oxygen (DO) values in the pilot study have remained very low for eight months.

***Scenario 3 Results***

Plates F16-A through F16-D depict the performance of the A-Aquifer CT plume in model layer 2 for several time periods. Scenario 4 simulation results show that the CT plume in the A-Aquifer breaks up into several separate and smaller plumes after a period of one year, with each plume situated between adjoining lactate injection locations. Each of these separate plumes will naturally attenuate with time, and the rate of natural attenuation will be dependent upon the concentration of the plume. Simulation results also indicate that the addition of lactate to these areas would result in the remediation of the A-Aquifer in approximately 15 years. Thus, to maintain desirable conditions, lactate may have to be reapplied to the areas of high concentration a maximum of 15 times to fully remediate the A-Aquifer. However, given the conservative nature of the simulation discussed above, and the limitations associated with the grid size, especially near the toe of the plume, it is likely that far less time would be required to remediate the A-Aquifer.

## 9.4 Scenario 4

This scenario simulates a Permeable Reactive Barrier (PRB) in the model domain in a location between monitoring wells MW-BW-43-A and MW-BW-44-A, east (upgradient) of the higher hydraulic conductivity zone coincident with the wave-cut terrace in the underlying FO-SVA. This location was chosen for three reasons: (1) property within the former Fort Ord footprint is accessible for significant remedial activities associated with a PRB, (2) a roadway along the perimeter of the biological reserve provides an area where a PRB may be installed without disturbing the reserve, and (3) the depth to the FO-SVA is shallowest in this area (ranging from 35 to 65 feet), reducing the cost of installing a PRB relative to areas east or west of this location.

A disadvantage to installing a PRB in this area, however, is that CT has been detected at concentrations exceeding the state MCL (0.50 µg/L) in monitoring wells downgradient of this area. In particular, the detection of 4.8 µg/L of CT at MW-BW-49-A in December 2004 indicates that a relatively significant amount of mass has already migrated into the high conductivity area of the A-Aquifer. The installation of a PRB further west (downgradient) of this monitoring well is not practicable due to dense residential and commercial development. Therefore, the simulated PRB will necessarily allow a portion of the CT plume to continue migrating westward and will be naturally attenuated primarily by advective and dispersive processes. The following sections describe the design procedures and the results for the remedial alternative Scenario 4 simulations.

***Design Procedures***

The PRB was simulated in the model domain by simulating a line of cells having higher degradation rates (lower contaminant half-lifes) at one location in a direction perpendicular to groundwater flow. The degradation rate (half-life) for the PRB was assumed to be similar to the rate derived from results of the field-scale Lactate pilot study. The PRB was simulated using the .RCT package of MT3DMS®.

The simulated PRB comprised three cells, fully penetrating the A-Aquifer, with a total length of 1,143 feet and width ranging from 36 to 65 feet; these dimensions are bound to the size of the grid cells in this portion of the domain. In reality, a PRB would typically be less than one foot thick but would have the same affect on CT concentrations in groundwater. As stated earlier, the chemical effect of the PRB is simulated by assuming a CT half-life of 21 days within the three cells representing the PRB. This degradation rate (half-life) was assumed to be similar to the rate used in the Scenario 4 simulation. Thus, as contaminated groundwater passively migrates through these three cells, the rate of dechlorination is greatly amplified, as would be the case with a PRB.

As in the simulation of Scenario 4, this simulation was also initiated with current (2004) concentrations resulting from the steady state mass transport simulation. Therefore, as stated in the previous simulation, results of this simulation are considered to be conservative.

***Scenario 4 Results***

The steady state groundwater flow and mass transport model was used to simulate the performance of this remedial alternative. Plates F17-A through F17-G depict the performance of the A-Aquifer CT plume in model layer 2 for several time periods.

The results of this simulation indicate that the majority of the CT plume upgradient of the PRB could be remediated with the use of a PRB, as simulated, in 50 years, with only a small portion (located between the PRB and MW-BW-31-A) of the plume remaining at concentrations ranging from 0.5 to 1.5 μg/L (Plate F17-G). This simulation assumes that the decay rate resulting from the PRB is constant throughout the period of simulation. However, it does not appear that the simulated half-life of 10 days is sufficient to completely dechlorinate CT as it migrates through the PRB. The rate of decay is indirectly related to groundwater velocity and, as groundwater velocity increases as it approaches the wave-cut terrace, it appears that the effectiveness of a PRB in this area may be reduced.

Groundwater downgradient of the PRB then could remain contaminated at concentrations ranging between 0.5 and 5 μg/L due either to the continued migration of CT already present downgradient of the PRB or from residual CT emanating from the PRB. The effective rate of remediation of the CT plume could be increased with the installation of one or more PRBs upgradient to reduce the amount of time required for contaminated groundwater to passively migrate through the PRB; however, additional PRBs would not improve conditions further downgradient unless the rate of degradation were increased. Additionally, the typical lifespan of a PRB is 20 years and, since simulation results indicate that at least 50 years would be required, the PRB may have to be reinstalled should its ability to remediate the A-Aquifer decline. Hence, the viability of a PRB will for the required period of performance based on iron consumption rates will only be confirmed upon installation and operation of the PRB and observation of performance over long periods of time.

## 10.0 CONCLUSIONS

Based on the available data, the groundwater flow model was calibrated to known groundwater elevations and steady state flow in the model domain with no water budget discrepancy. A reasonable match between predicted and observed water levels was achieved for the model domain monitoring wells for both the calibration and verification simulations. In addition, the orientation of groundwater elevation contour lines within the model domain, determined from model calculated hydraulic heads, was consistent with the orientation of groundwater elevation contour lines determined from actual water level measurements.

Following calibration and verification of the groundwater flow model, the mass transport model was calibrated to existing CT-plume distribution in the A-Aquifer. This simulation was performed to obtain the final transport parameters, before utilizing the model to evaluate the remedial alternatives identified in the GCMP. A qualitative analysis of the similarity between the interpreted and predicted CT plume footprint, and the concentrations at selected target wells, indicate a close correlation between the observed and simulated CT plume within the A-Aquifer.

Following completion of the steady state calibration, the verification check, and the sensitivity analysis of the groundwater flow model, and calibration of the mass transport model, a series of predictive simulations were performed to evaluate various remedial alternatives in support of the FS (Volume III). Based on the evaluation of the three remedial options for mitigating the A-Aquifer CT-plume, the following conclusions can be stated:

- Only the enhanced natural attenuation using a Lactate Recirculation and Injection System (*Scenario 3*) was observed to be effective in containing and mitigating the A-Aquifer CT-plume within a time period of approximately 15 years.

- The groundwater extraction remedial alternative (*Scenario 1*) was observed to provide adequate capture of the CT plume upgradient of extraction well EW-OUCTP-01. In addition, the CT plume in this area could also be remediated in 30 years. However, groundwater downgradient of EW-OUCTP-01 would remain contaminated at concentrations ranging between 0.5 and 5 μg/L because of the inability of well EW-OUCTP-01 to capture the CT mass that is already present downgradient of the capture radius of the well.

- The PRB remedial alternative (*Scenario 4*) was observed to remediate the majority of the CT plume upgradient of the PRB in 50 years, with only a small portion (located between the PRB and MW-BW-31-A) of the plume remaining at concentrations ranging from 0.5 to 1.5 μg/L (Plate F17-G). However, groundwater downgradient of the PRB would remain contaminated at concentrations ranging between 0.5 and 5 μg/L due either to the continued migration of CT already present downgradient of the PRB or from residual CT emanating from the PRB.

The result of the Scenario 2 simulation, which simulates the capture of the CT-plume in the Upper 180-Foot aquifer using particle analysis, indicates that extraction of groundwater at a rate of 150 gpm from EW-OU2-07-180 along with the ongoing extraction from the other Upper 180-Foot Aquifer extraction wells sufficiently captures the Upper 180-Foot Aquifer CT plumes, in addition to providing capture to the TCE plume associated with OU2.

## 11.0 LIMITATIONS

Modeling simulations have provided useful screening information for evaluating the remedial alternatives including groundwater extraction, enhanced natural attenuation, and the permeable reactive barrier with the OUCTP A-Aquifer and groundwater extraction in the Upper 180-Foot Aquifer. The accuracy of model derived impacts is dependent on the:

- Construction of the model and its assumptions of limited heterogeneity within the modeled water bearing units
- Field measurements of groundwater elevations, aquifer hydraulic parameters, and lithologic data; and
- Accuracy of data provided to MACTEC.

The numerical model developed by MACTEC is based on available literature information and previous site investigations. The information for model parameters like hydraulic conductivity of the soils, anisotropy, and CT source location and concentration is either sparse in nature, or is not adequately constrained. Model sensitivity results indicate the flows to and from the model domain are significantly affected by variations in the hydraulic conductivity values. Hence, while the model completed by MACTEC is believed to be accurate within the confines of the information available and the modeling approach, the estimated groundwater flow and mass transport model may be limited by the nature of the information available to construct the model.

Another limitation of the model's structure was that each extraction well had to be simulated as a 10-foot by 10-foot well, whereas in reality, the wells would not be larger than 10 inches in diameter. The only way to simulate a smaller diameter well is to refine the grid. But, the MODFLOW2000® numerical code has limitations for variations in grid size. Refining the grid increases the number of cells, adding to the computational time, and also increases the ratio of the smallest to the largest cell from an acceptable value of 10 to greater than 100. This results in numerical instability in the model. Hence, to obtain a compromise between model stability and model accuracy, the model grid used was considered to provide results with the appropriate accuracy.

The conclusions and recommendations contained in this report/assessment are based upon professional opinions with regard to the subject matter. These opinions have been arrived at in accordance with currently accepted hydrogeologic and engineering standards and practices applicable to this location and are subject to the following inherent limitations:

The data and findings presented in this report are valid as of the dates when the investigations were performed. The passage of time, manifestation of latent conditions or occurrence of future events may require further exploration at the site, analysis of the data, and reevaluation of the findings, observations, and conclusions expressed in the report.

The data reported and the findings, observations, and conclusions expressed in the report are limited by the Scope of Work. The Scope of Work was defined by the request of the client, the time and budgetary constraints imposed by the client, and availability of access to the site.

Because of the limitations stated above, the findings, observations, and conclusions expressed by MACTEC in this report are not, and should not be, considered an opinion concerning the compliance of any past or present owner or operator of the site with any federal, state or local law or regulation.

No warranty or guarantee, whether expressed or implied, is made with respect to the data or the reported findings, observations, and conclusions, which are based solely upon site conditions in existence at the time of investigation.

MACTEC reports present professional opinions and findings of a scientific and technical nature. While attempts were made to relate the data and findings to applicable environmental laws and regulations, the report shall not be construed to offer legal opinion or representations as to the requirements of, nor compliance with, environmental laws, rules, regulations or policies of federal, state or local governmental agencies. Any use of the report constitutes acceptance of the limits of MACTEC's liability. MACTEC's liability extends only to its client and not to any other parties who may obtain the report. Issues raised by the report should be reviewed by appropriate legal counsel.

# 12.0 REFERENCES

American Society for Testing and Materials (ASTM) Standard D 5447 *Application of a Ground-Water Flow Model to a Site-Specific Problem* (ASTM, 1994).

_____, ASTM Standard D 5981-96 (re-approved 2002) *Standard Guide for Calibrating a Ground-Water Flow Model Application.*

_____, *ASTM Standard D6170-97 Standard Guide for Selecting a Ground-Water Flow Model Code*.

Zheng, C. and Wang, P., 1999. *MT3DMS – A Modular 3-D Multispecies Model, US Army COE, Contract Report SERDP-99-1*.

TABLES

Table F1. Summary of Calibration Statistics - California Steady State Flow Model
OUTCP RI/FS Former Fort Ord, California

| A-Aquifer | Well Name | June 2004 Observed Head (ft) | Computed Head (ft) | Residuals (ft) |
|---|---|---|---|---|
| | MW-BW-75-A | 9.43 | 7.91 | 1.52 |
| | MW-BW-74-A | 7.67 | 7.13 | 0.54 |
| | MW-BW-71-A | 80.36 | 82.36 | -2.00 |
| | MW-BW-76-A | 5.88 | 6.00 | -0.12 |
| | MW-BW-73-A | 8.07 | 7.21 | 0.86 |
| | MW-OU2-77-A | 83.55 | 85.84 | -2.29 |
| | MW-OU2-76-A | 67.93 | 74.68 | -6.75 |
| | MW-OU2-75-A | 78.83 | 82.96 | -4.13 |
| | MW-OU2-74-A | 90.64 | 89.06 | 1.58 |
| | MW-OU2-73-A | 87.69 | 90.09 | -2.40 |
| | MW-OU2-60-A | 82.91 | 86.56 | -3.65 |
| | MW-OU2-59-A | 79.62 | 80.42 | -0.80 |
| | MW-OU2-58-A | 79.59 | 80.47 | -0.88 |
| | MW-OU2-57-A | 92.69 | 93.10 | -0.41 |
| | MW-OU2-45-A | 81.37 | 85.74 | -4.37 |
| | MW-OU2-31-A | 9.08 | 8.39 | 0.69 |
| | MW-OU2-30-A | 82.27 | 83.13 | -0.86 |
| | MW-OU2-28-A | 87.56 | 89.89 | -2.33 |
| | MW-OU2-27-A | 89.14 | 90.23 | -1.09 |
| | MW-OU2-25-A | 79.82 | 78.08 | 1.74 |
| | MW-OU2-23-A | 62.46 | 70.29 | -7.83 |
| | MW-OU2-21-A | 39.56 | 43.09 | -3.53 |
| | MW-OU2-13-A | 92.16 | 93.40 | -1.24 |
| | MW-OU2-12-A | 49.52 | 61.09 | -11.57 |
| | MW-OU2-09-A | 47.58 | 56.93 | -9.35 |
| | MW-OU2-08-A | 63.20 | 70.22 | -7.02 |
| | MW-OU2-07-A | 56.54 | 64.67 | -8.13 |
| | MW-OU2-06-A | 48.76 | 58.49 | -9.73 |
| | MW-OU2-05-A | 48.32 | 51.72 | -3.40 |
| | MW-OU2-04-A | 43.51 | 43.74 | -0.23 |
| | MW-OU2-03-A | 63.42 | 74.63 | -11.21 |
| | MW-OU2-02-A | 87.05 | 88.75 | -1.70 |
| | MW-BW-67-A | 33.86 | 31.52 | 2.34 |
| | MW-BW-66-A | 33.99 | 26.62 | 7.37 |
| | MW-BW-65-A | 9.54 | 8.73 | 0.81 |
| | MW-BW-64-A | 81.94 | 82.78 | -0.84 |
| | MW-BW-61-A | 82.04 | 84.96 | -2.92 |
| | MW-BW-59-A | 44.71 | 43.85 | 0.86 |
| | MW-BW-58-A | 70.03 | 68.84 | 1.19 |
| | MW-BW-57-A | 73.90 | 73.08 | 0.83 |
| | MW-BW-56-A | 74.63 | 73.37 | 1.26 |
| | MW-BW-55-A | 77.05 | 77.92 | -0.87 |
| | MW-BW-54-A | 77.68 | 76.65 | 1.04 |
| | MW-BW-53-A | 78.33 | 77.75 | 0.58 |
| | MW-BW-52-A | 79.36 | 78.66 | 0.70 |
| | MW-BW-51-A | 80.79 | 80.36 | 0.44 |
| | MW-BW-50-A | 82.82 | 84.61 | -1.79 |
| | MW-BW-49-A | 9.50 | 8.38 | 1.12 |
| | MW-BW-48-A | 9.10 | 9.21 | -0.11 |
| | MW-BW-47-A | 9.03 | 8.83 | 0.19 |
| | MW-BW-46-A | 9.74 | 9.51 | 0.23 |
| | MW-BW-45-A | 10.26 | 9.84 | 0.42 |
| | MW-BW-44-A | 10.27 | 10.25 | 0.02 |
| | MW-BW-43-A | 37.70 | 24.67 | 13.03 |
| | MW-BW-42-A | 43.52 | 37.21 | 6.31 |
| | MW-BW-41-A | 41.09 | 35.44 | 5.65 |
| | MW-BW-40-A | 42.19 | 35.63 | 6.56 |

Table F1. Summary of Calibration Statistics - California Steady State Flow Model

OUTCP RI/FS Former Fort Ord, California

| *A-Aquifer* | *Well Name* | *June 2004 Observed Head (ft)* | *Computed Head (ft)* | *Residuals (ft)* |
|---|---|---|---|---|
| | MW-BW-39-A | 47.08 | 46.01 | 1.07 |
| | MW-BW-38-A | 51.06 | 52.48 | -1.42 |
| | MW-BW-37-A | 47.52 | 45.66 | 1.87 |
| | MW-BW-36-A | 52.05 | 55.60 | -3.55 |
| | MW-BW-35-A | 52.27 | 54.16 | -1.89 |
| | MW-BW-34-A | 54.76 | 56.36 | -1.60 |
| | MW-BW-33-A | 54.15 | 57.14 | -2.99 |
| | MW-BW-32-A | 58.07 | 61.26 | -3.19 |
| | MW-BW-31-A | 57.72 | 59.76 | -2.04 |
| | MW-BW-30-A | 61.80 | 62.07 | -0.27 |
| | MW-BW-28-A | 68.13 | 66.52 | 1.61 |
| | MW-BW-27-A | 65.36 | 64.68 | 0.68 |
| | MW-BW-26-A | 63.26 | 64.49 | -1.23 |
| | MW-BW-25-A | 74.75 | 73.87 | 0.88 |
| | MW-BW-24-A | 74.31 | 71.65 | 2.66 |
| | MW-BW-23-A | 79.89 | 80.31 | -0.42 |
| | MW-BW-18-A | 63.08 | 68.11 | -5.03 |
| | MW-BW-17-A | 71.62 | 70.05 | 1.57 |
| | MW-BW-16-A | 72.42 | 71.22 | 1.20 |
| | MW-BW-13-A | 7.69 | 10.33 | -2.64 |
| | MW-BW-10-A | 66.23 | 64.49 | 1.74 |
| | MW-BW-01-A | 65.47 | 65.40 | 0.07 |
| | MW-B-18-A | 67.62 | 65.89 | 1.73 |
| | MW-B-14-A | 70.84 | 69.22 | 1.62 |
| | MW-B-12-A | 48.05 | 46.51 | 1.54 |
| | MW-B-10-A | 41.93 | 41.90 | 0.03 |
| | MW-B-02-A | 54.46 | 54.72 | -0.26 |
| | MW-40-01-A | 62.40 | 61.90 | 0.50 |
| | MW-16-01-A | 19.33 | 29.49 | -10.16 |

***Error Summary:***

***Mean Error = 0.856***

***Mean Absolute Error = 2.683***

***Root Mean Squared Error = 3.967***

| *Upper 180 - Foot Aquifer* | *Well Name* | *Observed Head (ft)* | *Computed Head (ft)* | *Residuals (ft)* |
|---|---|---|---|---|
| | MP-BW-41-256 | -11.26 | -10.62 | -0.64 |
| | MP-BW-41-231 | -11.32 | -10.62 | -0.70 |
| | MW-OU2-70-180 | -13.23 | -11.55 | -1.68 |
| | MW-OU2-67-180 | -12.95 | -11.00 | -1.95 |
| | MW-OU2-64-180 | -11.59 | -10.11 | -1.48 |
| | MW-OU2-63-180 | -10.10 | -9.64 | -0.46 |
| | MW-OU2-62-180 | -9.92 | -10.85 | 0.93 |
| | MW-OU2-61-180 | -12.03 | -11.13 | -0.90 |
| | MW-OU2-56-180 | -9.22 | -10.11 | 0.89 |
| | MW-OU2-55-180 | -6.58 | -8.23 | 1.65 |
| | MW-OU2-53-180 | -8.32 | -9.02 | 0.70 |
| | MW-OU2-52-180 | -3.69 | -4.48 | 0.79 |
| | MW-OU2-51-180 | -2.82 | -3.16 | 0.34 |
| | MW-OU2-50-180 | -2.81 | -3.01 | 0.20 |
| | MW-OU2-49-180 | -8.61 | -8.77 | 0.16 |
| | MW-OU2-48-180 | -8.74 | -8.47 | -0.27 |
| | MW-OU2-47-180 | -10.23 | -10.50 | 0.27 |
| | MW-OU2-46-180 | -10.53 | -10.86 | 0.33 |
| | MW-OU2-44-180 | -9.61 | -10.24 | 0.63 |
| | MW-OU2-43-180 | -1.34 | -2.65 | 1.31 |
| | MW-OU2-42-180 | 3.31 | 2.00 | 1.31 |
| | MW-OU2-39-180 | -6.29 | -8.15 | 1.86 |

