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Abstract
WHC, 1994, Capture Zone Analyses for the 200-ZP-1 and 200-UP-1 Pilot-Scale Pump-and-Treat Tests, WHC-SD-EN-TI-252, Rev.0, prepared by M. P. Connelly for Westinghouse Hanford Company, Richland, WA

This report describes the numerical simulations used for determining the effects of the 200-ZP-1 and 200-UP-1 Pilot Scale Pump-and-Treat Tests on the regionally unconfined aquifer. The objectives of the analyses were to determine the size of the capture and injections zones, the extent and timing of hydrologic communication between injection and withdrawal wells, and possible effects that heterogeneity would have on the shape of the capture and injection zones.

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CONTENTS

1.0 INTRODUCTION AND BACKGROUND 1-1
- 1.1 SCOPE AND OBJECTIVE 1-2
- 1.2 DESCRIPTION OF THE COMPUTER SOFTWARE 1-3
- 1.3 DATA REQUIREMENTS 1-4
- 1.4 GENERAL APPROACH 1-5

2.0 CONCEPTUAL MODEL 2-1
- 2.1 GEOLOGY 2-1
- 2.2 HYDROLOGY 2-1

3.0 NUMERICAL MODEL 3-1
- 3.1 GEOMETRY AND NUMERICAL DISCRETIZATION 3-1
- 3.2 HYDROLOGIC PROPERTIES 3-1
- 3.3 INITIAL AND BOUNDARY CONDITIONS 3-2

4.0 SIMULATION RESULTS 4-1
- 4.1 STEADY-STATE SIMULATION 4-1
- 4.2 SIMULATIONS OF CONDITIONS FROM 1977 TO 1993 4-1
- 4.3 CAPTURE ZONE ANALYSES 4-2
  - 4.3.1 200-ZP-1 Pilot-Scale Pump-and-Treat Tests 4-2
  - 4.3.2 200-UP-1 Pilot-Scale Pump-and-Treat Tests 4-3
  - 4.3.3 Effect of Heterogeneity on Capture Zone Analysis . 4-4

5.0 SUMMARY 5-1

6.0 REFERENCES 6-1

FIGURES

1-1. Plan View of the Carbon Tetrachloride (CCl_4) Plume in the 200 West Area. 1F-1
1-2. Plan View of the Chloroform Plume in the 200 West Area. 1F-2
1-3. Plan View of the Trichloroethylene (TCE) Plume in the 200 West Area. 1F-3
1-4. Plan View of the Uranium Plume in the 200 West Area. 1F-4
1-5. Plan View of the ^{99}Technetium Plume in the 200 West Area. 1F-5
1-6. Plan View of the Hydraulic Conductivity Field for the Ringold Gravel Unit E at the Water Table in the 200 West Area. 1F-6
2-1. Contour Map of the Bottom of the Regionally Unconfined Aquifer (Upper) and a Perspective View of that Surface (Lower). 2F-1
2-2. Contour Map of the Top of the Regionally Unconfined Aquifer in June 1993 (Upper) and a Perspective View of that Surface (Lower). 2F-2
2-3. Isopach Map of the Regionally Unconfined Aquifer. 2F-3
2-4. Four Perspective Views Showing the Shape of the Regionally Unconfined Aquifer. 2F-4

CONTENTS (cont)

FIGURES (cont):

3-1. Nested Grid with ~9.5 x 9.5 m Elements in the Vicinity of the Proposed 200-ZP-1 and 200-UP-1 Pilot-Scale Pump-and-Treat Test Analyses 3F-1
3-2. Final Three-Dimensional Nested Grid Mesh Used for the Simulations. 3F-2
3-3. Modification of Hydraulic Conductivity Map Constructed Using Data Collected in 1993 . . . . . 3F-3
3-4. Material Property Designations for Each Element within the Model Domain 3F-4
4-1. Simulation to Steady-State Conditions in 1976 . . . . . 4F-1
4-2. Model-Predicted Water Table Elevations for 1977 (a), 1982 (b), 1987 (c) and 1992 (d) 4F-2
4-3. Comparison of the Observed Elevation of the Water Table (a) in 1993 with the Elevation Predicted by the Numerical Model (b) 4F-3
4-4. Capture and Injection Zone Analyses for 200-ZP-1 PSPTT Wells 299-W18-5 and 299-W18-2 after 30 (a), 45 (b), 60 (c), and 90 (d) Days 4F-4
4-5. Capture And Injection Zone Analyses for 200-ZP-1 PSPTT Pumping and Injection Wells Located Cross Gradient from One Another after 30 (a), 45 (b), 60 (c), and 90 (d) Days of Operation 4F-5
4-6. Capture and Injection Zone Analyses for the 200-UP-1 PSPTT after 60 (a), 90 (b), 120 (c), and 150 (d) Days of Operation 4F-6
4-7. Capture and Injection Zone Analyses for the 200-UP-1 PSPTT after 60 (a), 90 (b), 120 (c), and 150 (d) Days of Operation 4F-7
4-8. Effects of Heterogeneity on the Calculated 150-Day Capture and Injection Zones 4F-8

1.0 INTRODUCTION AND BACKGROUND

The 1991 revision to the *Hanford Federal Facility Agreement and Consent Order* (Tri-Party Agreement) (Ecology et al. 1989) requires that an aggregate area approach to cleanup activities be used in the 200 Areas. This revision was based on the *Hanford Past Practice Investigation Strategy* (DOE-RL 1991). The Washington State Department of Ecology (Ecology), the U.S. Department of Energy (DOE), and the U.S. Environment Protection Agency (EPA) developed the Hanford Past Practice Investigation Strategy to streamline the existing Remedial Investigation/Feasibility Study (RI/FS) and RCRA Facility Investigation/Corrective Measures Study (RFI/CMS) processes. It promotes the use of interim actions to accelerate cleanup activities. For the 200 Areas, the first step in the strategy was to conduct Aggregate Area Management Study (AAMS) reports.

Ten AAMS investigations were completed in the 200 Areas for eight source and two groundwater aggregate areas. These investigations evaluated completed field investigations, and collected and compiled existing operational and environmental data. Based on this information, decisions were made on which Hanford Past Practice Investigation Strategy path (i.e., expedited response action (ERA), interim remedial measure (IRM), limited field investigation (LFI), and final remedy selection) to pursue at each aggregate area. The results were summarized in the 10 AAMS Reports.

Partially because of this work, the Tri-Party Agreement was revised to include milestone M-13-93-03. This 200 West Area milestone entails the startup of two pilot-scale pump-and-treat tests (PSPTT). The 200-ZP-1 Operable Unit PSPTT will focus on carbon tetrachloride (CCl_4), chloroform, and trichloroethylene (TCE) contamination in the groundwater. A second PSPTT for the 200-UP-1 Operable Unit will focus on uranium and ^{99}Tc groundwater contamination in this operable unit.