***Upper 180 - Foot Aquifer***

| Well Name | Observed Head (ft) | Computed Head (ft) | Residuals (ft) |
|---|---|---|---|
| MW-OU2-31-180R | 1.33 | 1.15 | 0.18 |
| MW-OU2-30-180 | -10.29 | -9.90 | -0.39 |
| MW-OU2-28-180 | -10.77 | -11.33 | 0.56 |
| MW-OU2-24-180 | -8.24 | -8.80 | 0.56 |
| MW-OU2-23-180 | -5.29 | -6.28 | 0.99 |
| MW-OU2-09-180R | -6.40 | -6.93 | 0.53 |
| MW-OU2-07-180R | -8.06 | -8.39 | 0.33 |
| MW-OU2-06-180R | -6.27 | -7.41 | 1.14 |
| MW-OU2-05-180 | -4.15 | -5.59 | 1.44 |
| MW-BW-56-180 | -11.31 | -10.39 | -0.92 |
| MW-BW-55-180 | -7.97 | -7.89 | -0.08 |
| MW-BW-54-180 | -6.89 | -7.33 | 0.44 |
| MW-BW-53-180 | -9.70 | -8.98 | -0.72 |
| MW-BW-52-180 | -9.80 | -9.05 | -0.75 |
| MW-BW-51-180 | -10.27 | -9.47 | -0.80 |
| MW-BW-50-180 | -10.50 | -10.21 | -0.29 |
| MW-BW-47-180 | -9.74 | -8.99 | -0.75 |
| MW-BW-45-180 | -9.00 | -8.46 | -0.55 |
| MW-BW-43-180 | -8.24 | -7.96 | -0.28 |
| MW-BW-29-180 | -7.87 | -7.86 | -0.01 |
| MW-BW-26-180 | -7.68 | -7.78 | 0.10 |
| MW-BW-25-180 | -8.54 | -8.32 | -0.22 |
| MW-BW-22-180 | -8.26 | -8.09 | -0.17 |
| MW-BW-21-180 | -8.06 | -7.99 | -0.07 |
| MW-BW-20-180 | -8.16 | -8.00 | -0.16 |
| MW-BW-19-180R | -9.66 | -8.08 | -1.58 |
| MW-BW-14-180 | 1.14 | 0.39 | 0.75 |
| MW-BW-02-180 | -9.50 | -9.91 | 0.41 |
| MW-B-13-180 | -7.83 | -7.91 | 0.08 |
| MW-B-05-180 | -6.27 | -5.80 | -0.47 |
| MP-BW-46-215 | -8.67 | -8.46 | -0.21 |
| MP-BW-46-200 | -8.74 | -8.46 | -0.28 |
| MP-BW-46-185 | -8.70 | -8.46 | -0.24 |
| MP-BW-46-170 | -8.68 | -8.46 | -0.22 |
| MP-BW-42-195 | -10.45 | -9.70 | -0.75 |
| MP-BW-41-202 | -12.30 | -10.62 | -1.68 |
| MP-BW-37-193 | -7.25 | -7.47 | 0.22 |
| MP-BW-37-178 | -7.41 | -7.47 | 0.05 |
| MP-BW-35-242 | -7.68 | -7.68 | 0.00 |
| IW-OU2-03-180 | -9.65 | -9.06 | -0.59 |

***Error Summary:***
***Mean Error = 0.018***
***Mean Absolute Error = 0.635***
***Root Mean Squared Error = 0.811***

***Lower 180 - Foot Aquifer***

| Well Name | Observed Head (ft) | Computed Head (ft) | Residuals (ft) |
|---|---|---|---|
| MP-BW-42-195 | -10.45 | -9.70 | -0.75 |
| MW-OU2-66-180 | -12.17 | -13.35 | 1.18 |
| MW-OU2-69-180 | -13.50 | -14.10 | 0.60 |
| MW-OU2-72-180 | -14.89 | -14.05 | -0.84 |
| Airfield | -15.43 | -15.51 | 0.08 |
| MCWD-08A | -10.99 | -11.12 | 0.13 |
| MP-BW-30-317 | -11.02 | -11.30 | 0.28 |
| MP-BW-30-342 | -11.01 | -11.30 | 0.29 |
| MP-BW-30-397 | -10.72 | -11.30 | 0.58 |
| MP-BW-31-292 | -12.22 | -9.74 | -2.48 |
| MP-BW-31-332 | -11.61 | -11.91 | 0.30 |
| MP-BW-31-362 | -11.46 | -11.91 | 0.45 |
| MP-BW-31-407 | -11.03 | -11.91 | 0.88 |

## Table F1. Summary of Calibration Statistics - California Steady State Flow Model
## OUTCP RI/FS Former Fort Ord, California

| *Lower 180 - Foot Aquifer* | *Well Name* | *Observed Head (ft)* | *Computed Head (ft)* | *Residuals (ft)* |
|---|---|---|---|---|
| | MP-BW-32-332 | -11.46 | -9.97 | -1.49 |
| | MP-BW-32-366 | -11.36 | -12.12 | 0.76 |
| | MP-BW-32-412 | -11.25 | -12.12 | 0.87 |
| | MP-BW-33-317 | -11.62 | -10.25 | -1.37 |
| | MP-BW-33-352 | -11.56 | -10.25 | -1.31 |
| | MP-BW-33-397 | -11.49 | -12.42 | 0.93 |
| | MP-BW-34-292 | -15.46 | -11.61 | -3.85 |
| | MP-BW-34-357 | -14.05 | -15.16 | 1.11 |
| | MP-BW-34-422 | -13.76 | -15.16 | 1.40 |
| | MP-BW-35-312 | -15.78 | -16.56 | 0.78 |
| | MP-BW-35-366 | -15.46 | -16.56 | 1.10 |
| | MP-BW-35-402 | -15.40 | -16.56 | 1.16 |
| | MP-BW-37-303 | -11.68 | -11.53 | -0.15 |
| | MP-BW-37-328 | -11.72 | -11.53 | -0.19 |
| | MP-BW-37-368 | -11.40 | -11.53 | 0.13 |
| | MP-BW-37-398 | -11.19 | -11.53 | 0.34 |
| | MP-BW-38-327 | -15.98 | -17.35 | 1.37 |
| | MP-BW-38-341 | -13.90 | -17.35 | 3.45 |
| | MP-BW-38-353 | -13.83 | -17.35 | 3.52 |
| | MP-BW-38-368 | -16.06 | -17.35 | 1.29 |
| | MP-BW-39-310 | -14.14 | -14.74 | 0.60 |
| | MP-BW-39-330 | -14.01 | -14.74 | 0.73 |
| | MP-BW-39-350 | -13.97 | -14.74 | 0.77 |
| | MP-BW-39-395 | -13.19 | -14.74 | 1.55 |
| | MP-BW-40-333 | -18.96 | -17.84 | -1.12 |
| | MP-BW-40-353 | -18.97 | -17.84 | -1.13 |
| | MP-BW-40-375 | -18.68 | -17.84 | -0.84 |
| | MP-BW-40-400 | -18.79 | -17.84 | -0.95 |
| | MP-BW-41-286 | -11.23 | -12.21 | 0.98 |
| | MP-BW-41-318 | -11.29 | -12.21 | 0.92 |
| | MP-BW-41-353 | -11.35 | -12.21 | 0.86 |
| | MP-BW-42-295 | -11.33 | -12.67 | 1.34 |
| | MP-BW-42-314 | -11.52 | -12.67 | 1.15 |
| | MP-BW-42-345 | -10.94 | -12.67 | 1.73 |
| | MW-OU2-06-400 | -7.29 | -7.34 | 0.05 |
| | MW-OU2-09-400 | -6.95 | -6.86 | -0.09 |
| | MW-OU2-22-400 | -6.88 | -6.20 | -0.68 |
| | MW-OU2-28-400 | -10.66 | -11.36 | 0.70 |

***Error Summary:***
***Mean Error =0.336***
***Mean Absolute Error = 1.012***
***Root Mean Squared Error =1.296***

Checked: MDT

Approved: CM

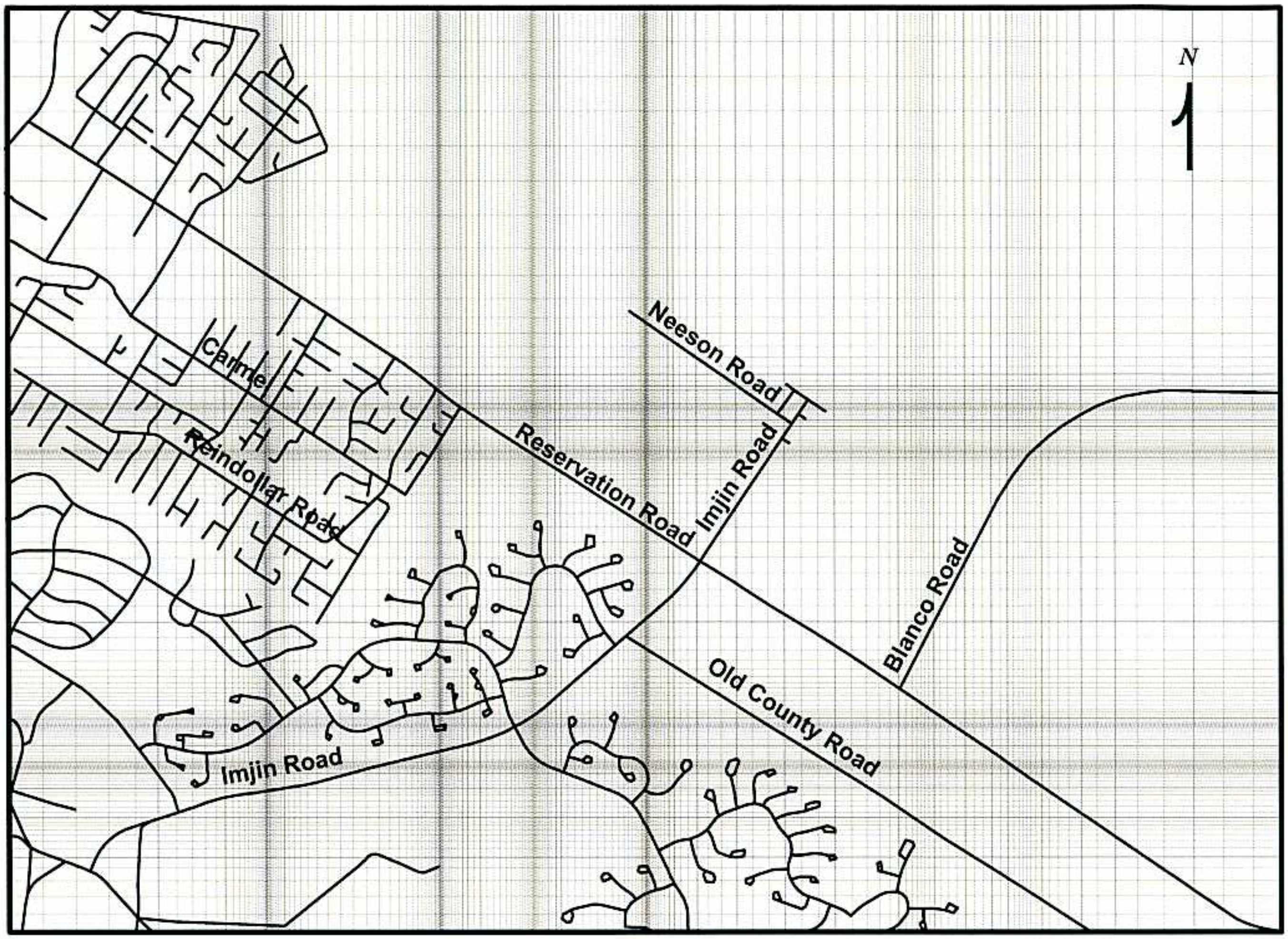
**Table F2. Summary of Verification Simulations - Calibrated Steady State Flow Model**
**OUCTP RI/FS Former Fort Ord, California**

| ID | Pumping Well | Pumping Rate (gpm,ft$^3$/d) | Zone/ Aquifer | Observation Wells | Observed Drawdown (ft) | Simulated Drawdown (ft) | Test Date | Test Duration (days) |
|---|---|---|---|---|---|---|---|---|
| 1 | MW-BW-14A | 7, 1347.5 | A | MW-BW-60-A<br>MW-B-14-A<br>MW-BW-15-A | 0.7<br>none<br>none | 1.05<br>-<br>- | 7/22/2003 | 1 |
| 2 | MW-BW-44-A | 6.5, 1251.249 | A | PZ-BW-44-A<br>MW-BW-45-A<br>MW-B-11-A | 0.14<br>none<br>none | 0.09 | 7/24/2003 | 0.4 |
| 3 | MW-OU2-51-180 | 125, 24062.49 | Upper 180 | MW-OU2-180<br>MW-OU2-52-180 | 0.22<br>0.61 | 0.11<br>0.26 | 5/6/1997 | 3.01 |
| 4 | MW-OU2-53-180 | 150, 28874.99 | Upper 180 | MW-OU2-24-180<br>MW-OU2-39-180 | 0.39<br>0.39 | 0.39<br>0.44 | 5/28/1997 | 2.2 |
| 5 | MW-OU2-49-180 | 175, 33687.49 | Upper 180 | MW-OU2-06-180R<br>MW-OU2-07-180<br>MW-OU2-48-180 | 0.5<br>1.3<br>2 | 0.1<br>0.3<br>0.4 | 5/13/1997 | 3 |

Checked MDT

Approved CM

PLATES




MACTEC

Groundwater Model Domain
OUCTP RI/FS
Former Fort Ord, California

PLATE
F1

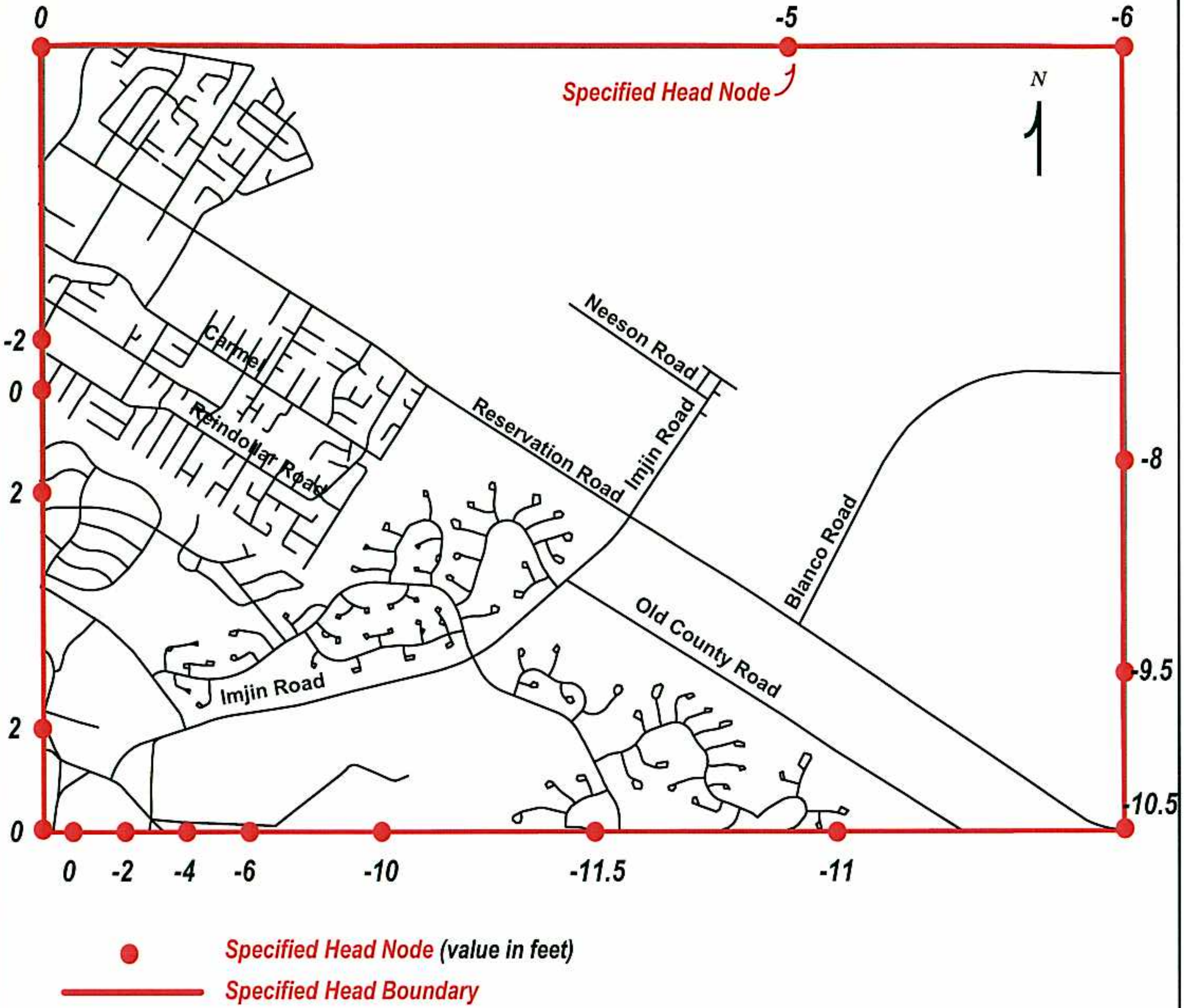
| DRAWN | JOB NUMBER | APPROVED | DATE | REVISED DATE |
|---|---|---|---|---|
| CLH | 408703007.010403 | MDT/CM | 04/05 | |


MACTEC

Model Boundary Condition, Layer 2
OUCTP RI/FS
Former Fort Ord, California

PLATE
F2

| DRAWN | JOB NUMBER | APPROVED | DATE | REVISED DATE |
|---|---|---|---|---|
| CLH | 408703007.010403 | MDT / CM | 04/05 | |

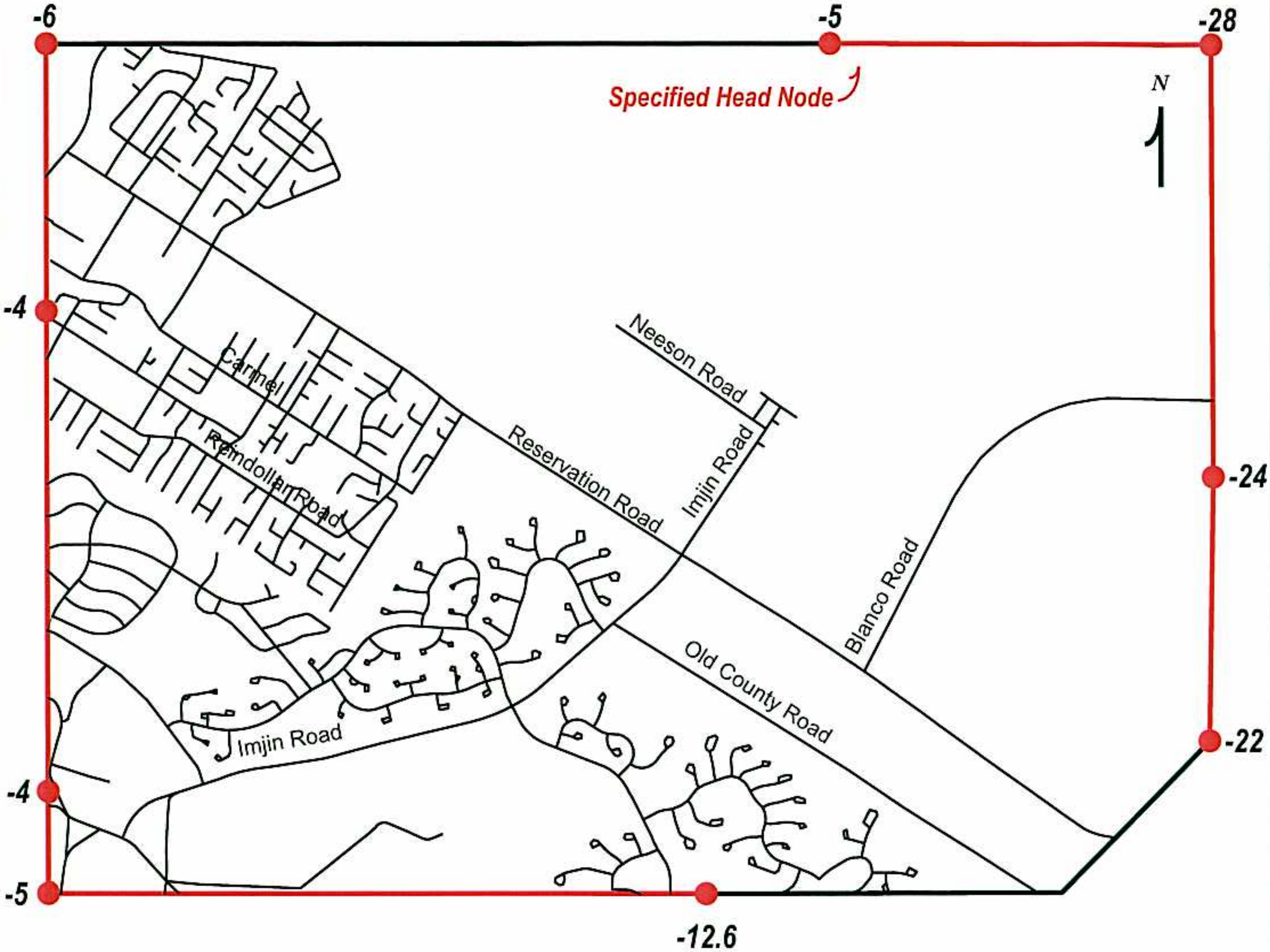



MACTEC

Model Boundary Condition, Layer 4
OUCTP RI/FS
Former Fort Ord, California

PLATE
F3

| DRAWN | JOB NUMBER | APPROVED | DATE | REVISED DATE |
|---|---|---|---|---|
| CLH | 408703007.010403 | MDI/CM | 04/05 | |




Specified Head Node (value in feet)