Accelerated remediation of these plumes will be sought because of their potentially high carcinogenic and radiological exposure risks. The AAMS for the 200 West Area recommended that site-specific capabilities be developed for computer simulation of groundwater flow and contaminant transport in the aggregate areas. The purpose of developing the model was to help evaluate alternatives for remediation and to aid in designing the remedial actions.

Limited field investigations were conducted to collect additional data for refinement of the conceptual model. These field investigations focused on aquifer testing and refinement of plume definition. Information was also collected to better describe the vertical extent of groundwater contamination in the 200-UP-1 aggregate area and the hydraulic conductivity of the regionally unconfined aquifer to the east and northeast of U Plant.

The CCl_4 plume extends over approximately 10,000,000 m^2 and is widespread in the regionally unconfined aquifer throughout much of the 200 West Area (Figure 1-1). However, the highest concentration of CCl_4 occurs in the central portion of the Z Plant Aggregate Area. The chloroform plume is also centered in the Z Plant Aggregate Area and covers an area of approximately 3,100,000 m^2 (Figure 1-2). The TCE plume covers approximately 660,000 m^2 and is in the northern half of the Z Plant Aggregate Area (Figure 1-3).

The uranium and ^{99}Tc plumes are on the southeast side of the 200 West Area, beneath the U Plant Aggregate Area. The uranium plume covers an area of approximately 830,000 m^2 (Figure 1-4); the area covered by ^{99}Tc plume is approximately 1,100,000 m^2 (Figure 1-5). The elevation of the water table in June 1993 is included in these figures to show the hydraulic gradient near these plumes.

1.1 SCOPE AND OBJECTIVE

The scope of this report is limited to the calibration of the numerical model to present-day conditions and the analyses of the capture zones for up to 150 days of pumping for the wells to be used in the 200-ZP-1 and 200-UP-1 PSPTT.

The 200 West Area conceptual and numerical models were developed to simulate the predicted physical responses of the regionally unconfined aquifer to the stresses that will be created by the PSPTT. The models will subsequently provide capability to (1) evaluate alternative interim remedial actions for contaminated groundwater, (2) assess refinements and/or expansions of the interim actions, and (3) help choose a final remedy for the Record of Decision (ROD). Specific objectives of the groundwater flow and contaminant transport are:

1. Assess impacts of changes in the elevation of the water table

2. Evaluate potential extraction and injection well configurations

3. Help design and evaluate monitoring networks

4. Evaluate potential hydraulic control and containment

5. Predict contaminant transport pathways and travel times for contaminants

The modeling effort will require the completion of the following tasks. This report will focus on the first four tasks with future reports being issued that describe tasks five and six, and any modifications to the model due to the collection of additional field data.

1. Assemble available information on the hydrogeology of the 200 West Area and vicinity appropriate to the preparation of conceptual and numerical models. Most of this information was provided by the AAMS.

2. Define the physical properties, boundary conditions, and initial conditions of the hydrologic system for input into numerical groundwater flow and transport model for the PSPTT (and subsequently for alternative remedial action scenarios).

3. Calibrate the model to the existing water table elevations.

4. Provide capture zone analyses for 200-ZP-1 and 200-UP-1 PSPTT operations (See Section 4.3 for a definition of capture zone).

5. Refine the model by incorporating aquifer testing and groundwater monitoring data from the LFI.

6. Define, model and evaluate alternative remedial actions.

1.2 DESCRIPTION OF THE COMPUTER SOFTWARE

VAM3DCG Version 2.4 software (Huyakorn and Panday, 1992) was used for these analyses. Concurrent work on a Hanford Sitewide groundwater model is also using VAM3DCG Version 2.4. Hence, the work done for 200 West Aggregate Area can easily be integrated into the much larger scale, sitewide model.

VAM3DCG uses the finite element method to simulate two- or three-dimensional groundwater flow and/or solute transport in variably saturated porous media. The software can handle a variety of boundary conditions, including infiltration, evaporation, and evapotranspiration. The software was chosen for both the 200 West Area model and the sitewide model for the following reasons:

1. VAM3DCG uses finite-element method that allows the user to make use of non-rectangular shapes and boundaries.

2. VAM3DCG allows the user to make use of nested grids (i.e., transitional elements) to reduce the number of nodes needed detailed simulations of small areas, thereby improving computational efficiency.

3. VAM3DCG employs a pseudo-soil function to simulate the variable saturation conditions inherent to unconfined aquifer groundwater flow problem.

4. The software has been approved for use on the Hanford Site by the DOE, EPA, and Ecology (DOE-RL 1991a).

Two features of VAM3DCG that are critical for the work reported here are the transitional elements and the pseudo-soil functions. The transitional elements allow for local refinement of the computational grid within a portion of the domain. This provides the flexibility of specifying a denser computational grid around the pumping and injection points, where most of the change occurs, and to space the grid less densely away from these centers. The pseudo-soil functions allow VAM3DCG to predict accurately the location of the water table elevations without modeling the flow of groundwater in the vadose zone.

1.3 DATA REQUIREMENTS

VAM3DCG requires the following data to simulate groundwater flow and contaminant transport (the parenthetical addition indicates if this data is a field measurement, laboratory measurement, or taken from the technical literature):

1. System Geometry

   - Horizontal and/or vertical dimensions including stratigraphic thickness and dimensions of lithologic heterogeneities (conceptual model)

2. Porous Media Flow Properties

   - Longitudinal and transverse components of saturated hydraulic conductivity (K_x and K_y, measured in the laboratory and field)

   - Vertical component of saturated hydraulic conductivity (K_z, measured in the laboratory and field)

   - Specific storage (S_s, measured in the field)

3. Solute Transport Properties in Porous Media

   - Longitudinal dispersivity (α_L, measured in the field and from the technical literature)

   - Transverse dispersivity (α_T, measured in the field and from the technical literature)

   - Free-water molecular diffusion coefficient (D_o, from the technical literature)

   - Effective Porosity (ϕ, measured in the field)

   - Bulk Density (ρ_b, measured in the laboratory)

4. Properties of Each Solute Species

   - Decay coefficient (λ, from the technical literature)

   - Soil Distribution coefficient (K_d, measured in the laboratory and from the technical literature)

5. Initial and Boundary Conditions

   - Initial distribution of pressure head (ψ, measured in the field)

   - Initial distribution of concentration (C_o, measured in the field)

- Head values and/or water fluxes assigned at boundaries of model domain (from conceptual model)

- Concentration values and/or fluxes assigned at boundaries of model domain (from conceptual model)

To properly model groundwater flow and contaminant transport, hydraulic and transport property data are needed for the hydrostratigraphic units that contain the regionally unconfined aquifer. In the 200 West Area, available information on the hydraulic and contaminant transport properties of the stratigraphic units above Ringold gravel unit E was sufficient, because the regionally unconfined aquifer is contained wholly within the Ringold gravel unit E. This unit is underlain by either the lower mud sequence of the Ringold Formation, or the top of the Elephant Mountain Basalt. Connelly et al. (1992b) prepared a map showing areas of high and low hydraulic conductivity for this unit within the 200 West Area (Figure 1-6). This map was the basis for initial assignments of hydraulic conductivities to the model.

Most of the field data used in this model came from wells completed to the top of the regionally unconfined aquifer, because few wells penetrate to the bottom of the aquifer. Hence, most information about deeper depths of the aquifer is inferred from shallower data. This conceptual model did not account for any vertical heterogeneity within the regionally unconfined aquifer. Additionally, the aquifer testing, which produced the hydraulic conductivity map consisted primarily of slug and constant discharge tests at the water table surface in partially penetrating wells. As a result of the model assumptions and simplifications, and shortcomings of the aquifer test methods, the model results should be viewed as approximations. However, if the modeling results compare favorably to the field-measured values during the PSPTT, the model can be used beneficially to establish capture zones, injection zones and aid in the design of monitoring networks.

1.4 GENERAL APPROACH

Preparing a diagrammatic conceptual model of the regionally unconfined aquifer and the associated contaminant plumes was the first step in the analysis. The objective of the conceptual model is to depict the solution domain in terms of pertinent properties of the geologic media and the domain boundary conditions. The conceptual model used for the analysis accounted for areas, volumes, and solute concentrations of the various plumes, the present elevation of the water table, the proposed alternative remedial actions (pump and treat scenarios, grout curtains, etc.), and the southwest-northeast trending zone of high hydraulic conductivity in the 200 West Area (Figure 1-6).

A list containing the hydraulic and transport properties was prepared using information from Connelly et al. (1992a). That report was the major source of information for the numerical model, although the hydraulic properties were supplemented by the results from LFI aquifer testing in the 200 West Area in the summer and fall of 1993.

Following the preparation of the conceptual model and compilation of information on the hydraulic and transport properties, a finite element grid was designed with due consideration to the domain geometry, grid spacing requirements, and available computing power. A sketch was prepared showing the orientation of the coordinate axes, the sequential numbering of all nodes and elements, and numerical discretization. After the grid design was completed, an input file for VAM3DCG was assembled that described the numerical and time discretizations, hydraulic and transport properties, boundary conditions, source and sink terms, and initial conditions. The software was run for a small number of timesteps to check the correctness of the input file. Once the input file was determined to be correct, the model was then calibrated to existing water table conditions.

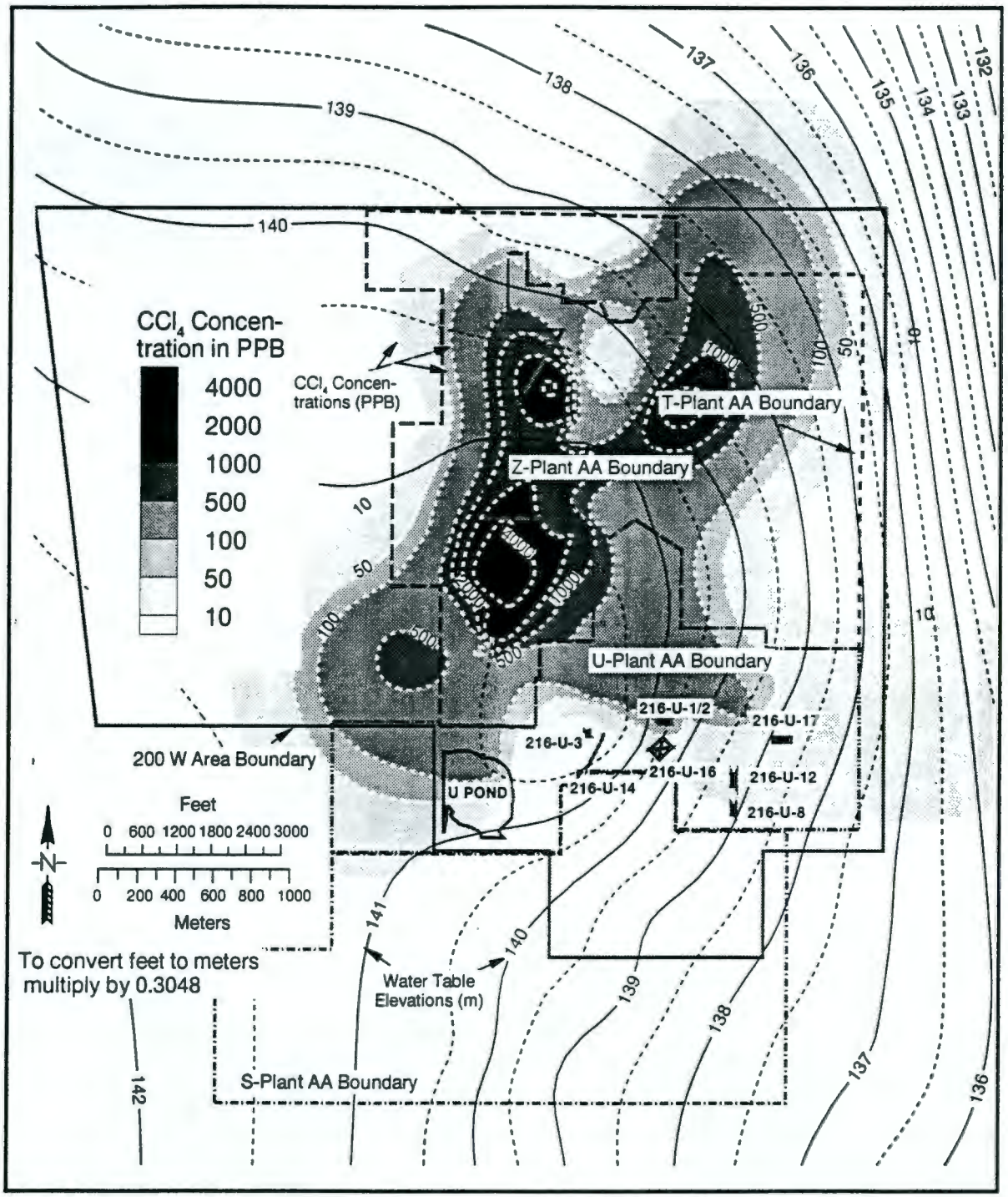

Figure 1-1. Plan View of the Carbon Tetrachloride (CCl_4) Plume in the 200 West Area.