Specified Head Boundary

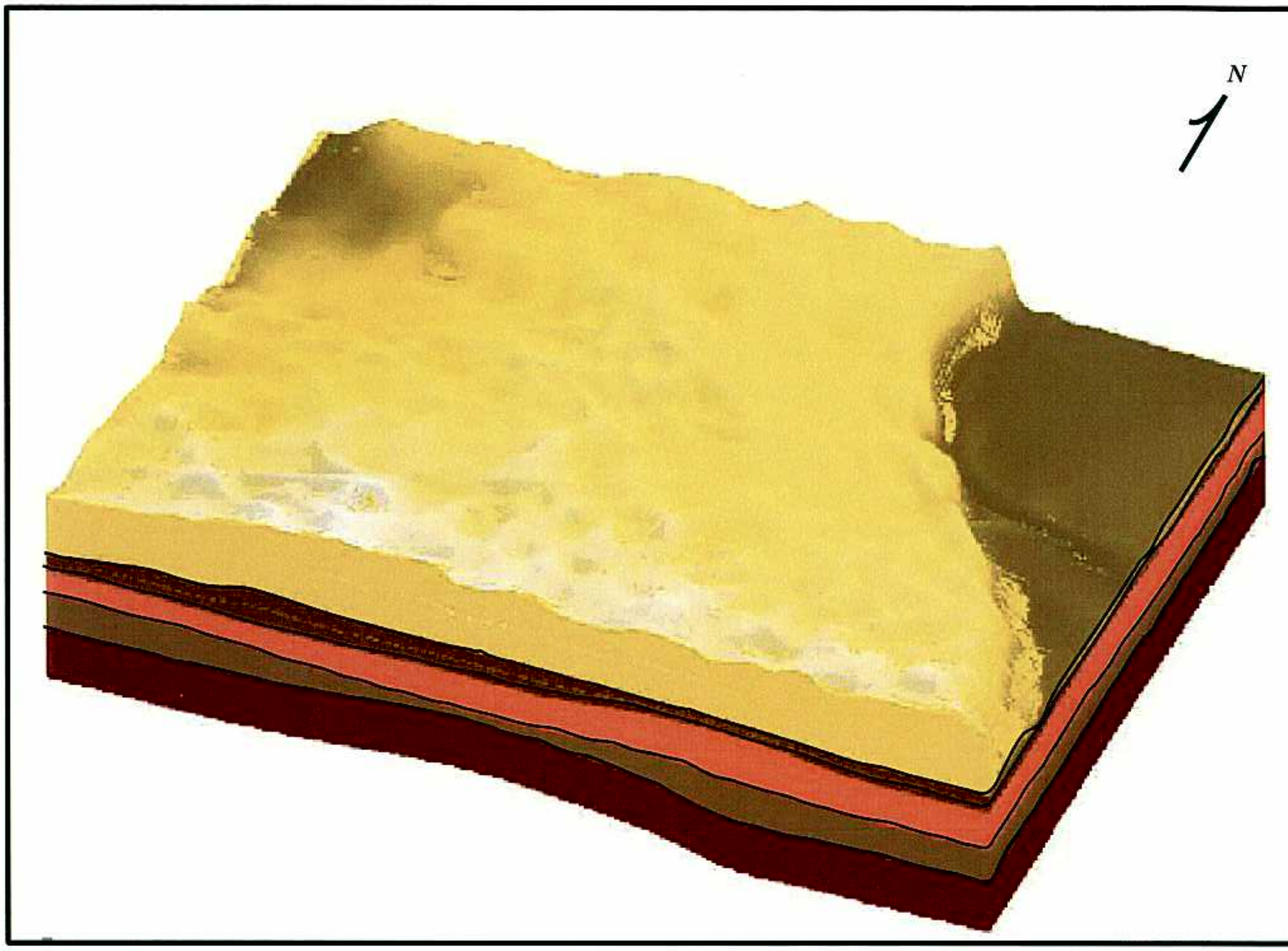
No Flow Boundary

MACTEC

Model Boundary Condition, Layer 6
OUCTP RI/FS
Former Fort Ord, California

PLATE
F4

| DRAWN | JOB NUMBER | APPROVED | DATE | REVISED DATE |
|---|---|---|---|---|
| CLH | 408703007.010403 | MDT/CM | 04/05 | |




**Model Layers**

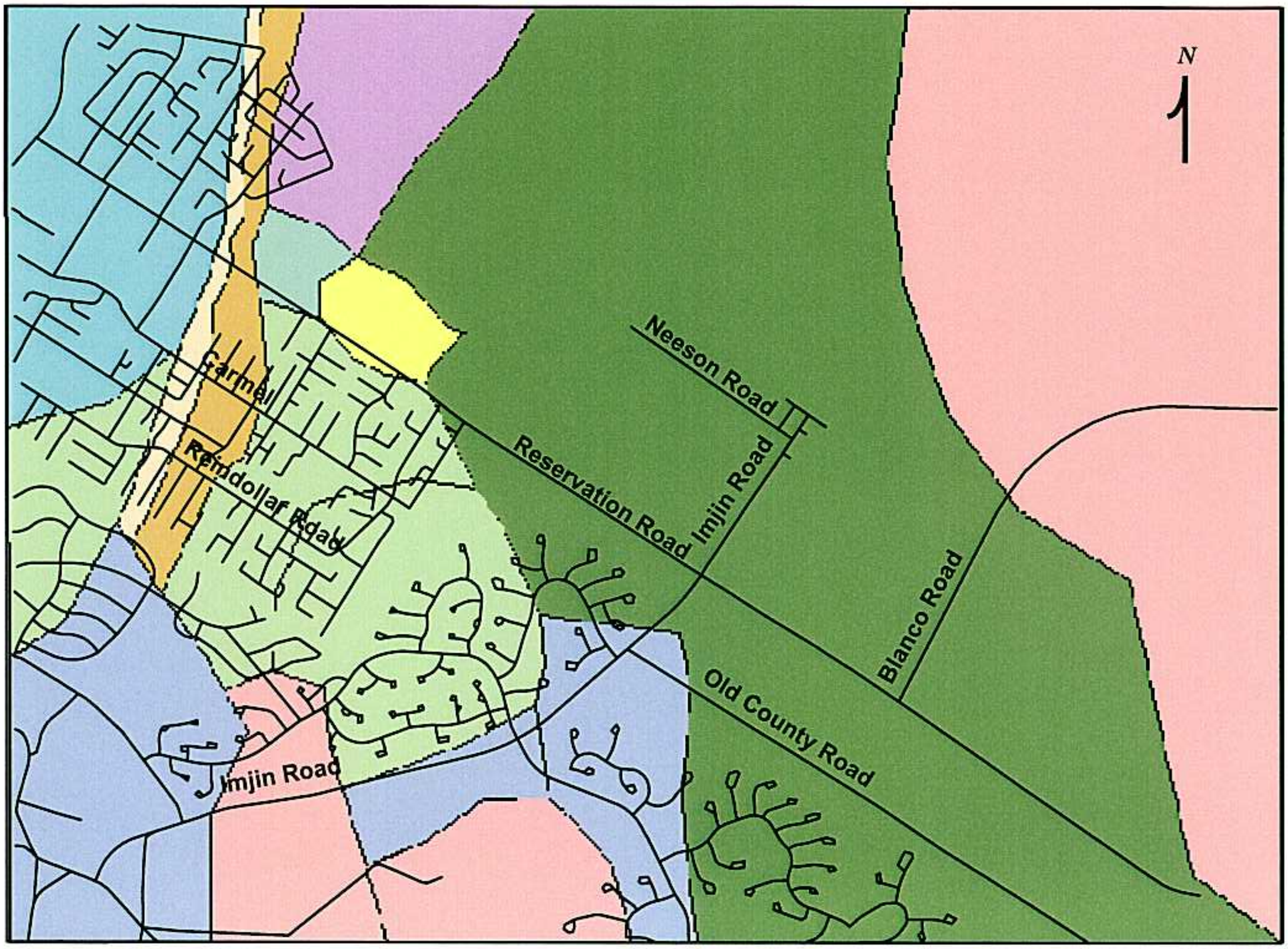
- A-Aquifer
- FO-SVA
- Upper 180-Foot Aquifer
- Intermediate 180-Foot Aquifer
- Lower 180-Foot Aquifer

MACTEC

3-Dimensional Perspective of Groundwater Model Layers
OUCTP RI/FS
Former Fort Ord, California

PLATE
F5

| DRAWN | JOB NUMBER | APPROVED | DATE | REVISED DATE |
|---|---|---|---|---|
| CLH | 408703007.010403 | MDT/CM | 04/05 | |




***Hydraulic Conductivity (ft/day)***

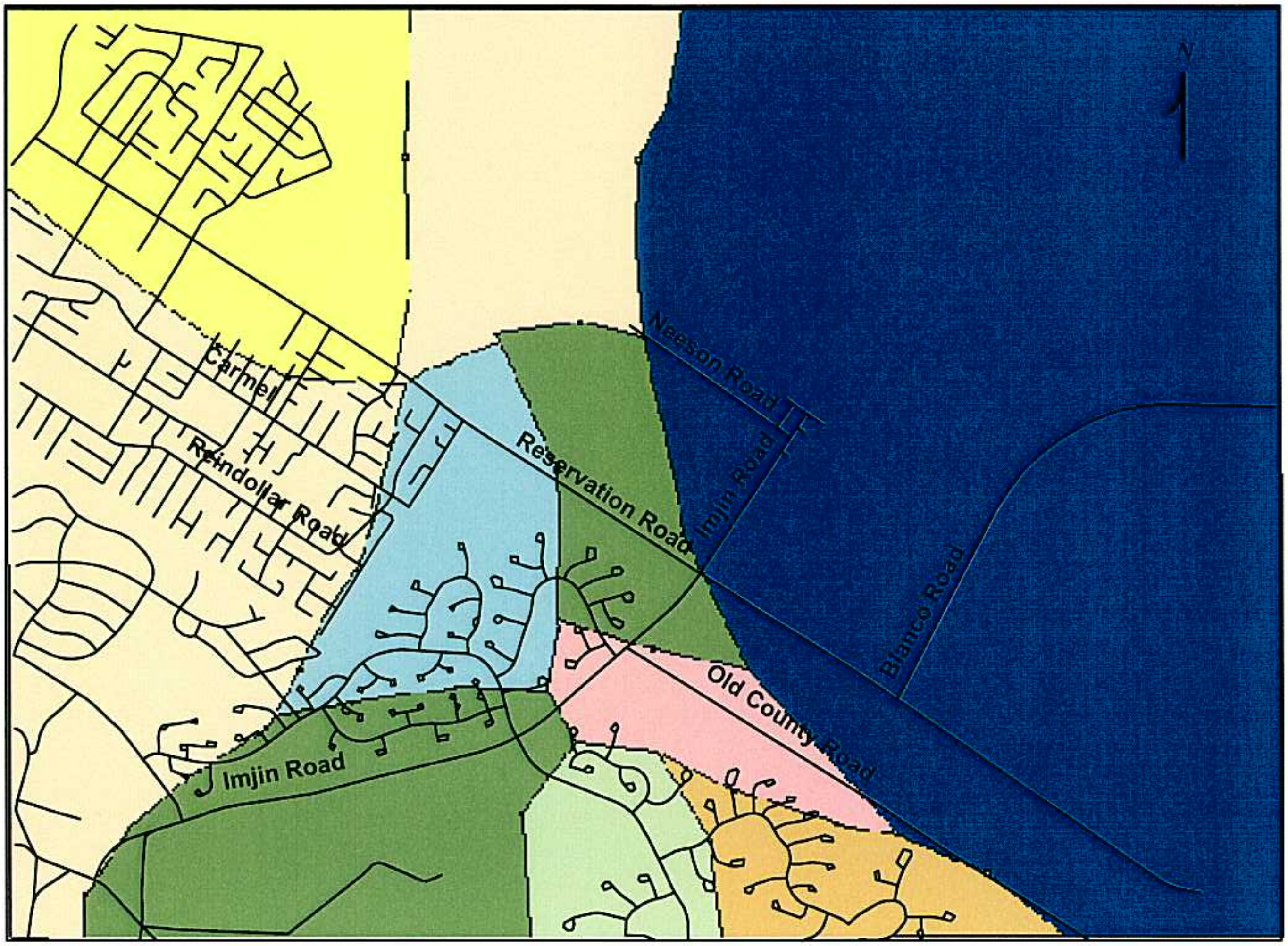
- **400**
- **200**
- **100**
- **75**
- **50**
- **40**
- **30**
- **25**
- **20**
- **8**
- **7**

MACTEC

Distribution of Hydraulic Conductivity
Layer 2
OUCTP RI/FS
Former Fort Ord, California

PLATE
F6

| DRAWN | JOB NUMBER | APPROVED | DATE | REVISED DATE |
|---|---|---|---|---|
| CLH | 408703007.010403 | MDT/CM | 04/05 | |




***Hydraulic Conductivity (ft/day)***

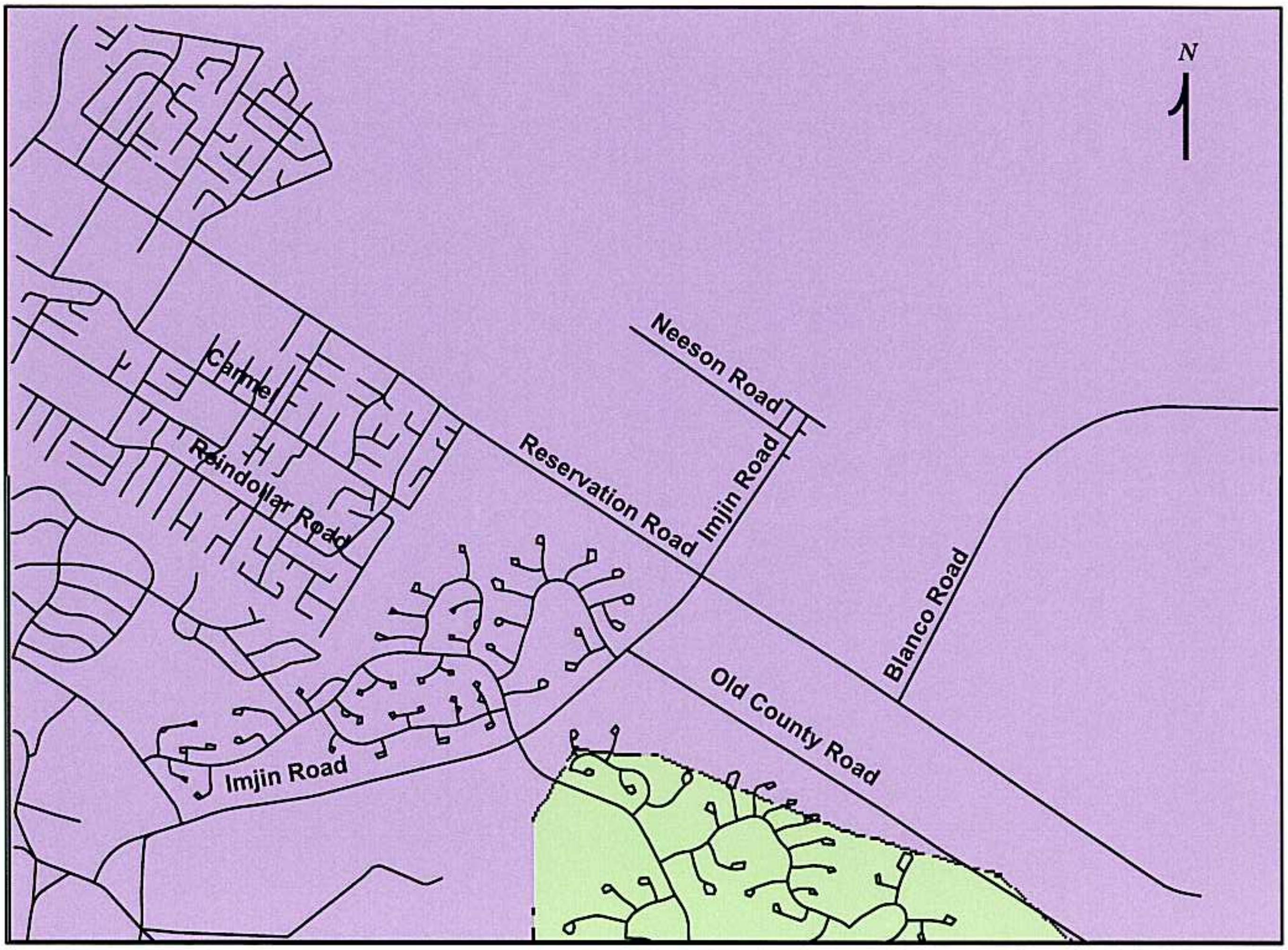
| | |
|---|---|
| Dark blue | 300 |
| Light blue | 275 |
| Green | 250 |
| Light green | 200 |
| Pink | 150 |
| Orange | 100 |
| Cream | 70 |
| Yellow | 50 |

MACTEC

Distribution of Hydraulic Conductivity
Layer 4
OUCTP RI/FS
Former Fort Ord, California

PLATE
**F7**

| DRAWN | JOB NUMBER | APPROVED | DATE | REVISED DATE |
|---|---|---|---|---|
| CLH | 408703007.010403 | MDT/CM | 04/05 | |




***Hydraulic Conductivity (ft/day)***

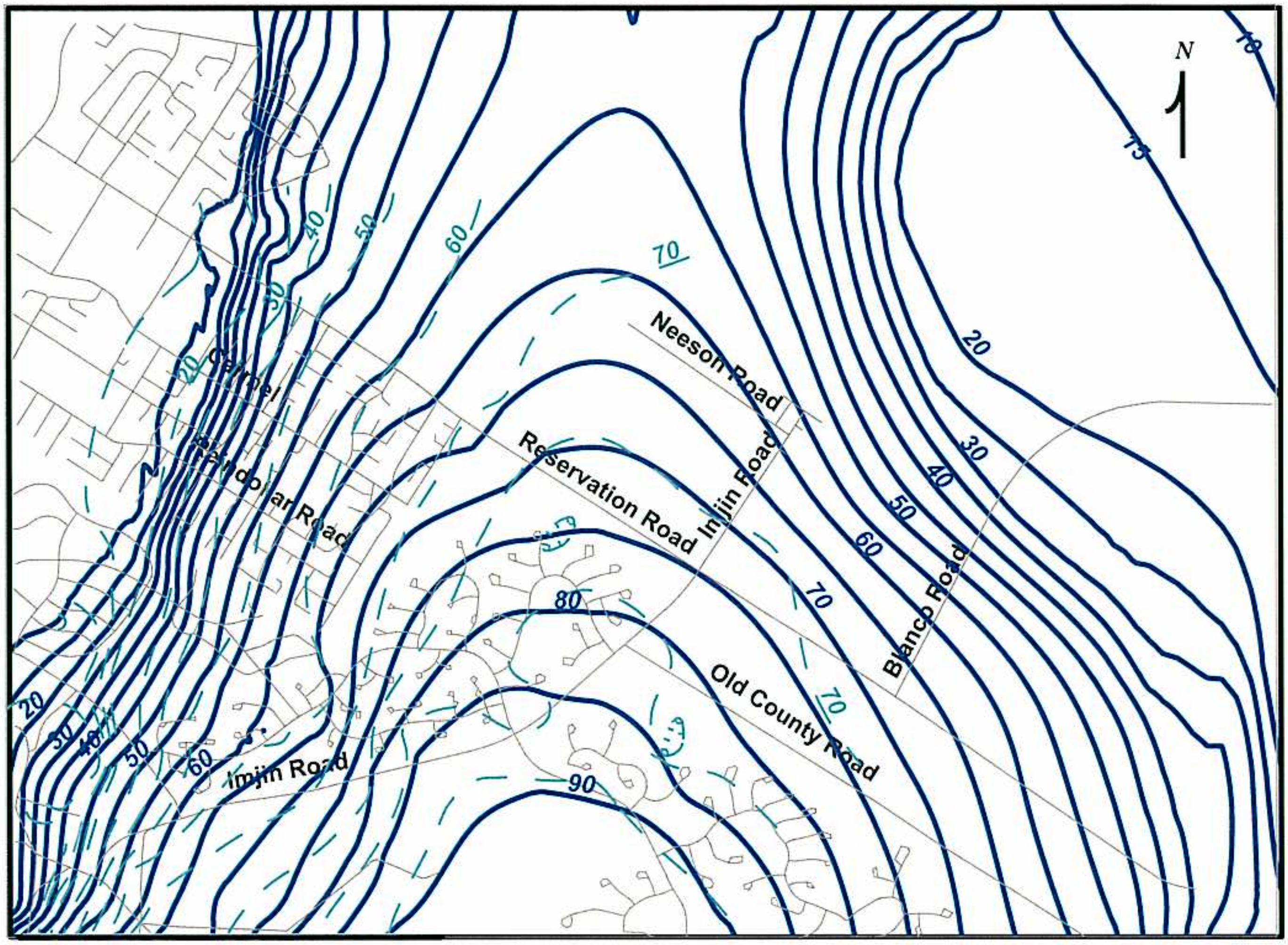
| | |
|---|---|
| (green) | *200* |
| (purple) | *.0007* |

MACTEC

Distribution of Hydraulic Conductivity
Layer 5
OUCTP RI/FS
Former Fort Ord, California

PLATE
F8

| DRAWN | JOB NUMBER | APPROVED | DATE | REVISED DATE |
|---|---|---|---|---|
| CLH | 408703007.010403 | MDT/CM | 04/05 | |