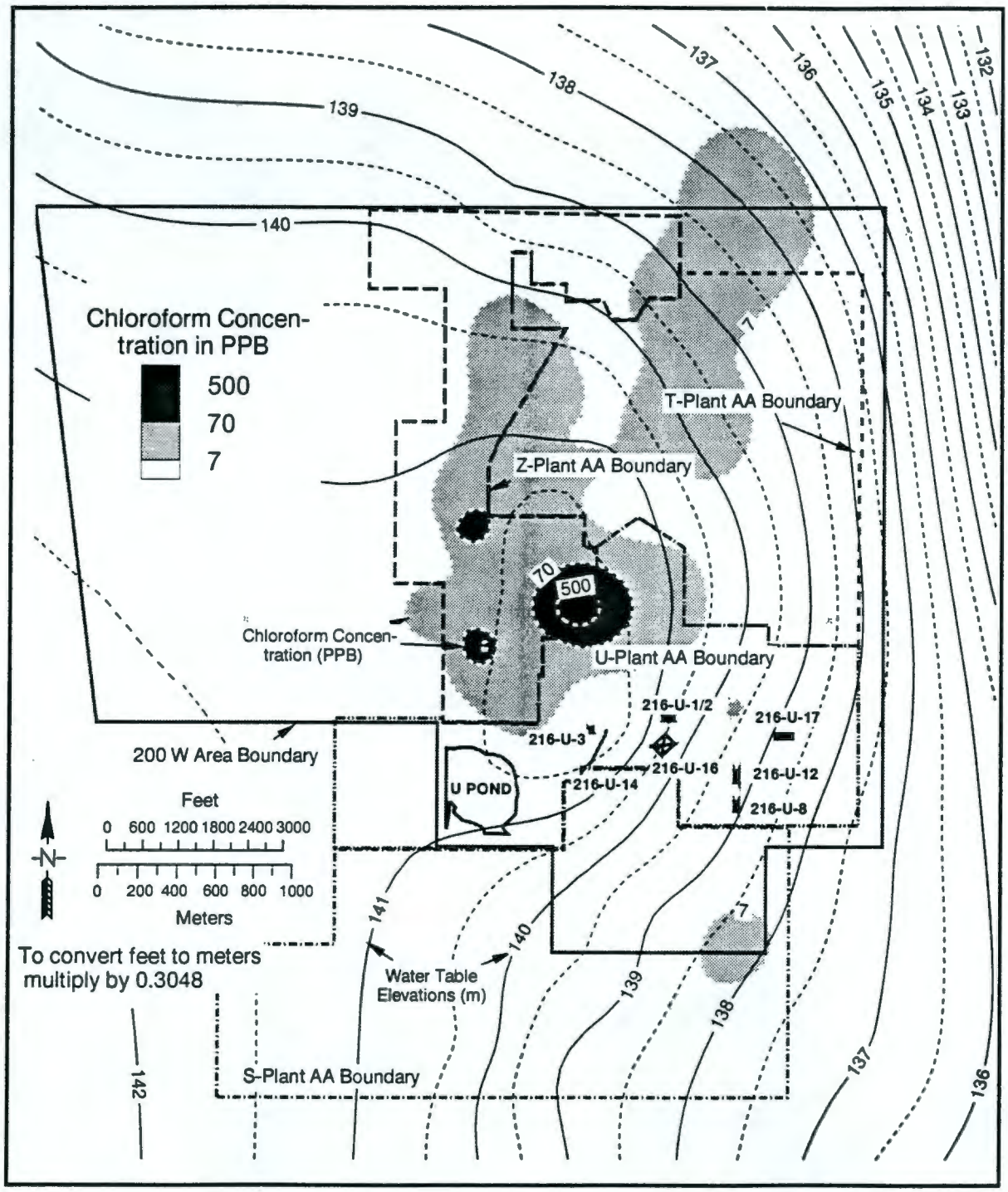

Figure 1-2. Plan View of the Chloroform Plume in the 200 West Area.

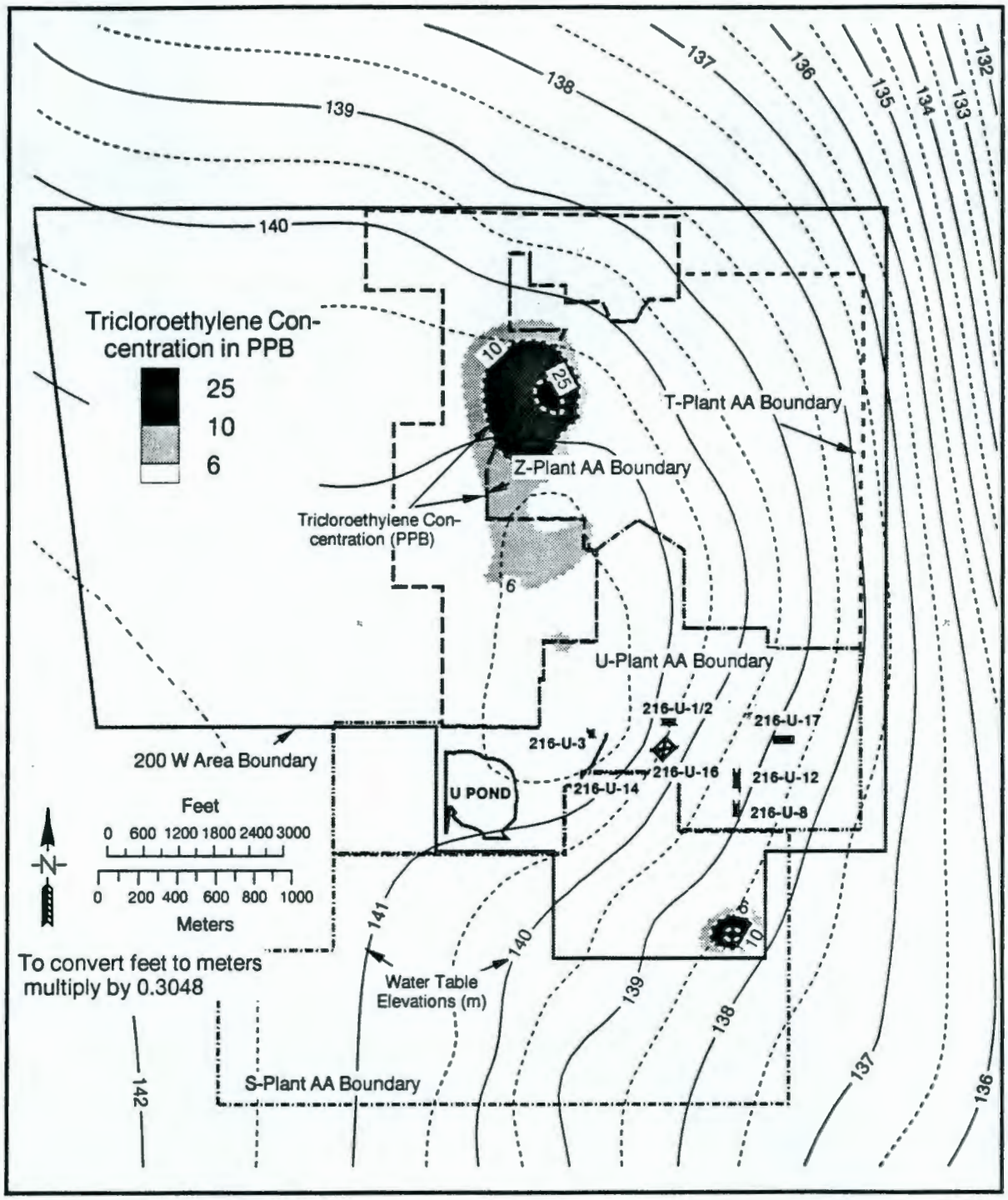

Figure 1-3. Plan View of the Trichloroethylene (TCE) Plume in the 200 West Area.

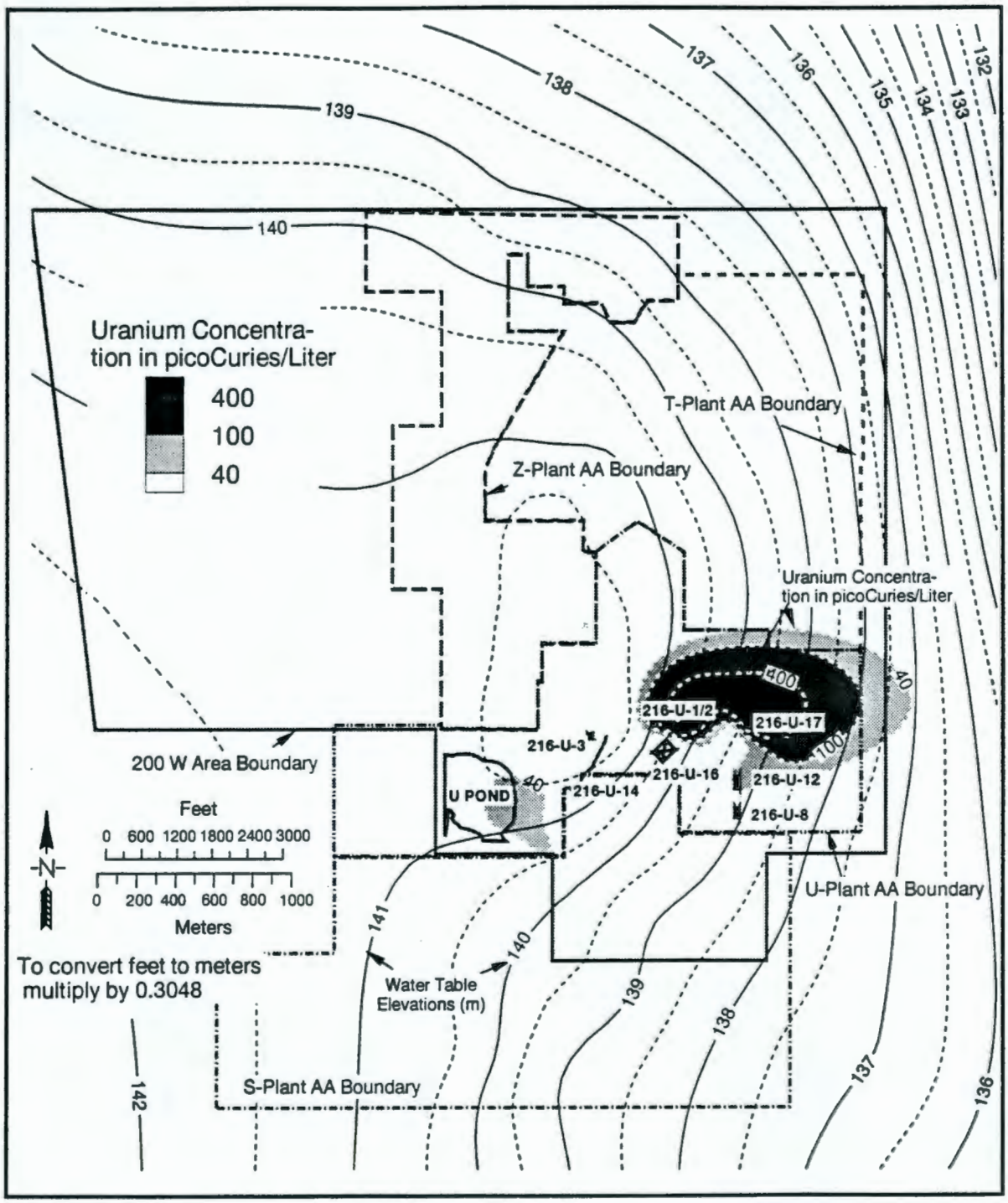

Figure 1-4. Plan View of the Uranium Plume in the 200 West Area.