***Groundwater Elevation Contours***

***Observed Groundwater Elevations (10 foot contour interval)***

***Simulated Groundwater Elevations (5 foot contour interval)***

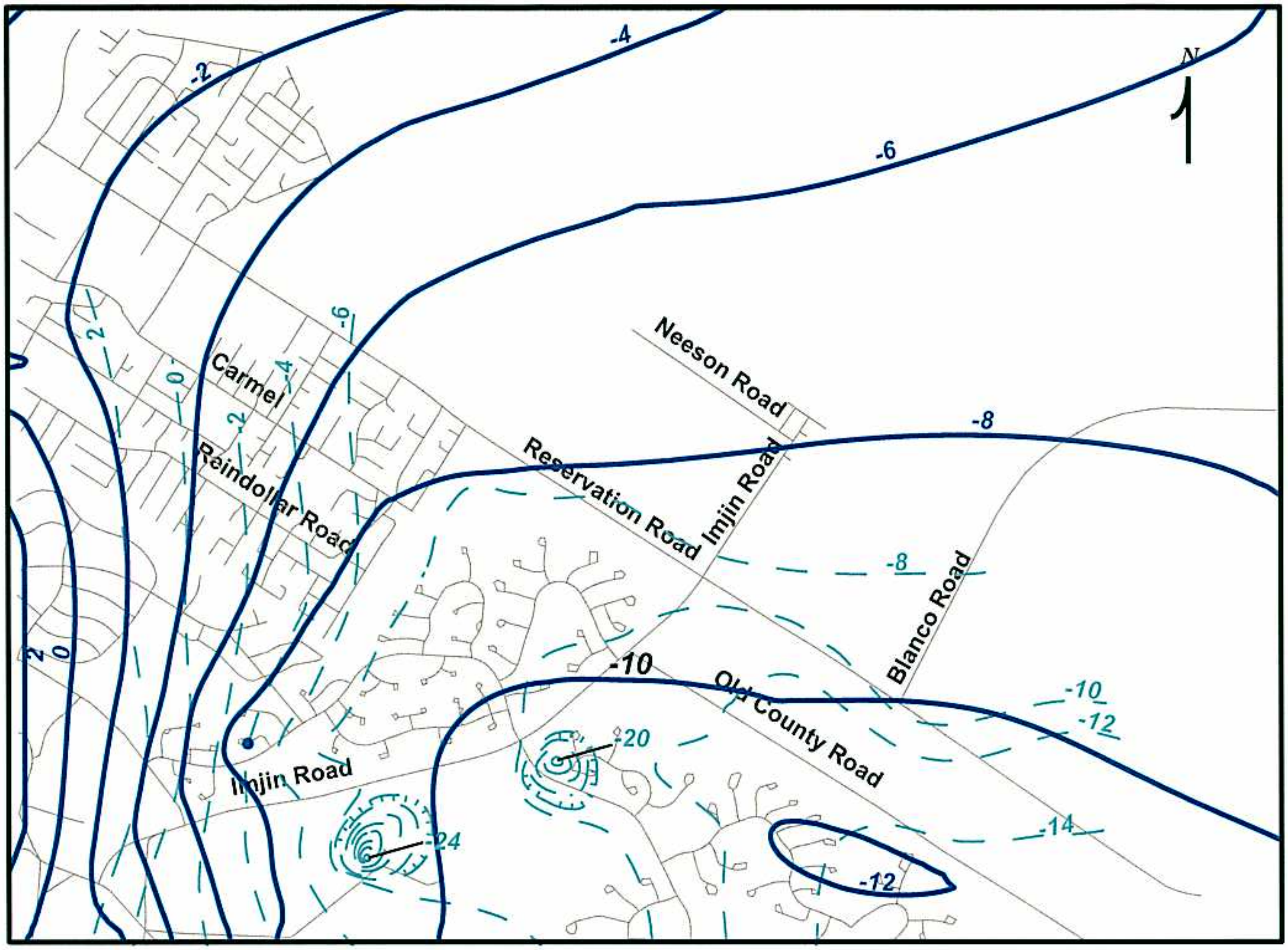
Elevation contours in feet above mean sea level

MACTEC

Simulated versus Observed Groundwater Elevation Contours, A-Aquifer, June 2004
OUCTP RI/FS
Former Fort Ord, California

PLATE
F9

| DRAWN | JOB NUMBER | APPROVED | DATE | REVISED DATE |
|---|---|---|---|---|
| CLH | 408703007.010403 | MDT/CML | 04/05 | |




***Groundwater Elevation Contours***

***Observed Groundwater Elevations (2 foot contour interval)***

***Simulated Groundwater Elevations (2 foot contour interval)***

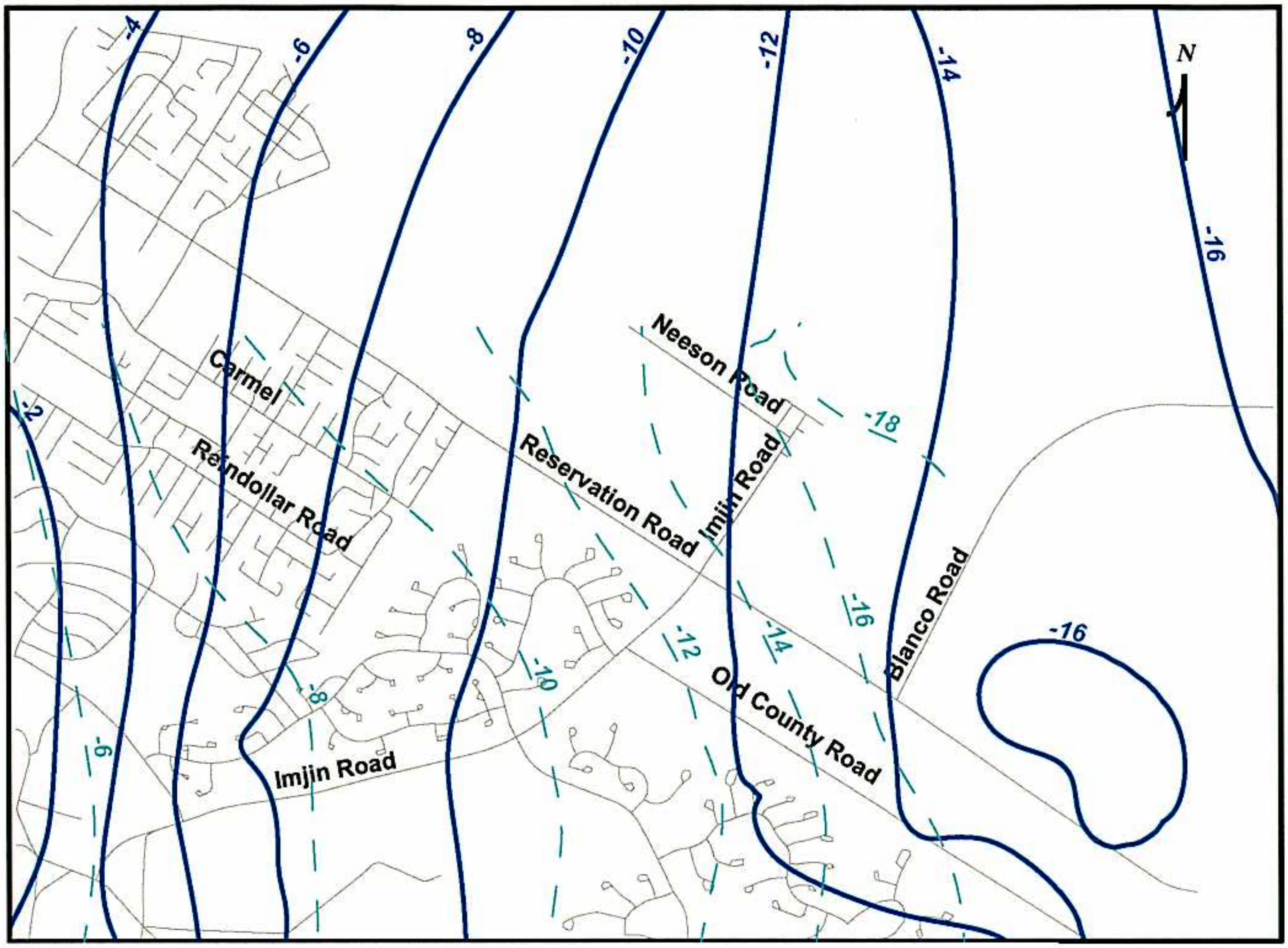
Elevation contours in feet above mean sea level

MACTEC

Simulated versus Observed Groundwater Elevation Contours, Upper 180-Foot Aquifer, June 2004, OUCTP RI/FS
Former Fort Ord, California

PLATE
F10

| DRAWN | JOB NUMBER | APPROVED | DATE | REVISED DATE |
|---|---|---|---|---|
| CLH | 408703007.010403 | MDT/CM | 04/05 | |




***Groundwater Elevation Contours***

***Observed Groundwater Elevations (2 foot contour interval)***

***Simulated Groundwater Elevations (2 foot contour interval)***

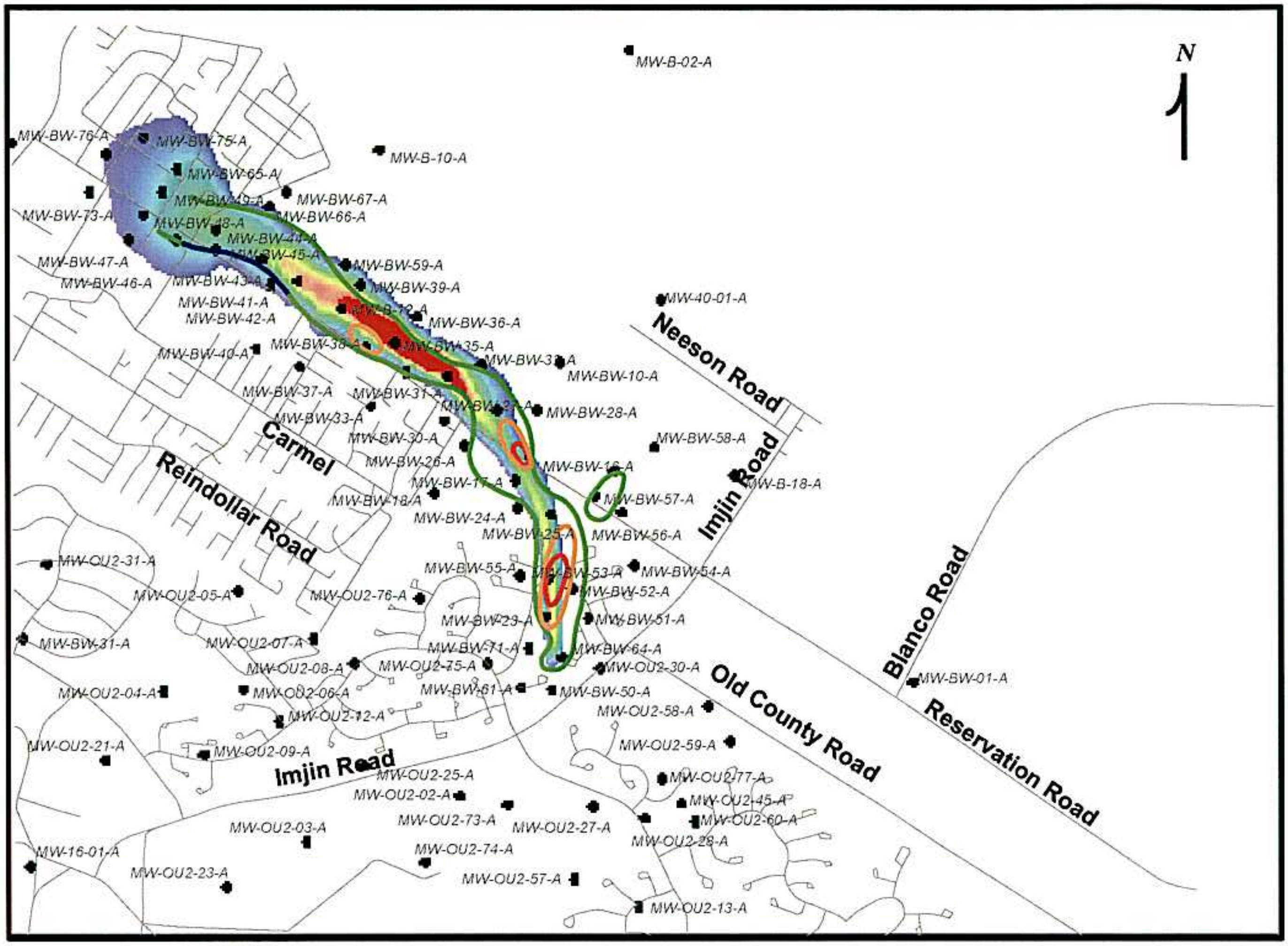
Elevation contours in feet above mean sea level

MACTEC

Simulated versus Observed Groundwater Elevation Contours, Lower 180-Foot Aquifer, June 2004, OUCTP RI/FS
Former Fort Ord, California

PLATE
**F11**

| DRAWN | JOB NUMBER | APPROVED | DATE | REVISED DATE |
| --- | --- | --- | --- | --- |
| CLH | 408703007.010403 | MDT / cm | 04/05 | |




***Observed Carbon Tetrachloride Plume (ppb)***

9 8 7 6 5 4 3 2 1

***Simulated Carbon Tetrachloride Plume (ppb)***

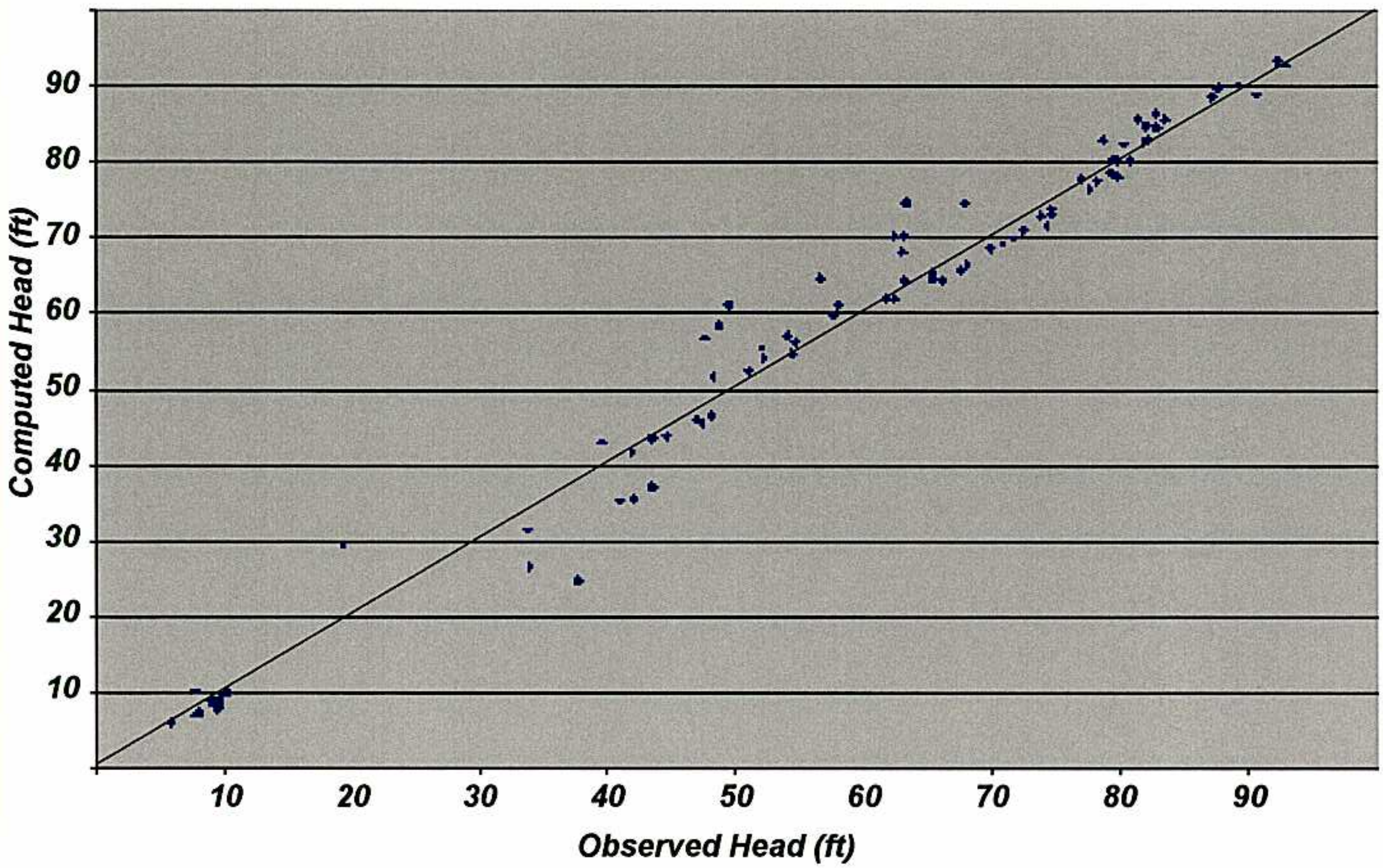
- 0
- 0-0.5
- 0.5-5
- 5-10

MACTEC

Simulated versus Observed Carbon Tetrachloride Concentrations, A-Aquifer, June 2004, OUCTP RI/FS
Former Fort Ord, California

PLATE
F12

| DRAWN | JOB NUMBER | APPROVED | DATE | REVISED DATE |
|---|---|---|---|---|
| CLH | 408703007.010403 | MDT / [signature] | 04/05 | |




***Statistical Error Summary of Computed Head vs. Obvserved Head:***

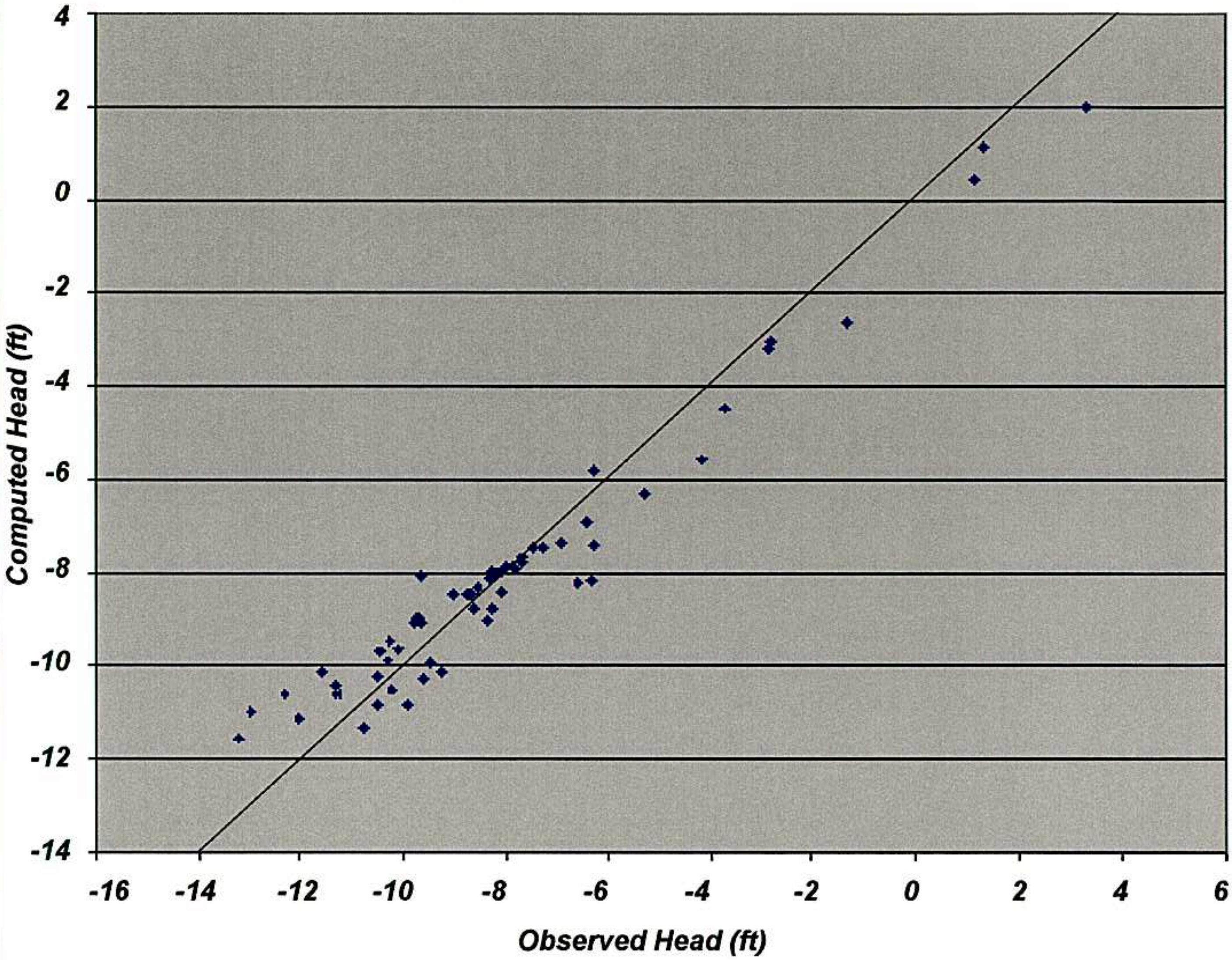
***Mean Error = 0.856***
***Mean Absolute Error = 2.683***
***Root Mean Squared Error = 3.967***

MACTEC

Computed versus Observed Head
A-Aquifer
OUCTP RI/FS
Former Fort Ord, California

PLATE
F13-A

| DRAWN | JOB NUMBER | APPROVED | DATE | REVISED DATE |
|---|---|---|---|---|
| CLH | 408703007.010403 | MDT /cm | 04/05 | |