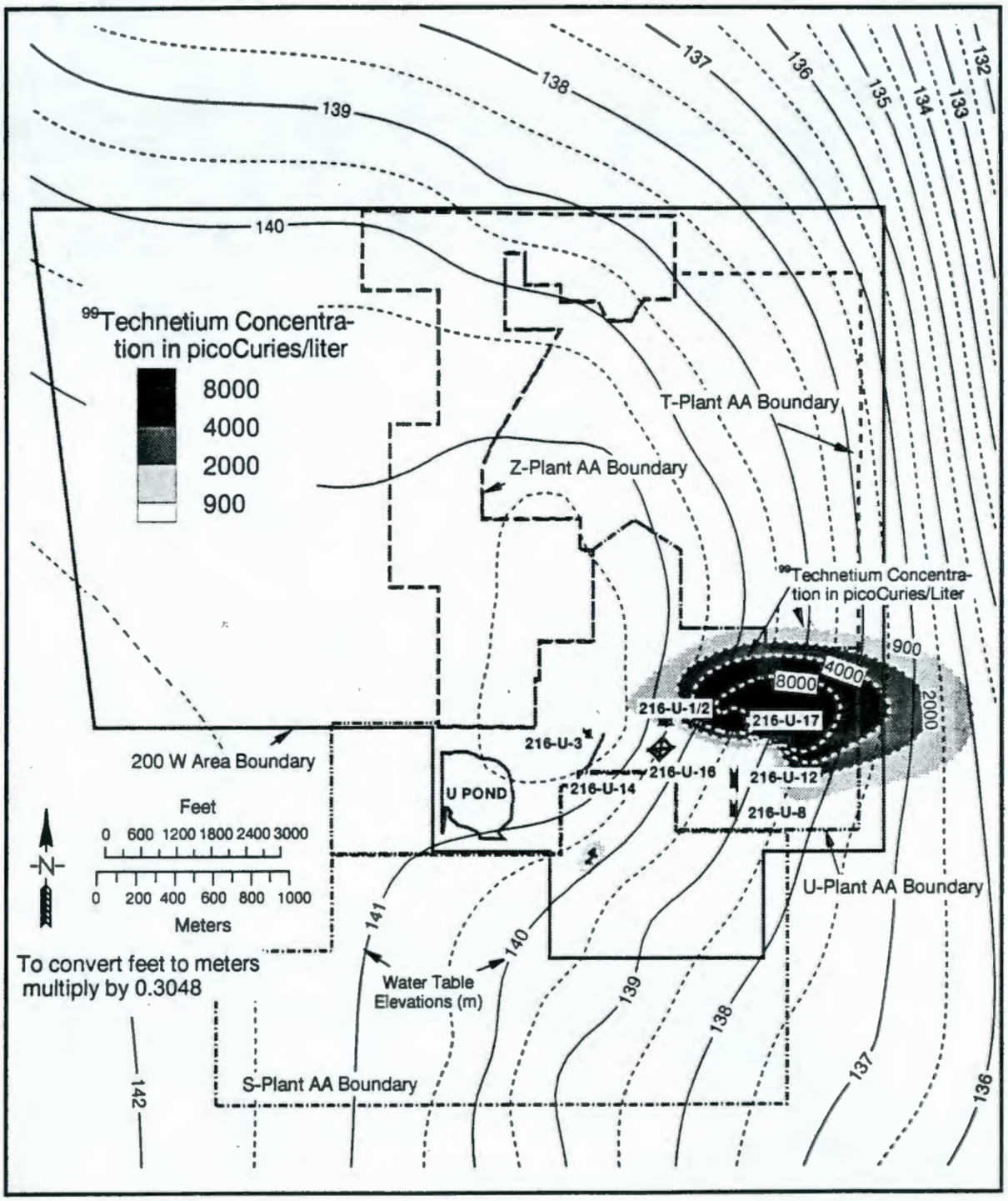

Figure 1-5. Plan View of the ^{99}Technetium (Tc) Plume in the 200 West Area.

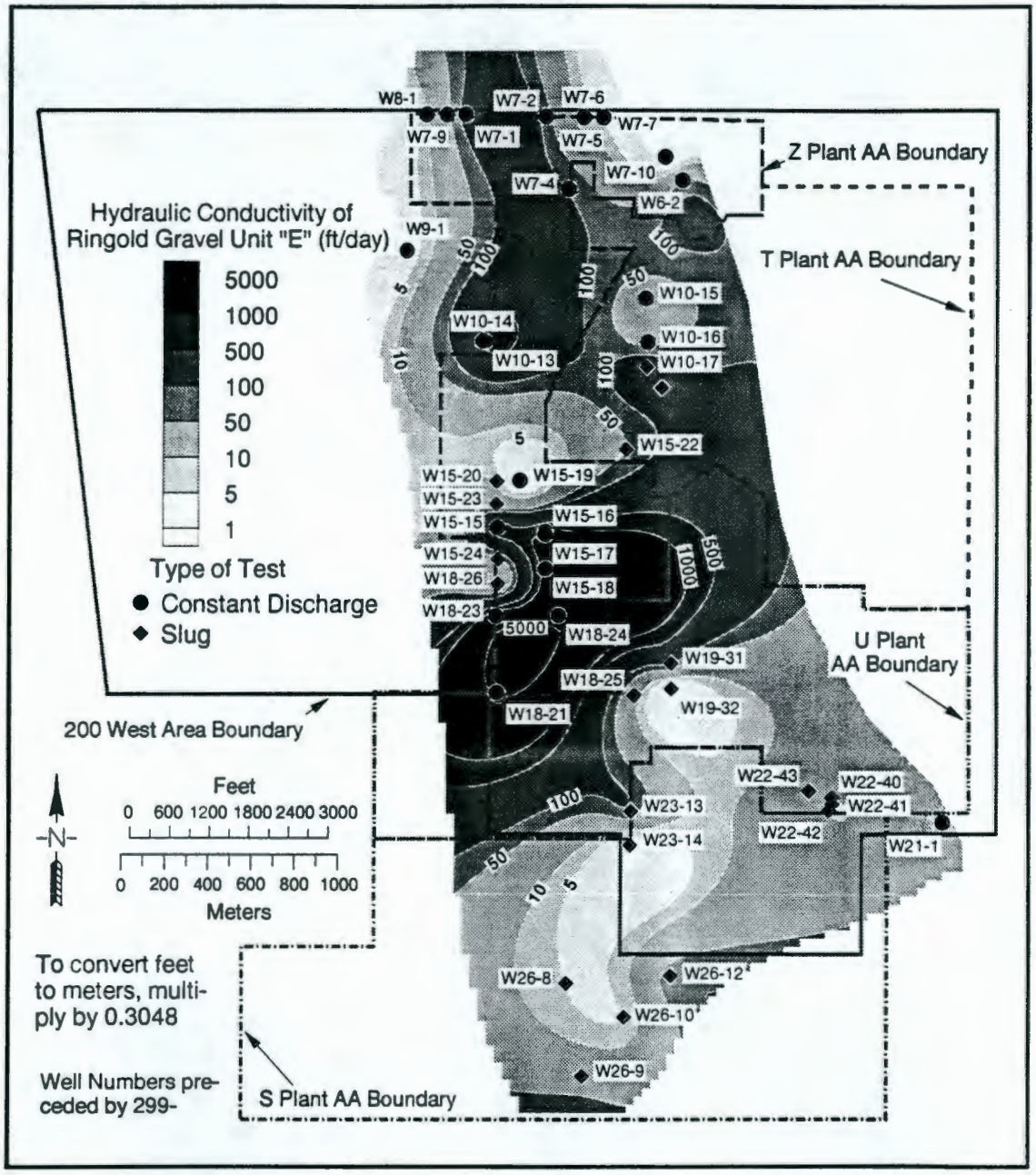

Figure 1-6. Plan View of the Hydraulic Conductivity Field for the Ringold Gravel Unit E at the Water Table in the 200 West Area.

2.0 CONCEPTUAL MODEL

The regionally unconfined aquifer in the 200 West Area is wholly contained within the Ringold gravel unit "E" (Lindsey et al. 1991). It is bounded on the north by Gable Butte and Umtanuum Ridge and to the south by Yakima Ridge. The aquifer thickens south of the 200 West Area along the axis of the Cold Creek Syncline. Natural recharge from surface runoff down Cold Creek occurs along the western boundary. Little recharge to the water table occurs directly from precipitation (Gephart et al. 1979). Artificial recharge to the regionally unconfined aquifer from effluent disposal operations within the 200 West Area has occurred since 1944.

2.1 GEOLOGY

Several reports describing the geology of the area have been based on studies completed by Hanford Site scientists; some of the more pertinent reports are Myers et al. (1979); Tallman et al. (1979, 1981); Myers and Price (1981), Reidel and Fecht (1981); Bjornstad (1984); DOE-RL (1988); Lindsey et al. (1991); Lindsey et al. (1992); Connelly et al. (1992a); and Connelly et al. (1992b). These references thoroughly discuss the geology underlying the 200 West Area.

2.2 HYDROLOGY

An initial step in formulating the conceptual model was to determine the thickness of the regionally unconfined aquifer. This was accomplished by using the elevations of the top of the Elephant Mountain Basalt and Ringold lower mud unit measured in boreholes to create a digitized map of the surface of each unit. The two surfaces were combined by taking the maximum elevation of each surface as the bottom of the aquifer. The results of these calculations are depicted in Figure 2-1. The upper figure is a contour map of the bottom of the aquifer; the lower figure is a perspective view of this surface as viewed looking west. The boundary of the 200 West Area is superimposed on both views shown in Figure 2-1.

The elevation of the top of regionally unconfined aquifer was determined by contouring the water table elevations for June 1993, as measured in wells in the 200 West Area. Figure 2-2 presents the results of this step, showing elevation contours of the regionally unconfined aquifer (upper) and a perspective view of the water table surface looking northwest (lower). The regionally unconfined aquifer is from 0 to 120 m thick (Figure 2-3). It thins to the northeast and thickens toward the axis of the Cold Creek Syncline, to the south of the 200 West Area. Four perspective views of the regionally unconfined aquifer are shown in Figure 2-4. The average thickness of the regionally unconfined aquifer where it is contaminated by ^{99}Tc concentrations greater than 900 pCi/L is 50 m.

The water table has risen significantly due to effluent disposal activities ongoing since 1944. This artificial recharge has caused the water table to rise more than 25 m from 1944 to 1978. Since 1976, the amount of artificial recharge in the 200 West Area has declined causing a corresponding drop

in water table elevations. There are two primary sources for artificial recharge in the 200 West Area. One source is from the nuclear process facilities (i.e., U Pond, U-14 ditch, Z-20 ditch, etc.); the other is from the utility facilities (i.e., powerhouse pond, the sanitary drain field, and laundry).

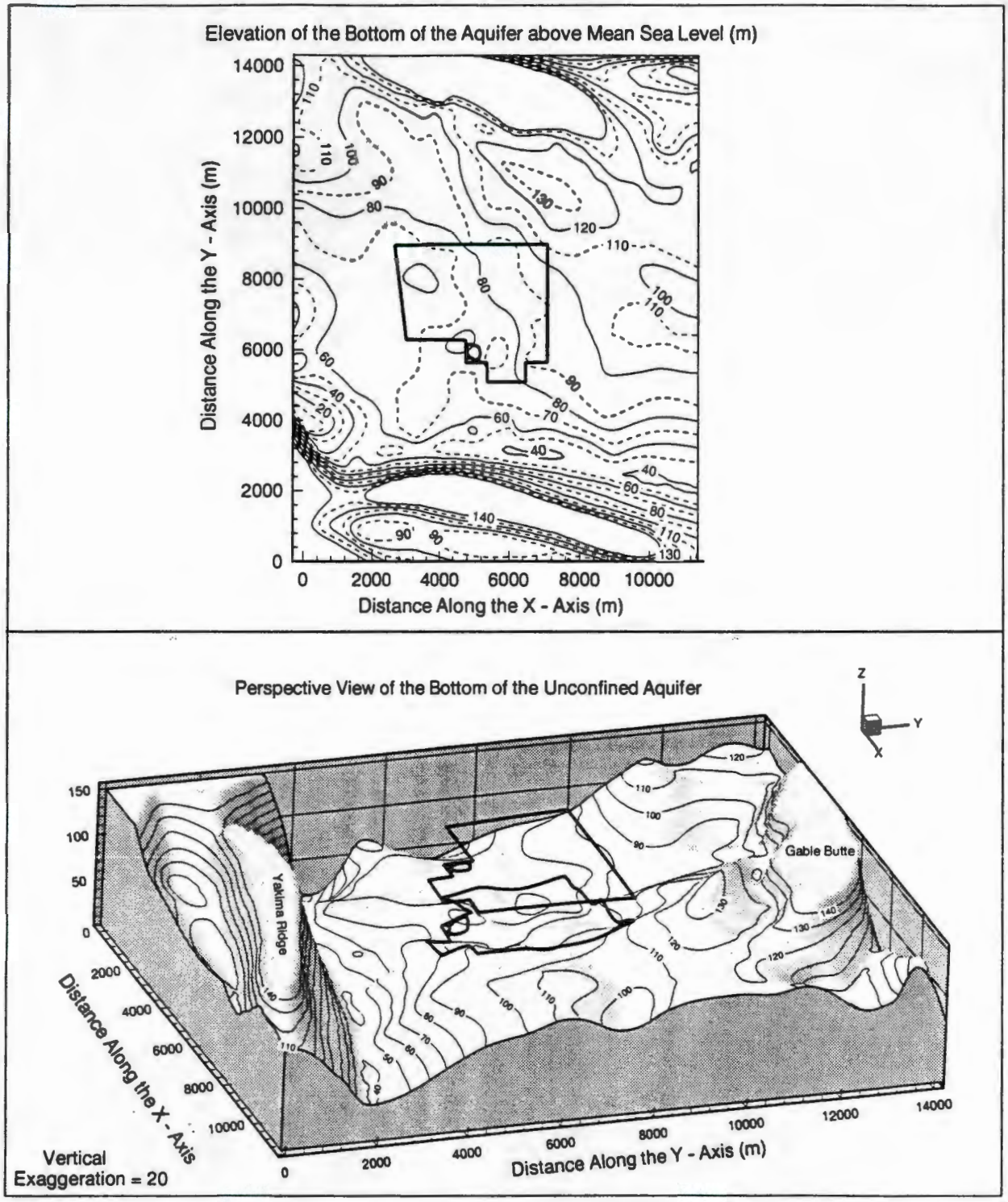

Figure 2-1. Contour Map of the Bottom of the Regionally Unconfined Aquifer (Upper) and a Perspective View of that Surface (Lower).