***Statistical Error Summary of Computed Head vs. Obvserved Head:***

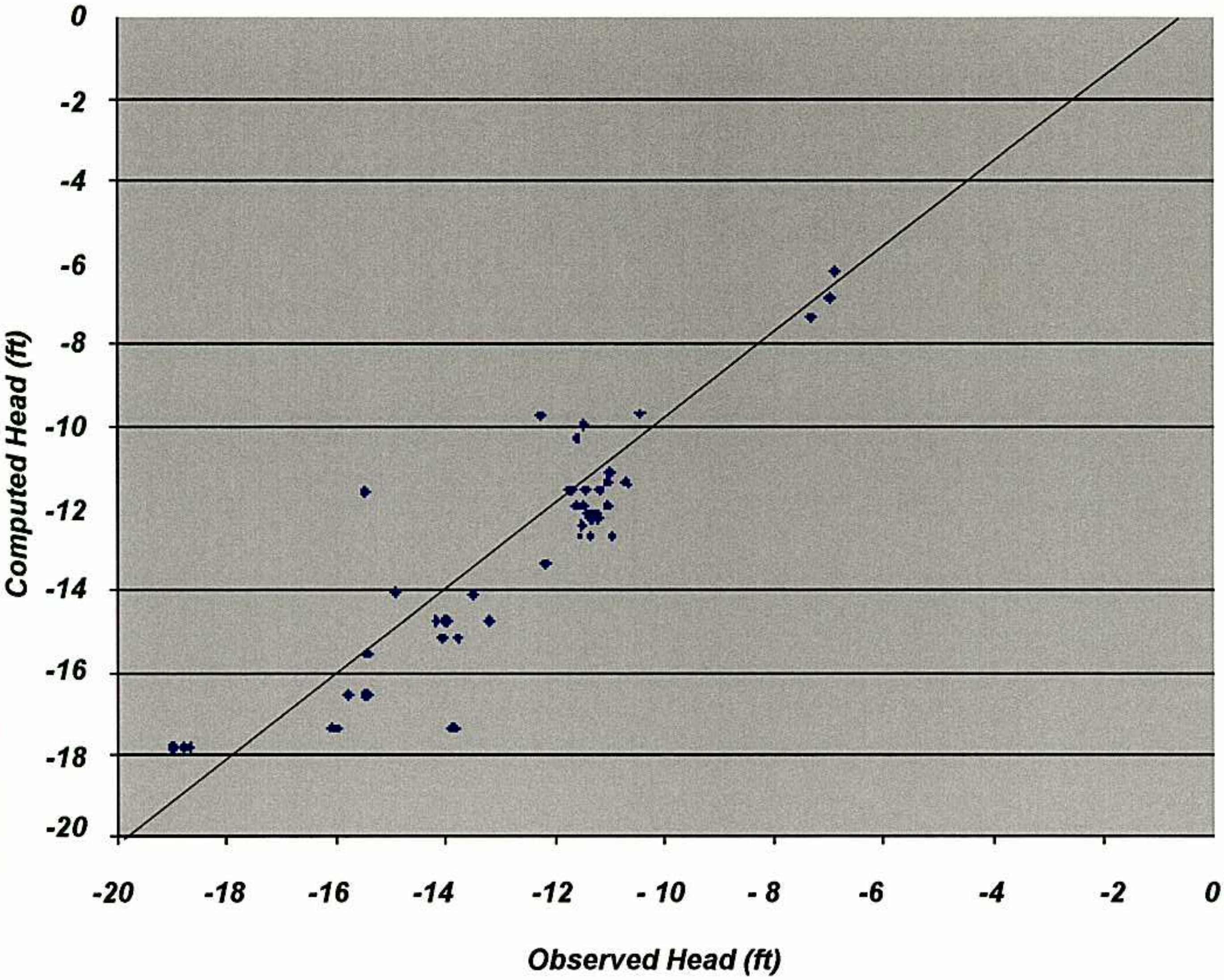
***Mean Error = 0.018***
***Mean Absolute Error = 0.635***
***Root Mean Squared Error = 0.811***

MACTEC

Computed versus Observed Head
Upper 180-Foot Aquifer
OUCTP RI/FS
Former Fort Ord, California

PLATE
# F13-B

| DRAWN | JOB NUMBER | APPROVED | DATE | REVISED DATE |
|---|---|---|---|---|
| CLH | 408703007.010403 | MDT/cm | 04/05 | |




***Statistical Error Summary of Computed Head vs. Obvserved Head:***

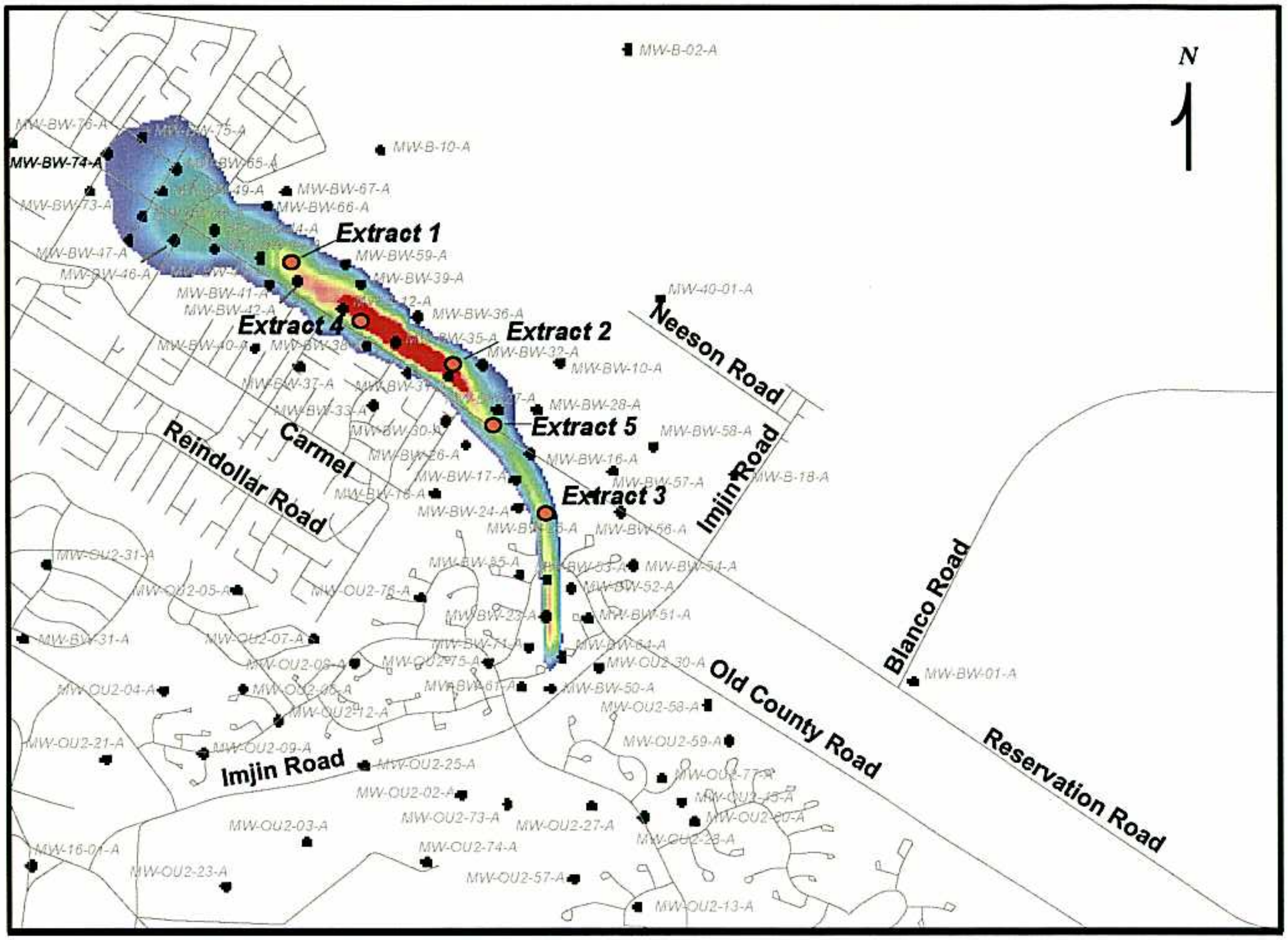
***Mean Error = -0.336***
***Mean Absolute Error = 1.012***
***Root Mean Squared Error = 1.296***

MACTEC

Computed versus Observed Head
Lower 180-Foot Aquifer
OUCTP RI/FS
Former Fort Ord, California

PLATE
F13-C

| DRAWN | JOB NUMBER | APPROVED | DATE | REVISED DATE |
|---|---|---|---|---|
| CLH | 408703007.010403 | MDT/LM | 04/05 | |




**Carbon Tetrachloride Concentration (ppb)**

9
8
7
6
5
4
3
2
1

**Extraction Well**

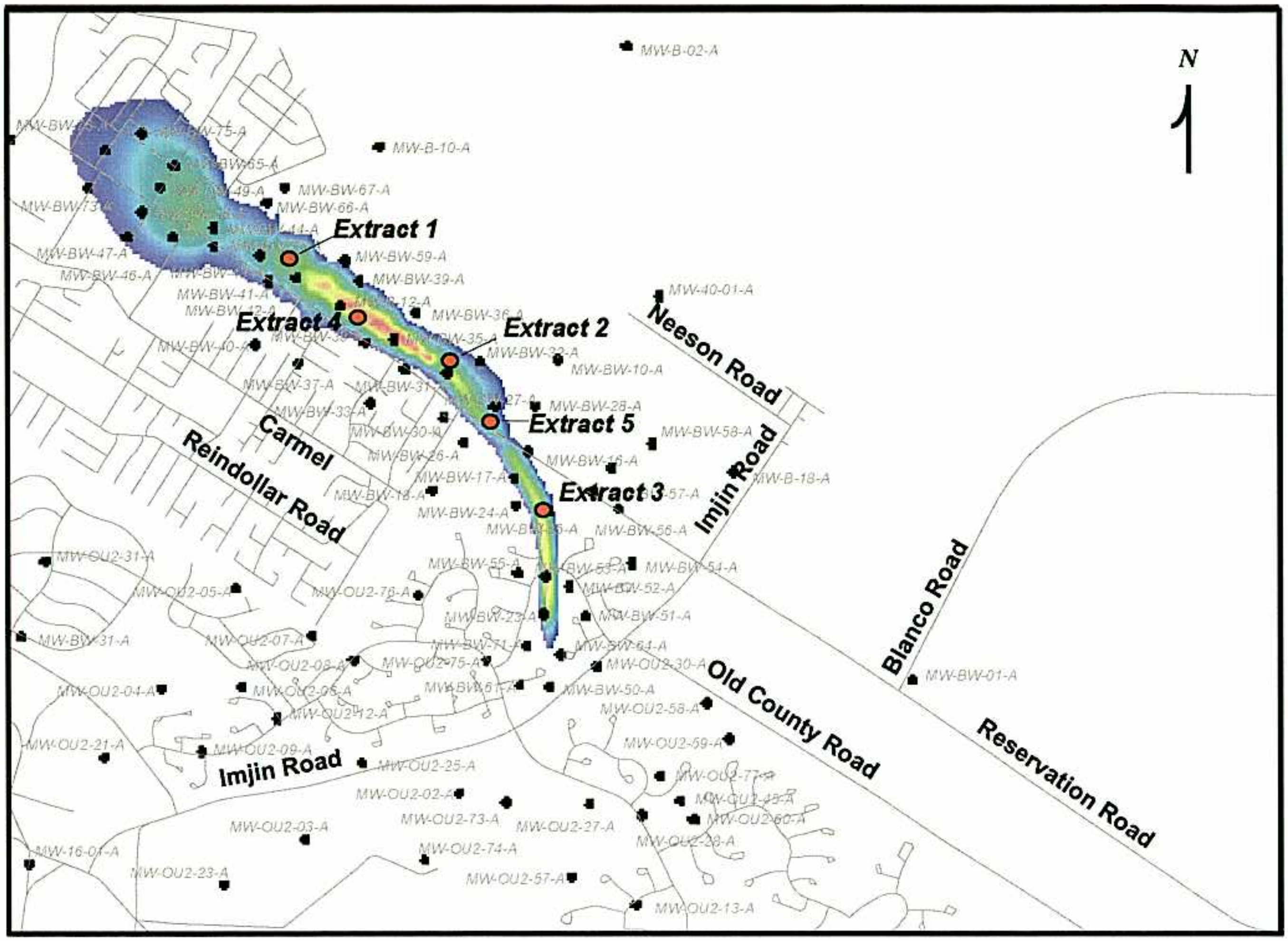
**Extraction Well Pumping Rates (gpm):**
**Extract 1 = 50**
**Extract 2 = 30**
**Extract 3 = 10**
**Extract 4 = 20**
**Extract 5 = 35**

MACTEC

Predictive Analysis, A-Aquifer Groundwater Extraction System - Year 1
OUCTP RI/FS
Former Fort Ord, California

PLATE
F14-A

| DRAWN | JOB NUMBER | APPROVED | DATE | REVISED DATE |
| --- | --- | --- | --- | --- |
| CLH | 408703007.010403 | MDT / cm | 04/05 | |




***Carbon Tetrachloride Concentration (ppb)***

9
8
7
6
5
4
3
2
1

***Extraction Well***

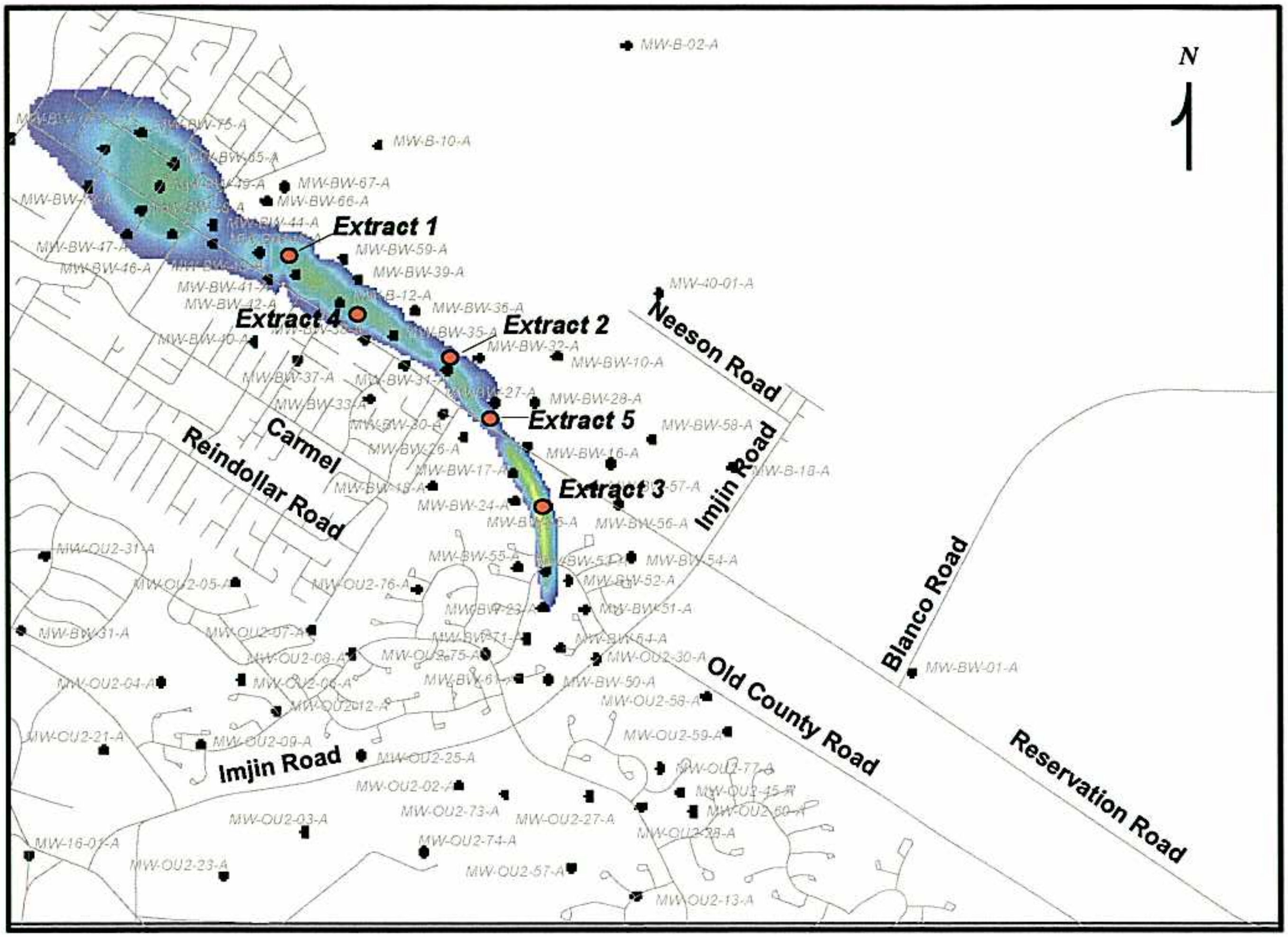
***Extraction Well Pumping Rates (gpm):***
***Extract 1 = 50***
***Extract 2 = 30***
***Extract 3 = 10***
***Extract 4 = 20***
***Extract 5 = 35***

MACTEC

Predictive Analysis, A-Aquifer Groundwater
Extraction System - Year 5
OUCTP RI/FS
**Former Fort Ord, California**

PLATE
# F14-B

| DRAWN | JOB NUMBER | APPROVED | DATE | REVISED DATE |
|---|---|---|---|---|
| CLH | 408703007.010403 | MDT / [illegible] | 04/05 | |




**Carbon Tetrachloride Concentration (ppb)**

9
8
7
6
5
4
3
2
1

**Extraction Well**

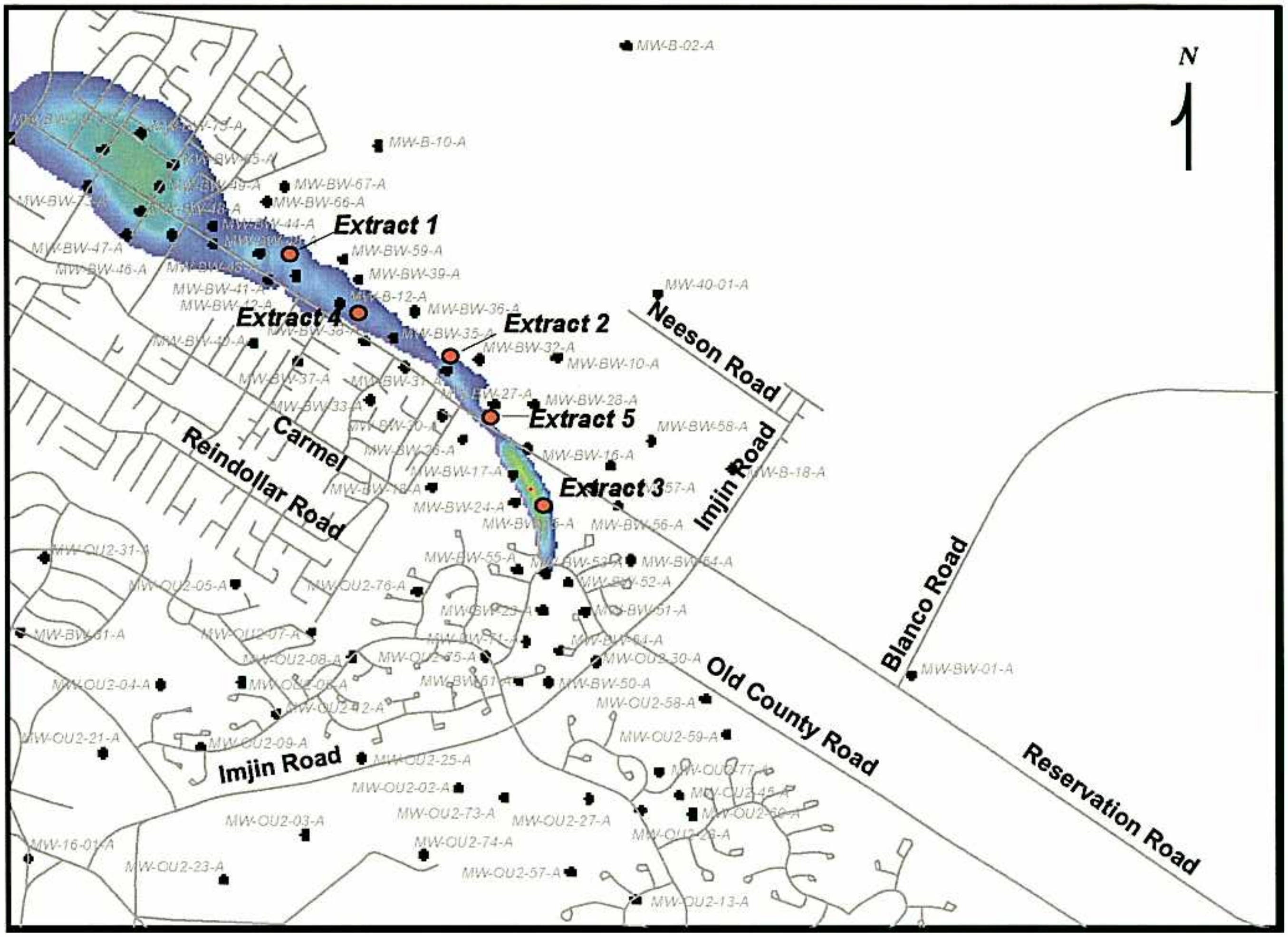
**Extraction Well Pumping Rates (gpm):**
**Extract 1 = 50**
**Extract 2 = 30**
**Extract 3 = 10**
**Extract 4 = 20**
**Extract 5 = 35**

MACTEC

Predictive Analysis, A-Aquifer Groundwater Extraction System - Year 10
OUCTP RI/FS
Former Fort Ord, California

PLATE
F14-C

| DRAWN | JOB NUMBER | APPROVED | DATE | REVISED DATE |
|---|---|---|---|---|
| CLH | 408703007.010403 | MOT / cm | 04/05 | |




**Carbon Tetrachloride Concentration (ppb)**

9
8
7
6
5
4
3
2
1

● **Extraction Well**

***Extraction Well Pumping Rates (gpm):***

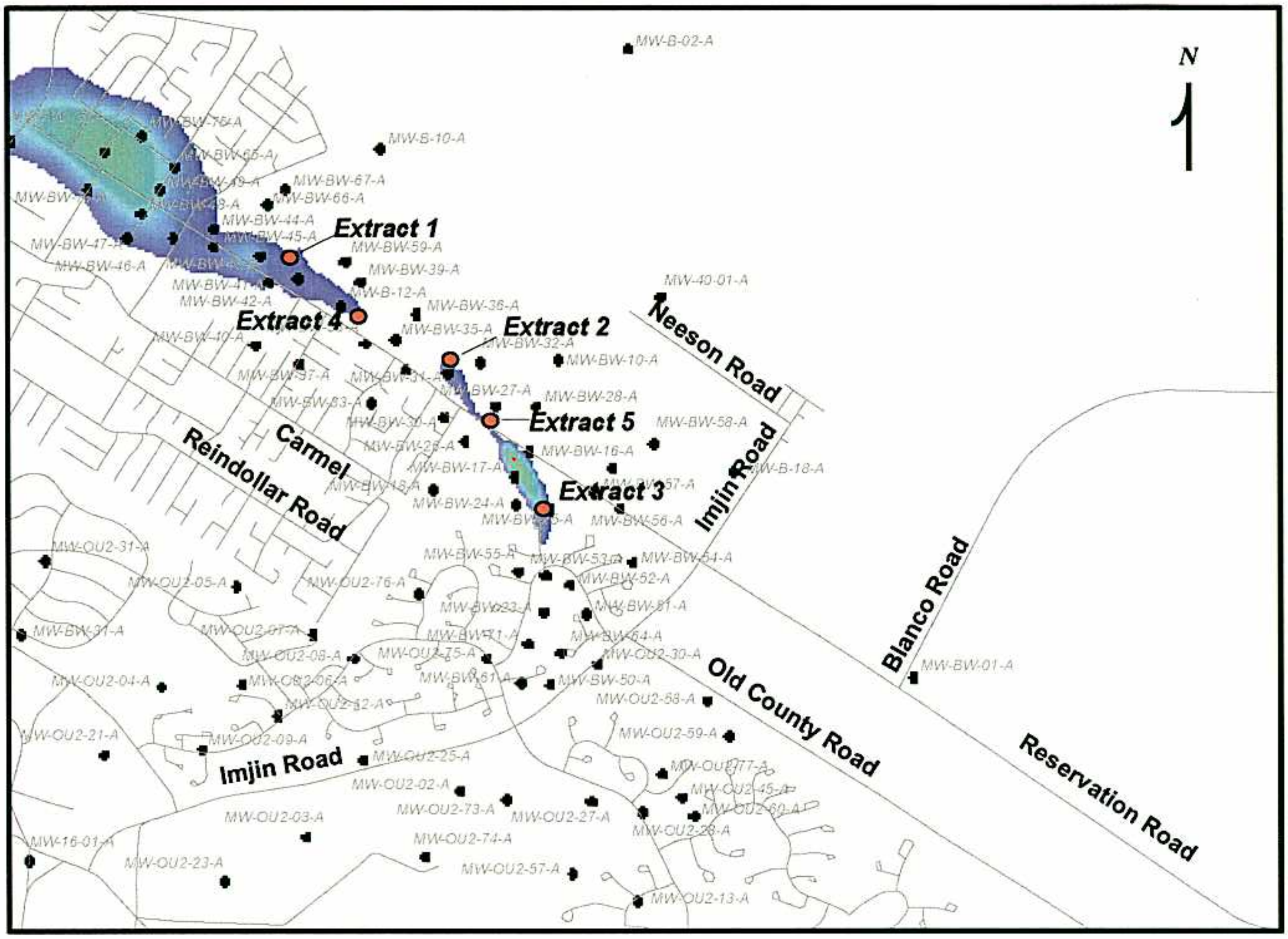
***Extract 1 = 50***
***Extract 2 = 30***
***Extract 3 = 10***
***Extract 4 = 20***
***Extract 5 = 35***

MACTEC

Predictive Analysis, A-Aquifer Groundwater Extraction System - Year 15
OUCTP RI/FS
Former Fort Ord, California

PLATE
F14-D

| DRAWN | JOB NUMBER | APPROVED | DATE | REVISED DATE |
|---|---|---|---|---|
| CLH | 408703007.010403 | MDT /[illegible] | 04/05 | |




**Carbon Tetrachloride Concentration (ppb)**

9
8
7
6
5
4
3
2
1

● **Extraction Well**

***Extraction Well Pumping Rates (gpm):***

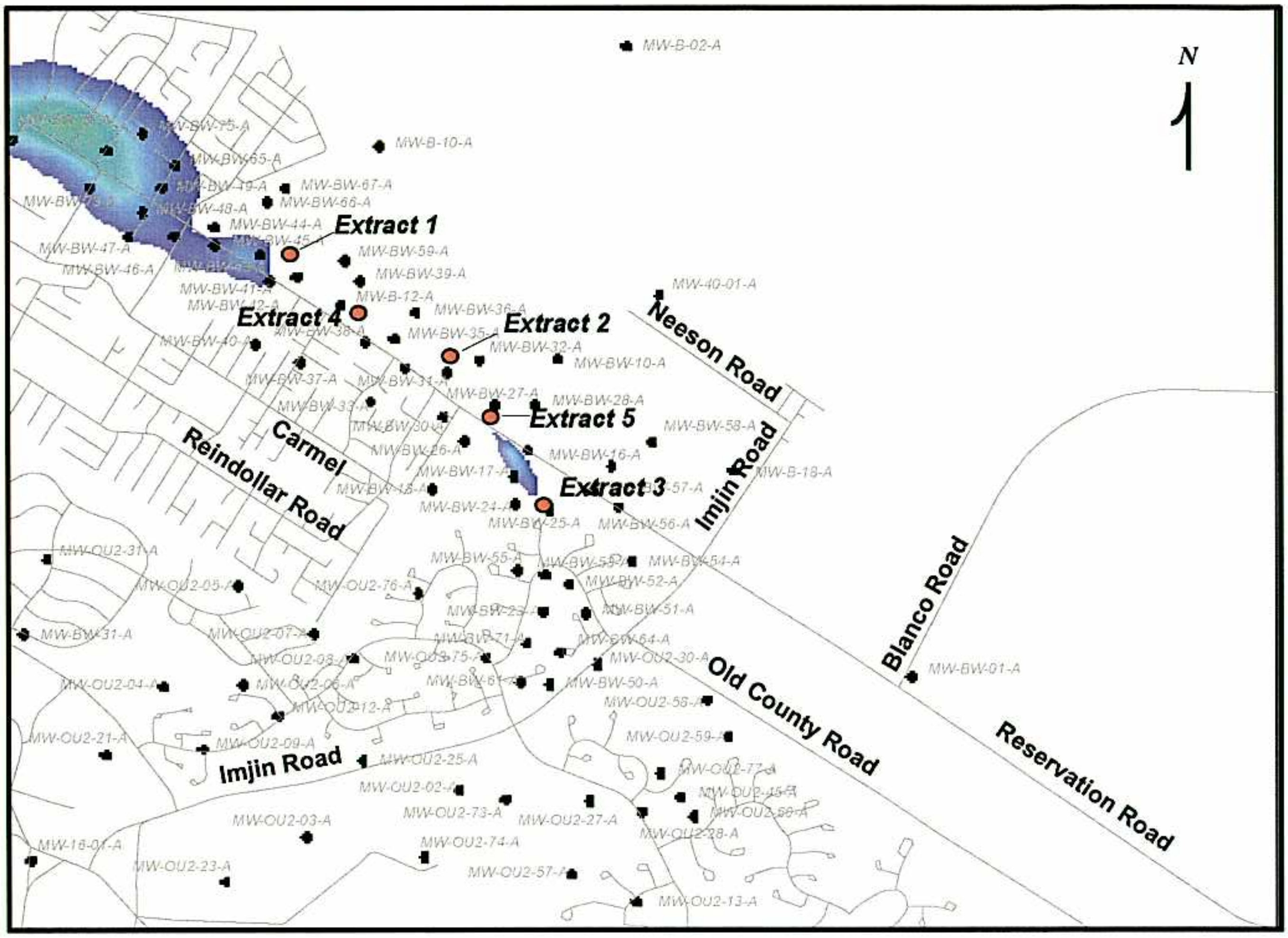
***Extract 1 = 50***
***Extract 2 = 30***
***Extract 3 = 10***
***Extract 4 = 20***
***Extract 5 = 35***

MACTEC

Predictive Analysis, A-Aquifer Groundwater Extraction System - Year 20
OUCTP RI/FS
Former Fort Ord, California

PLATE
# F14-E

| DRAWN | JOB NUMBER | APPROVED | DATE | REVISED DATE |
|---|---|---|---|---|
| CLH | 408703007.010403 | MDT / cm | 04/05 | |




**Carbon Tetrachloride Concentration (ppb)**

9
8
7
6
5
4
3
2
1

**Extraction Well**

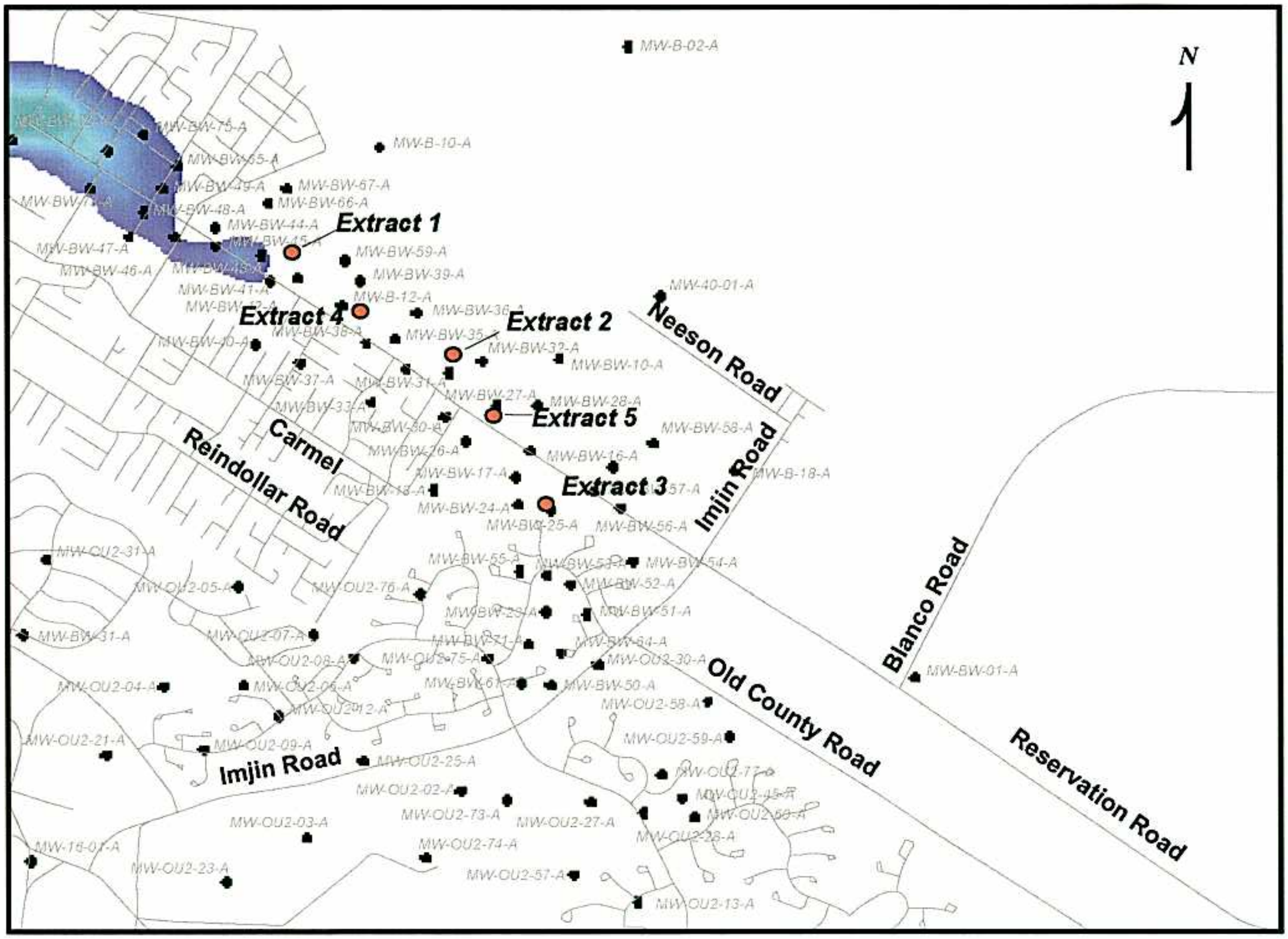
***Extraction Well Pumping Rates (gpm):***
***Extract 1 = 50***
***Extract 2 = 30***
***Extract 3 = 10***
***Extract 4 = 20***
***Extract 5 = 35***

MACTEC

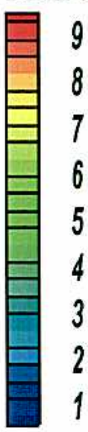
Predictive Analysis, A-Aquifer Groundwater Extraction System - Year 25
OUCTP RI/FS
Former Fort Ord, California

PLATE
F14-F

| DRAWN | JOB NUMBER | APPROVED | DATE | REVISED DATE |
| --- | --- | --- | --- | --- |
| CLH | 408703007.010403 | MDT/ [signature] | 04/05 | |




**Carbon Tetrachloride Concentration (ppb)**




**Extraction Well**

**Extraction Well Pumping Rates (gpm):**

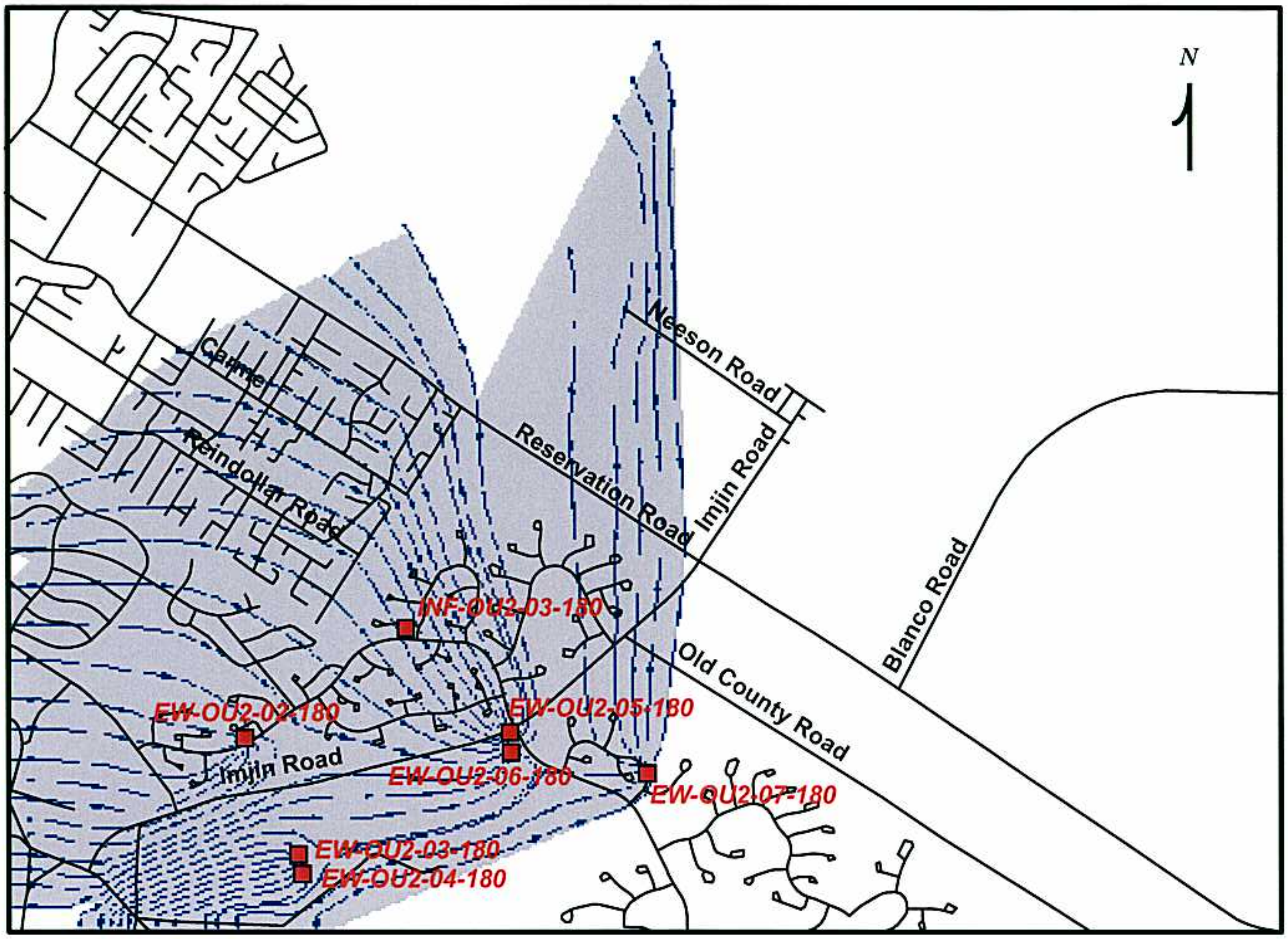
**Extract 1 = 50**
**Extract 2 = 30**
**Extract 3 = 10**
**Extract 4 = 20**
**Extract 5 = 35**

MACTEC

Predictive Analysis, A-Aquifer Groundwater Extraction System - Year 30
OUCTP RI/FS
Former Fort Ord, California

PLATE
F14-G

| DRAWN | JOB NUMBER | APPROVED | DATE | REVISED DATE |
|---|---|---|---|---|
| CLH | 408703007.010403 | MDT/cm | 04/05 | |




■ *Extraction Well* — — — *Particle Pathline*

**Extraction Well Pumping Rates (gpm):**

EW-OU2-02-180 = 122

EW-OU2-03-180 = 153

EW-OU2-04-180 = 0

EW-OU2-05-180 = 125

EW-OU2-06-180 = 125

EW-OU2-07-180 = 125

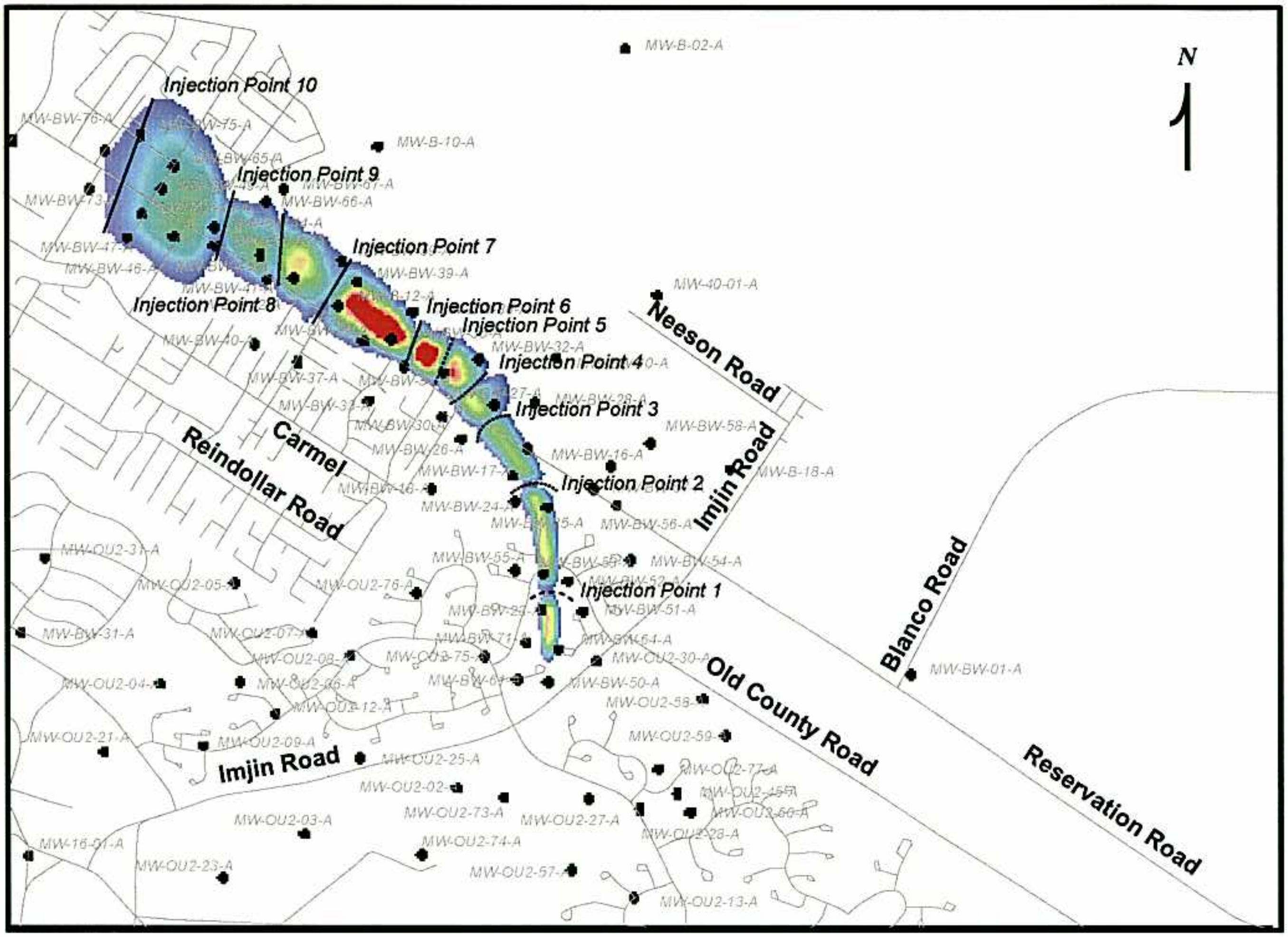
INF-OU2-03-180 = 0

MACTEC

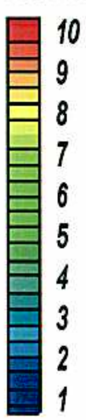
Predictive Analysis, Upper 180-Foot Groundwater Extraction System
OUCTP RI/FS
Former Fort Ord, California

PLATE
F15

| DRAWN | JOB NUMBER | APPROVED | DATE | REVISED DATE |
|---|---|---|---|---|
| CLH | 408703007.010403 | MJT/CM | 04/05 | |




**Carbon Tetrachloride Concentration (ppb)**

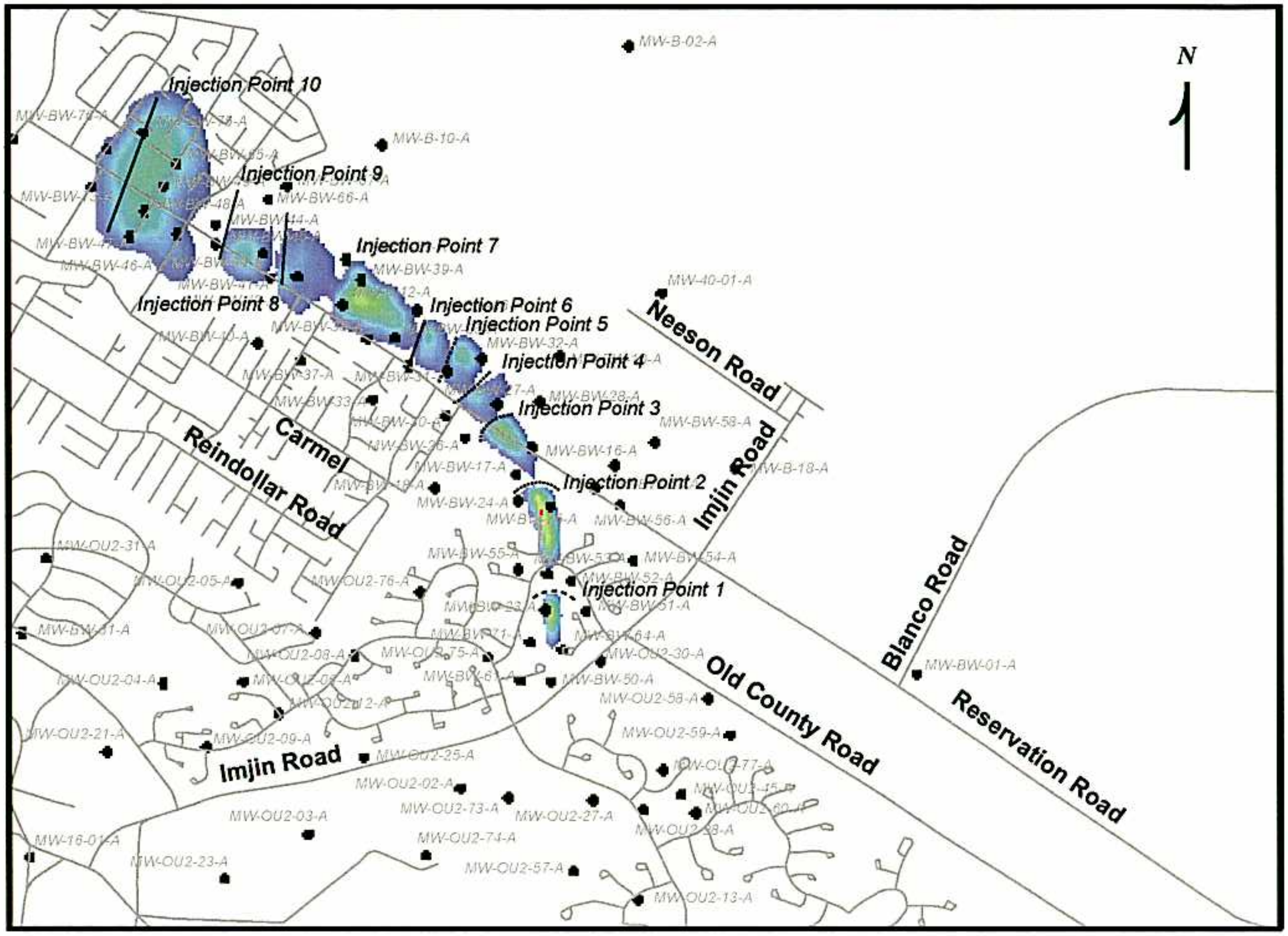



MACTEC

Predictive Analysis, A-Aquifer Enhanced Biodegradation - Year 1
OUCTP RI/FS
Former Fort Ord, California

PLATE
F16-A

| DRAWN | JOB NUMBER | APPROVED | DATE | REVISED DATE |
|---|---|---|---|---|
| CLH | 408703007.010403 | MDT/[illegible] | 04/05 | |




**Carbon Tetrachloride Concentration (ppb)**

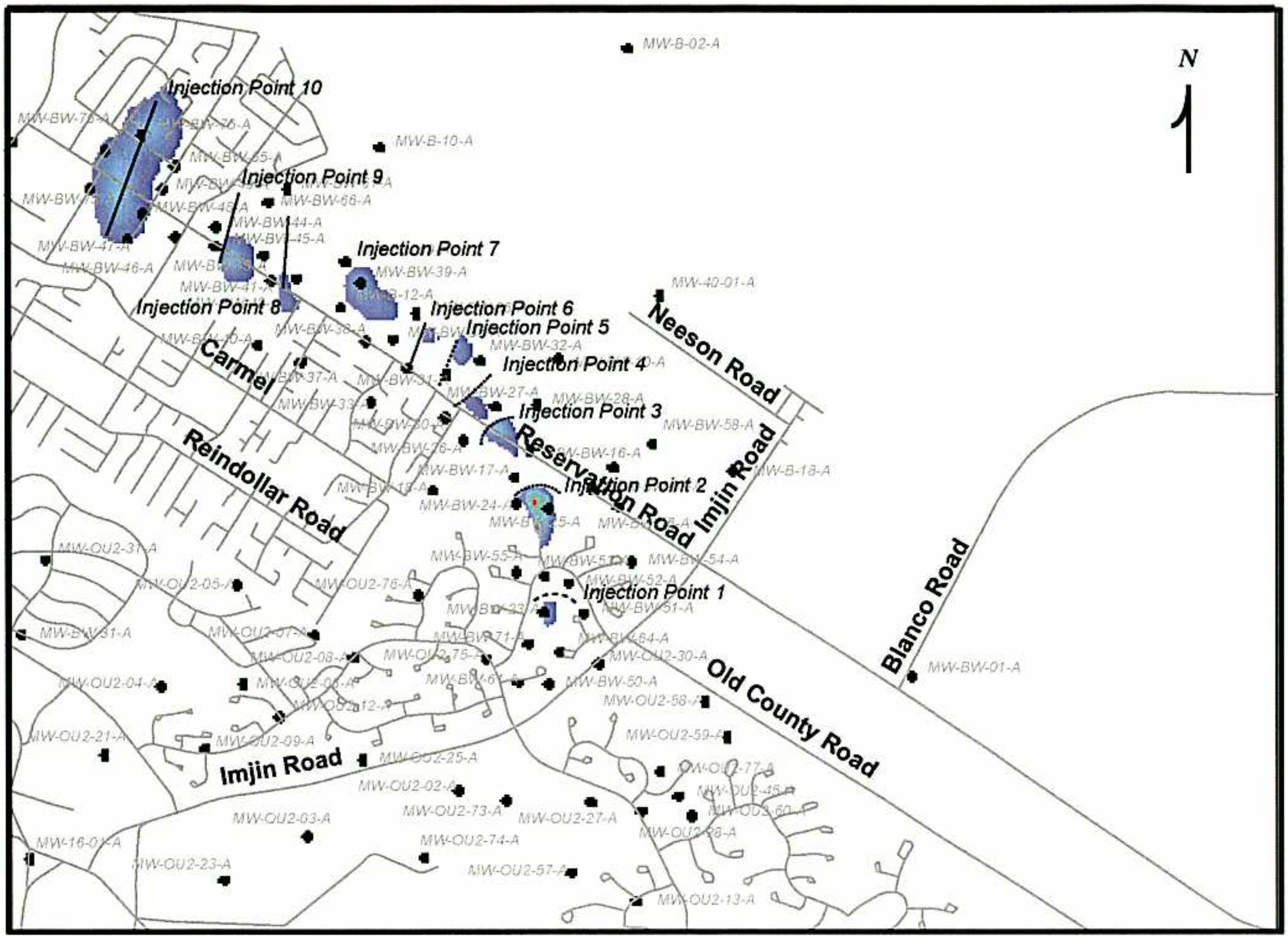
10
9
8
7
6
5
4
3
2
1

MACTEC

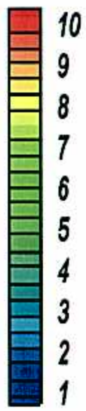
Predictive Analysis, A-Aquifer Enhanced Biodegradation - Year 5
OUCTP RI/FS
Former Fort Ord, California

PLATE
# F16-B

| DRAWN | JOB NUMBER | APPROVED | DATE | REVISED DATE |
|---|---|---|---|---|
| CLH | 408703007.010403 | MDT/cm | 04/05 | |




***Carbon Tetrachloride Concentration (ppb)***

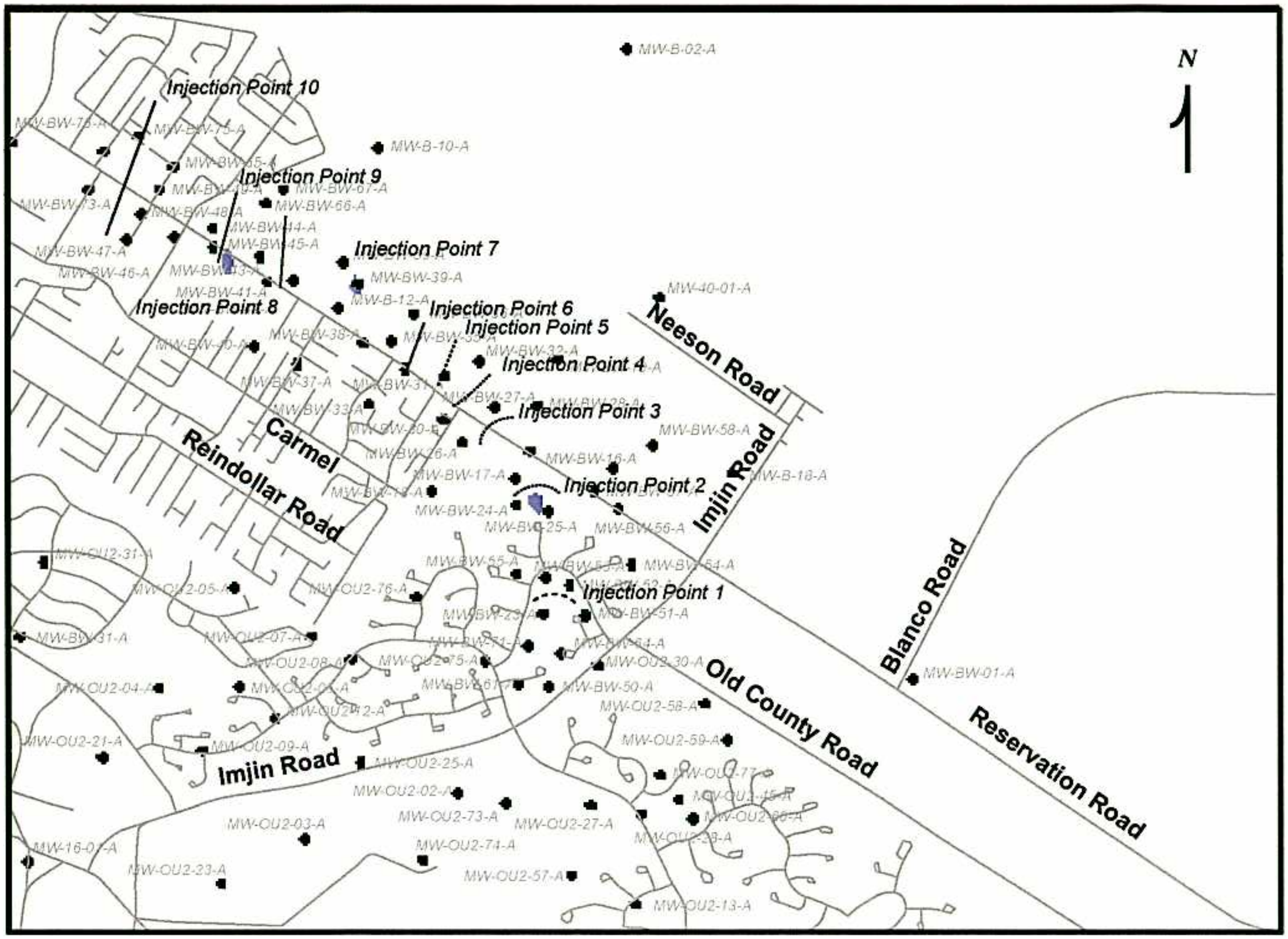



MACTEC

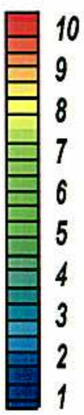
Predictive Analysis, A-Aquifer Enhanced Biodegradation - Year 10
OUCTP RI/FS
Former Fort Ord, California

PLATE
**F16-C**

| DRAWN | JOB NUMBER | APPROVED | DATE | REVISED DATE |
|---|---|---|---|---|
| CLH | 408703007.010403 | | 04/05 | |




**Carbon Tetrachloride Concentration (ppb)**

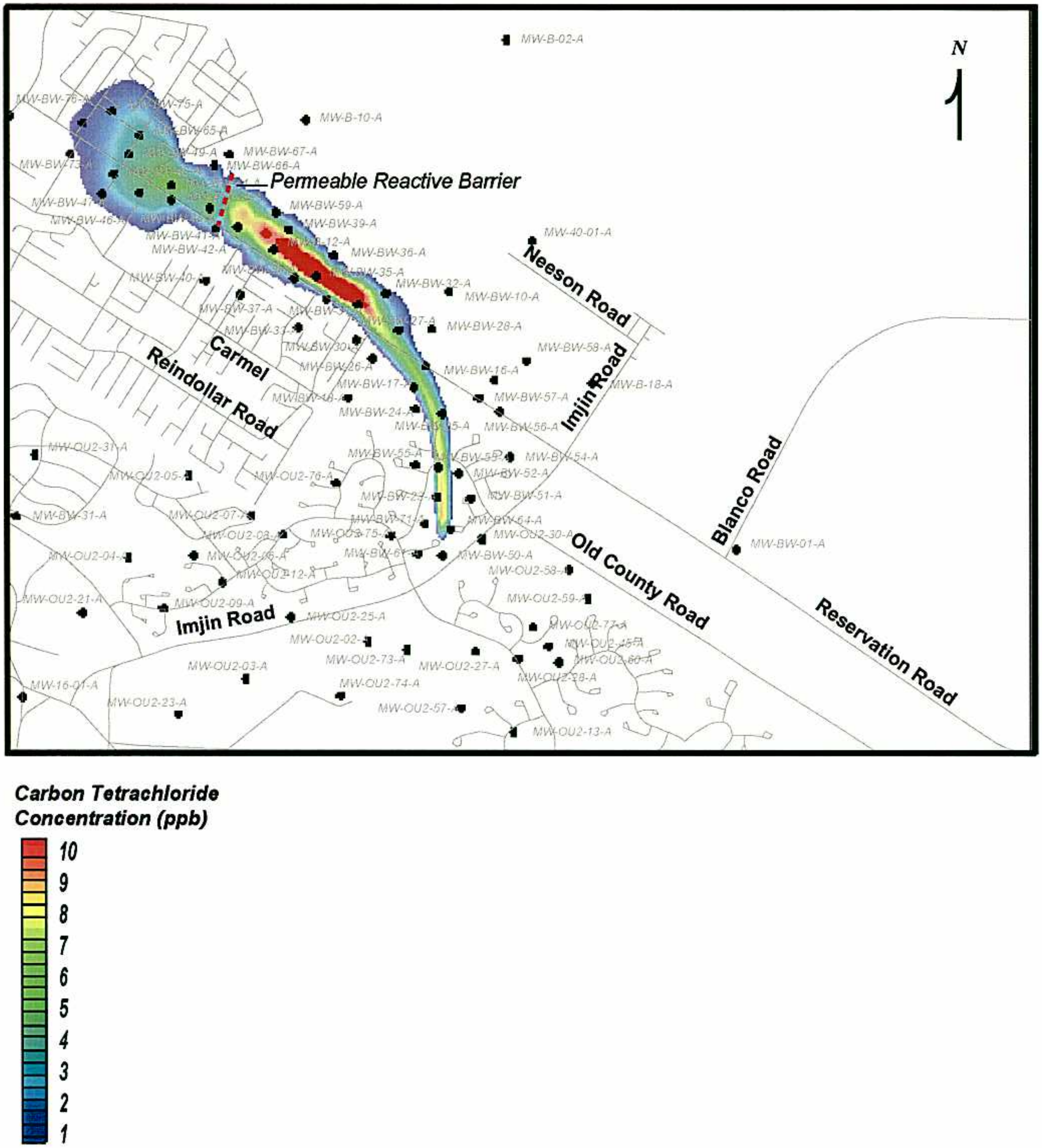



MACTEC

Predictive Analysis, A-Aquifer Enhanced Biodegradation - Year 15
OUCTP RI/FS
Former Fort Ord, California

PLATE
# F16-D

| DRAWN | JOB NUMBER | APPROVED | DATE | REVISED DATE |
|---|---|---|---|---|
| CLH | 408703007.010403 | MDT/cm | 04/05 | |

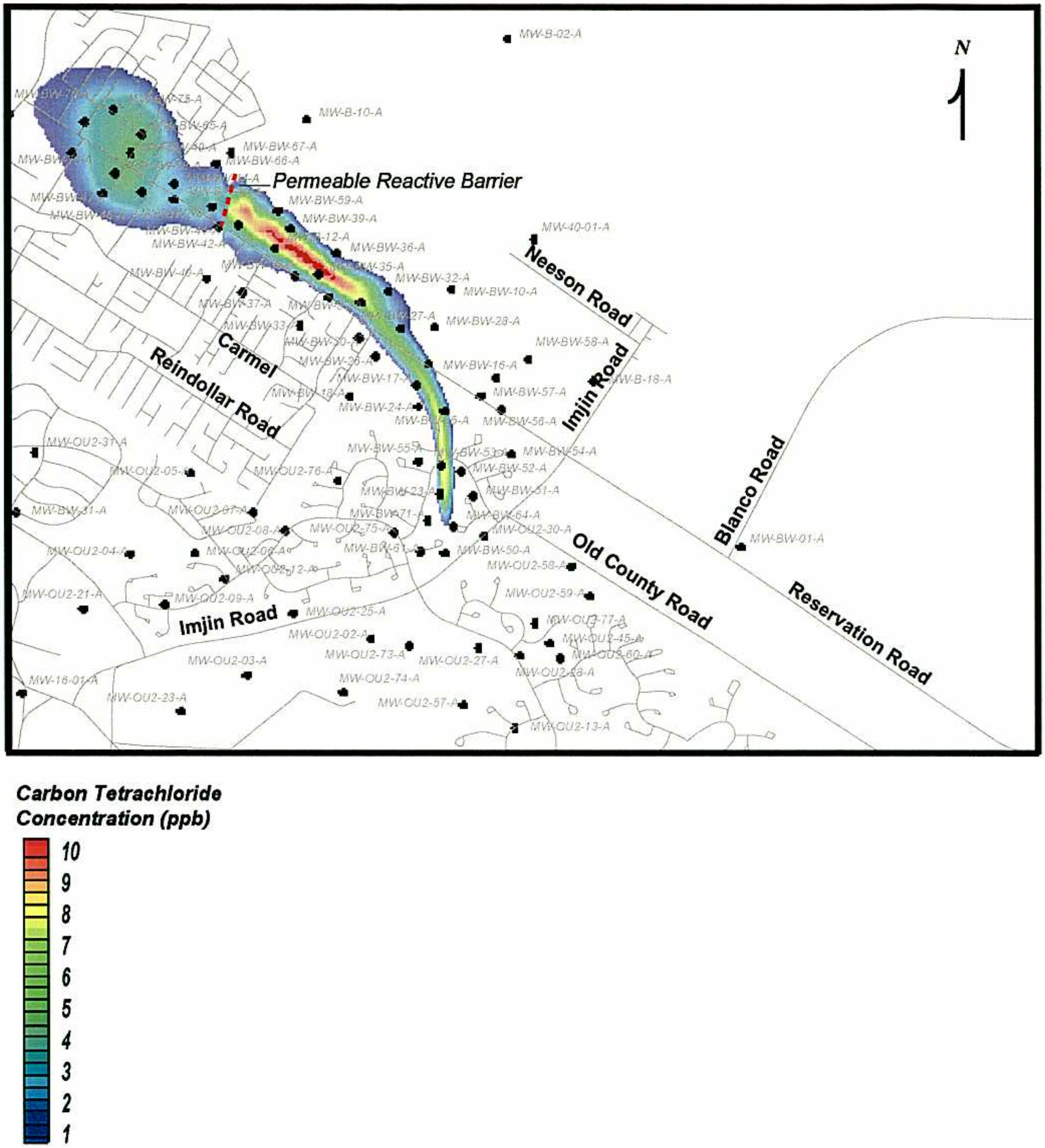



MACTEC

Predictive Analysis, A-Aquifer Permeable Reactive Barrier - Year 1
OUCTP RI/FS
Former Fort Ord, California

PLATE
F17-A

| DRAWN | JOB NUMBER | APPROVED | DATE | REVISED DATE |
|---|---|---|---|---|
| CLH | 408703007.010403 | MDT / cm | 04/05 | |

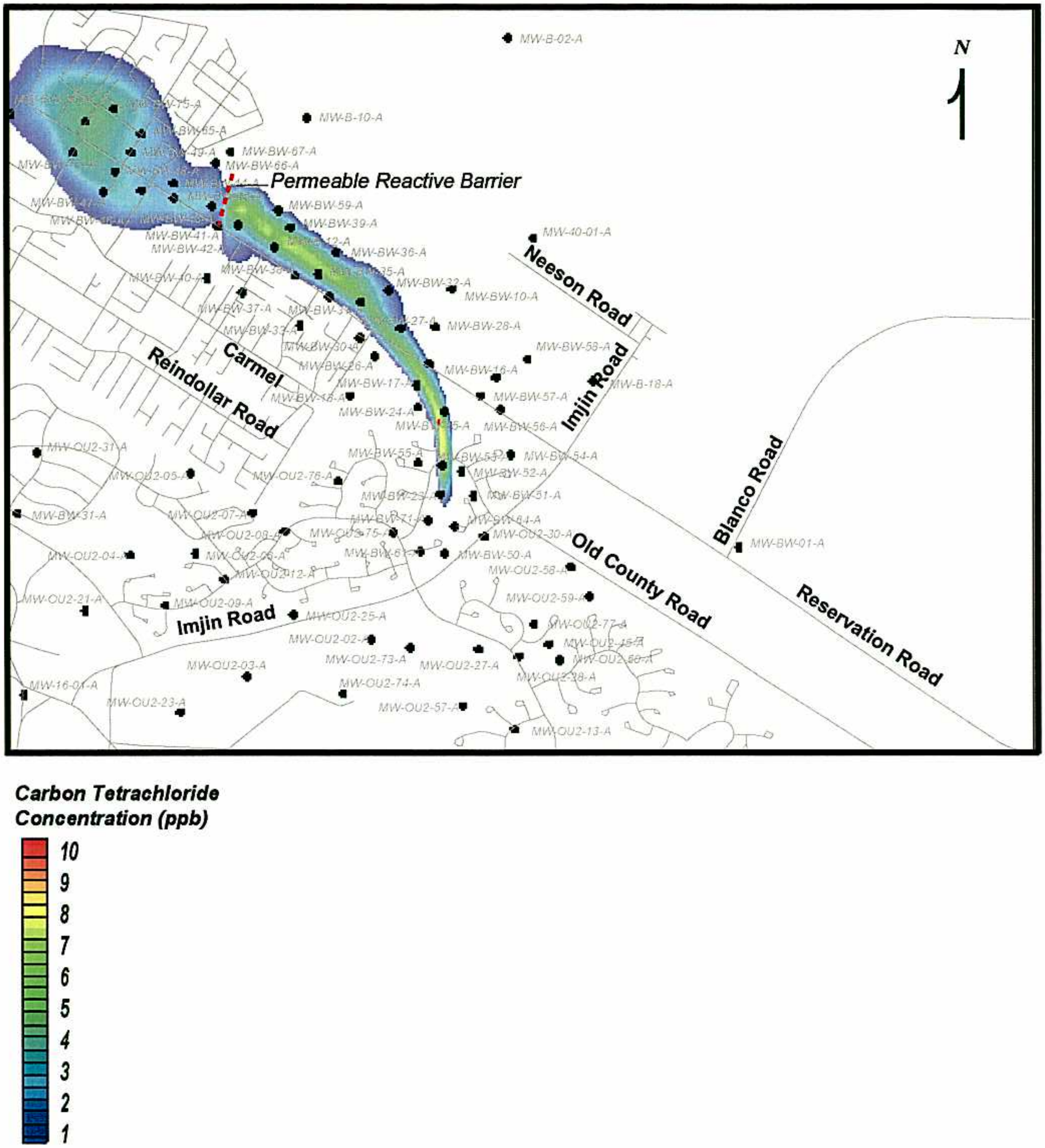



MACTEC

Predictive Analysis, A-Aquifer Permeable Reactive Barrier - Year 5
OUCTP RI/FS
Former Fort Ord, California

PLATE
# F17-B

| DRAWN | JOB NUMBER | APPROVED | DATE | REVISED DATE |
|---|---|---|---|---|
| CLH | 408703007.010403 | MDT /cm | 04/05 | |

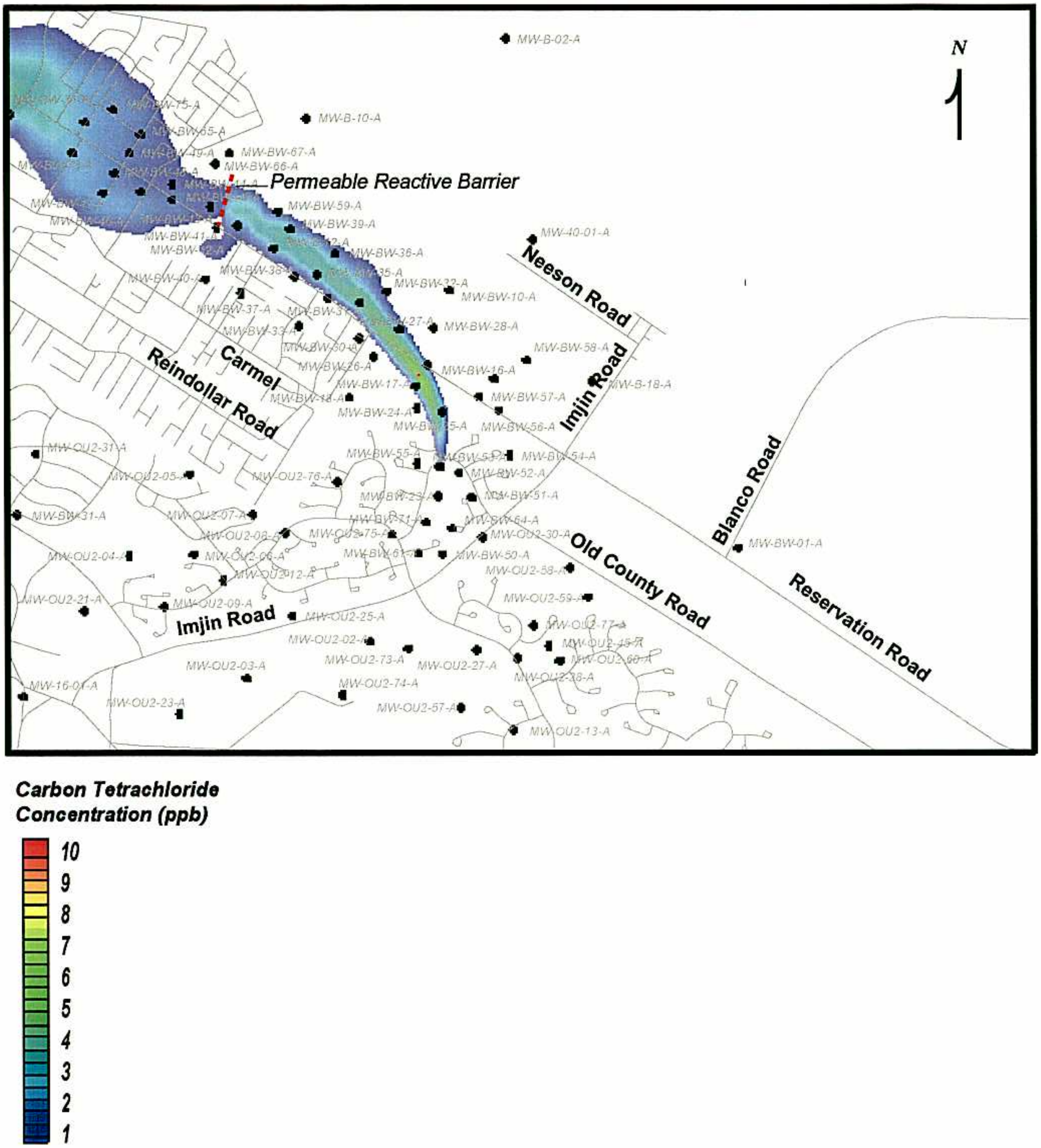



**MACTEC**

Predictive Analysis, A-Aquifer Permeable Reactive Barrier - Year 10
OUCTP RI/FS
Former Fort Ord, California

PLATE
# F17-C

| DRAWN | JOB NUMBER | APPROVED | DATE | REVISED DATE |
|---|---|---|---|---|
| CLH | 408703007.010403 | MDT/cm | 04/05 | |

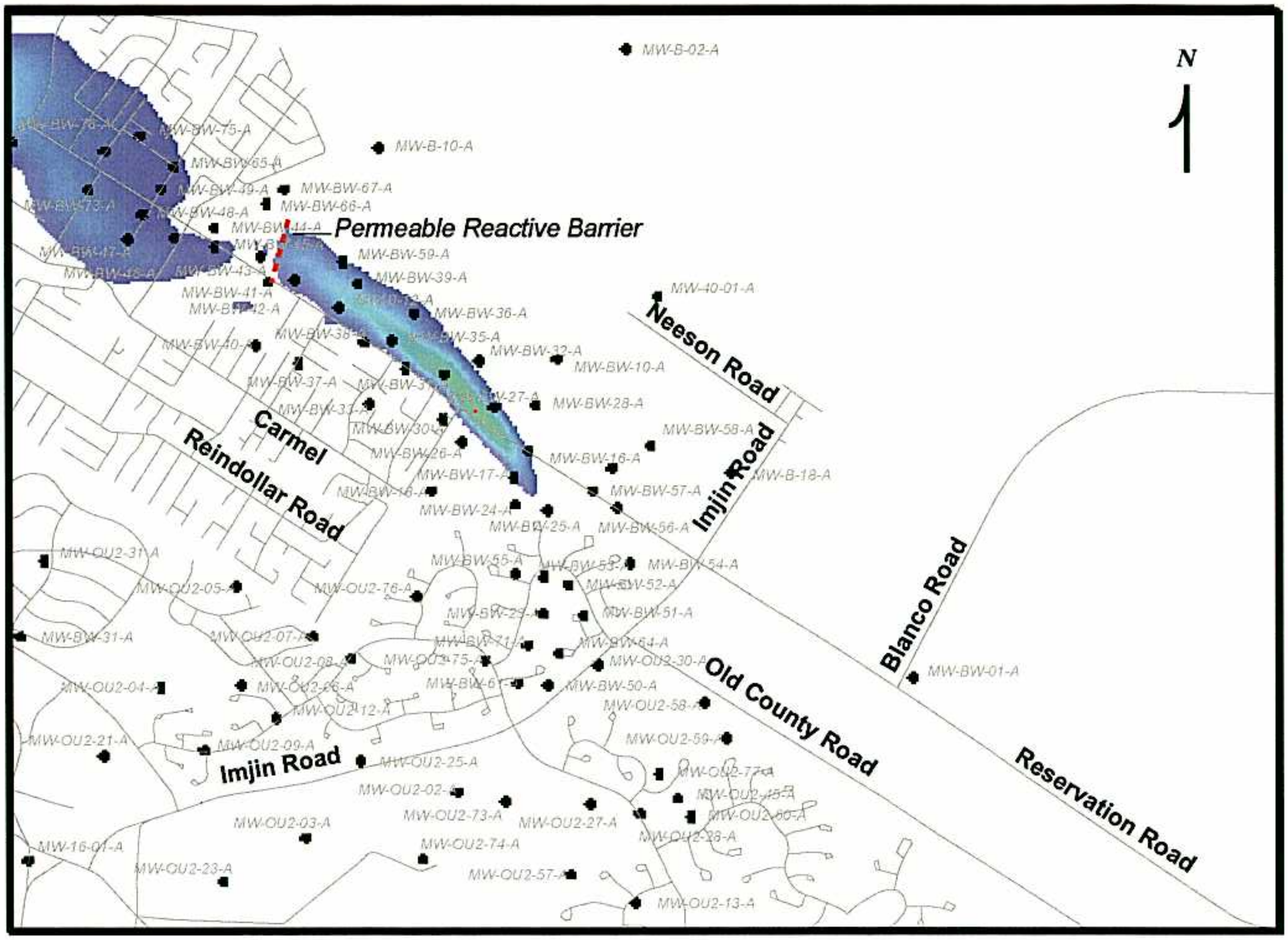



MACTEC

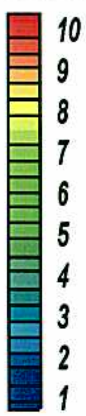
Predictive Analysis, A-Aquifer Permeable Reactive Barrier - Year 20
OUCTP RI/FS
Former Fort Ord, California

PLATE
F17-D

| DRAWN | JOB NUMBER | APPROVED | DATE | REVISED DATE |
|---|---|---|---|---|
| CLH | 408703007.010403 | | 04/05 | |




**Carbon Tetrachloride Concentration (ppb)**

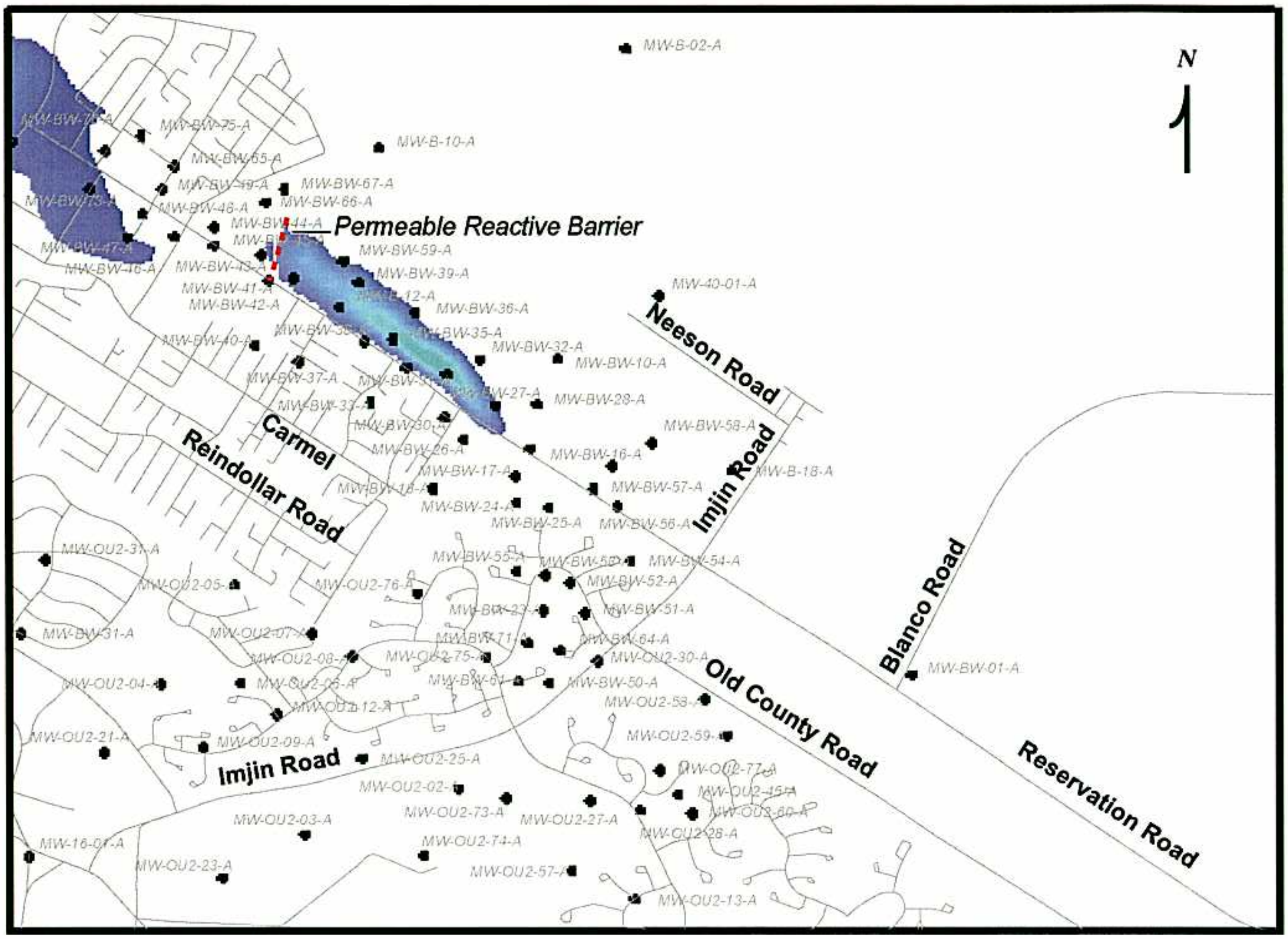


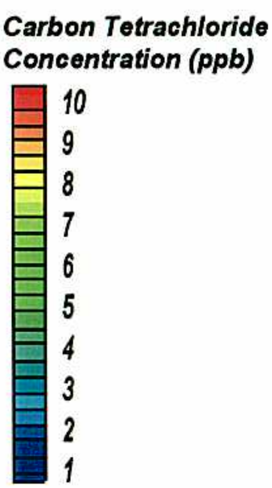

MACTEC

Predictive Analysis, A-Aquifer Permeable Reactive Barrier - Year 30
OUCTP RI/FS
**Former Fort Ord, California**

PLATE
# F17-E

| DRAWN | JOB NUMBER | APPROVED | DATE | REVISED DATE |
|---|---|---|---|---|
| CLH | 408703007.010403 | MOT / [illegible] | 04/05 | |



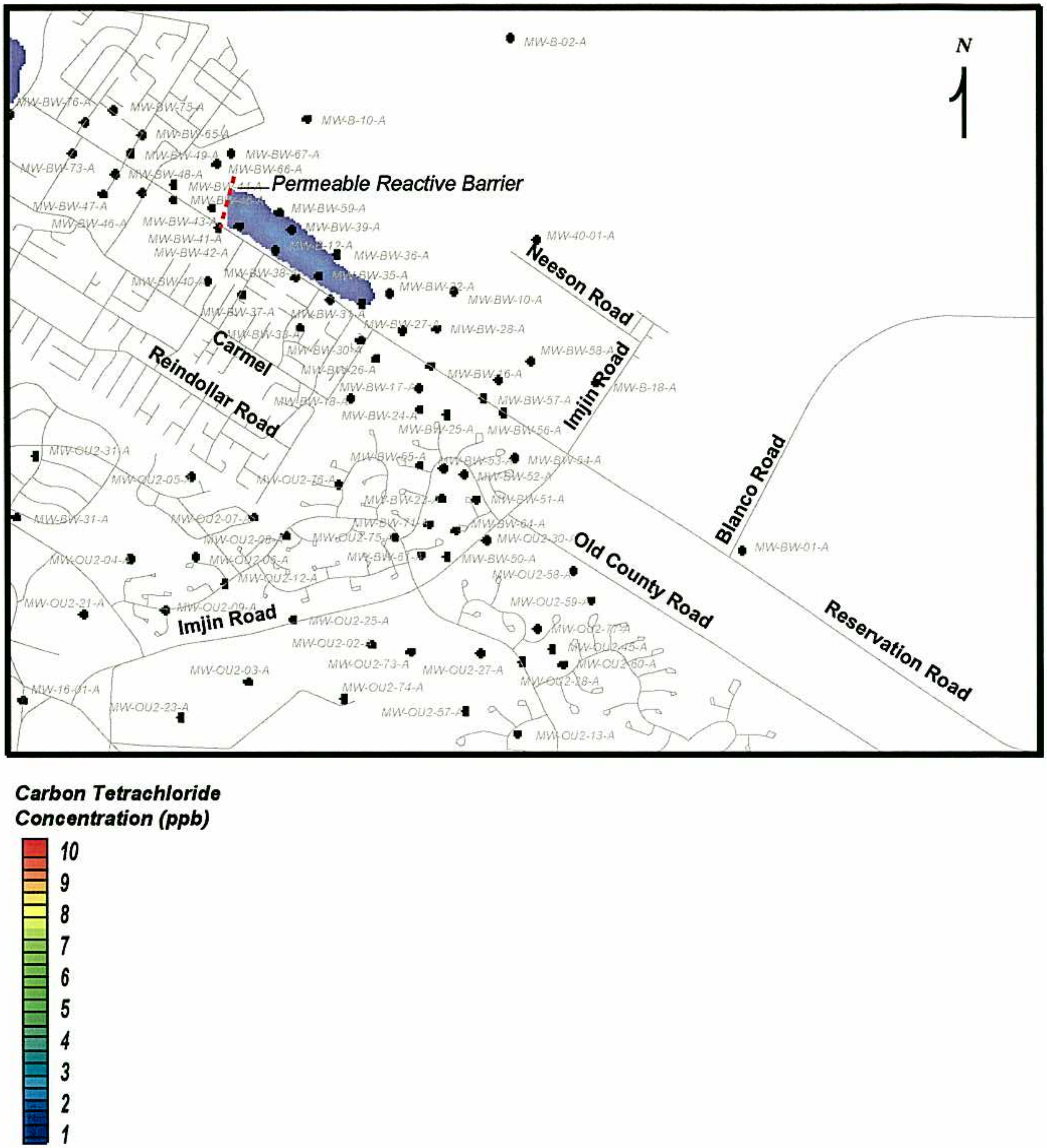




MACTEC

Predictive Analysis, A-Aquifer Permeable Reactive Barrier - Year 40
OUCTP RI/FS
Former Fort Ord, California

PLATE
F17-F

| DRAWN | JOB NUMBER | APPROVED | DATE | REVISED DATE |
| --- | --- | --- | --- | --- |
| CLH | 408703007.010403 | MDT /cm | 04/05 | |




MACTEC

**Predictive Analysis, A-Aquifer Permeable Reactive Barrier - Year 50**
**OUCTP RI/FS**
**Former Fort Ord, California**

PLATE
# F17-G

| DRAWN | JOB NUMBER | APPROVED | DATE | REVISED DATE |
|---|---|---|---|---|
| CLH | 408703007.010403 | MDT /cm | 04/05 | |