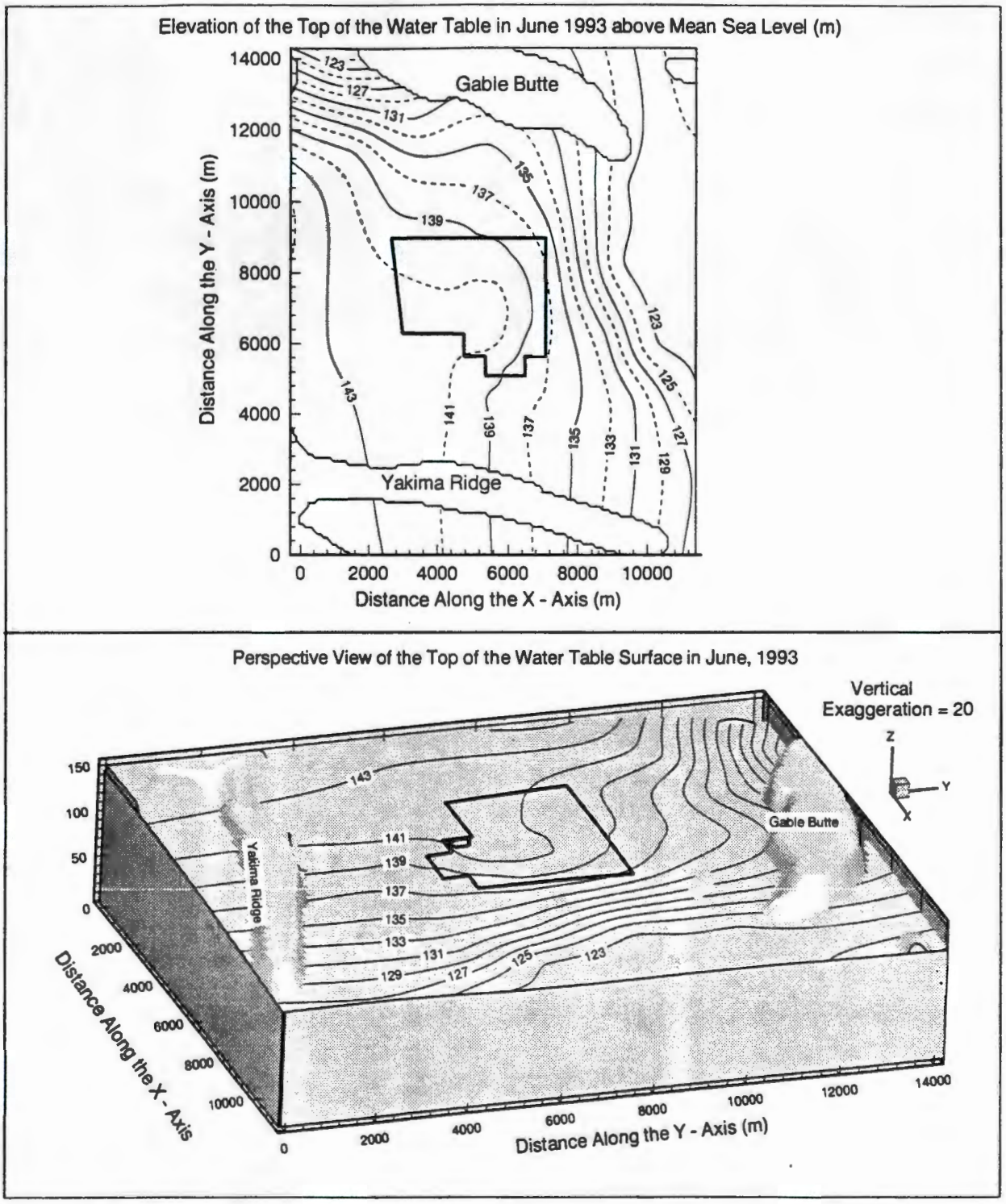

Figure 2-2. Contour Map of the Top of the Regionally Unconfined Aquifer in June 1993 (Upper) and a Perspective View of that Surface (Lower).

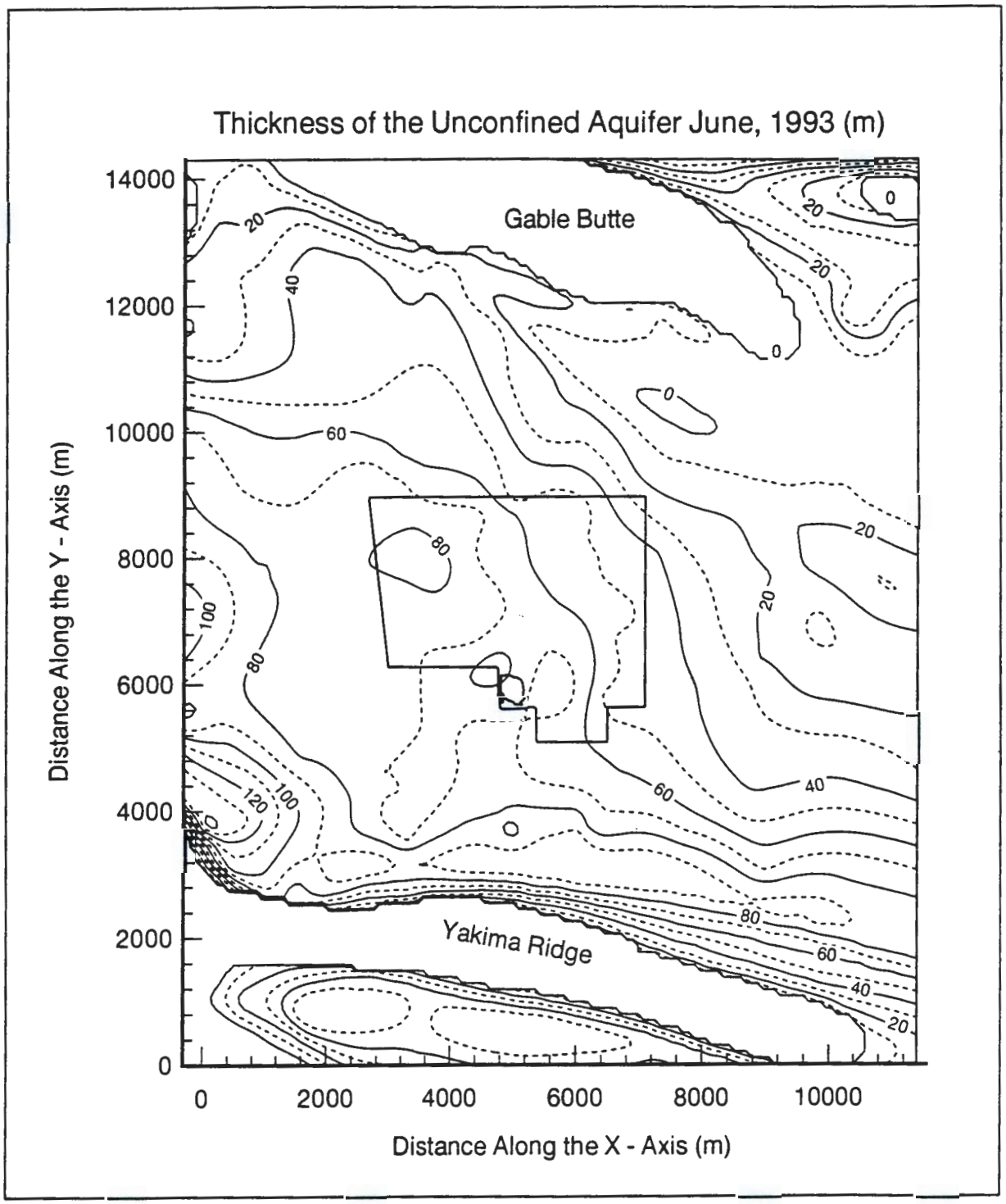

Figure 2-3. Isopach Map of the Regionally Unconfined Aquifer.

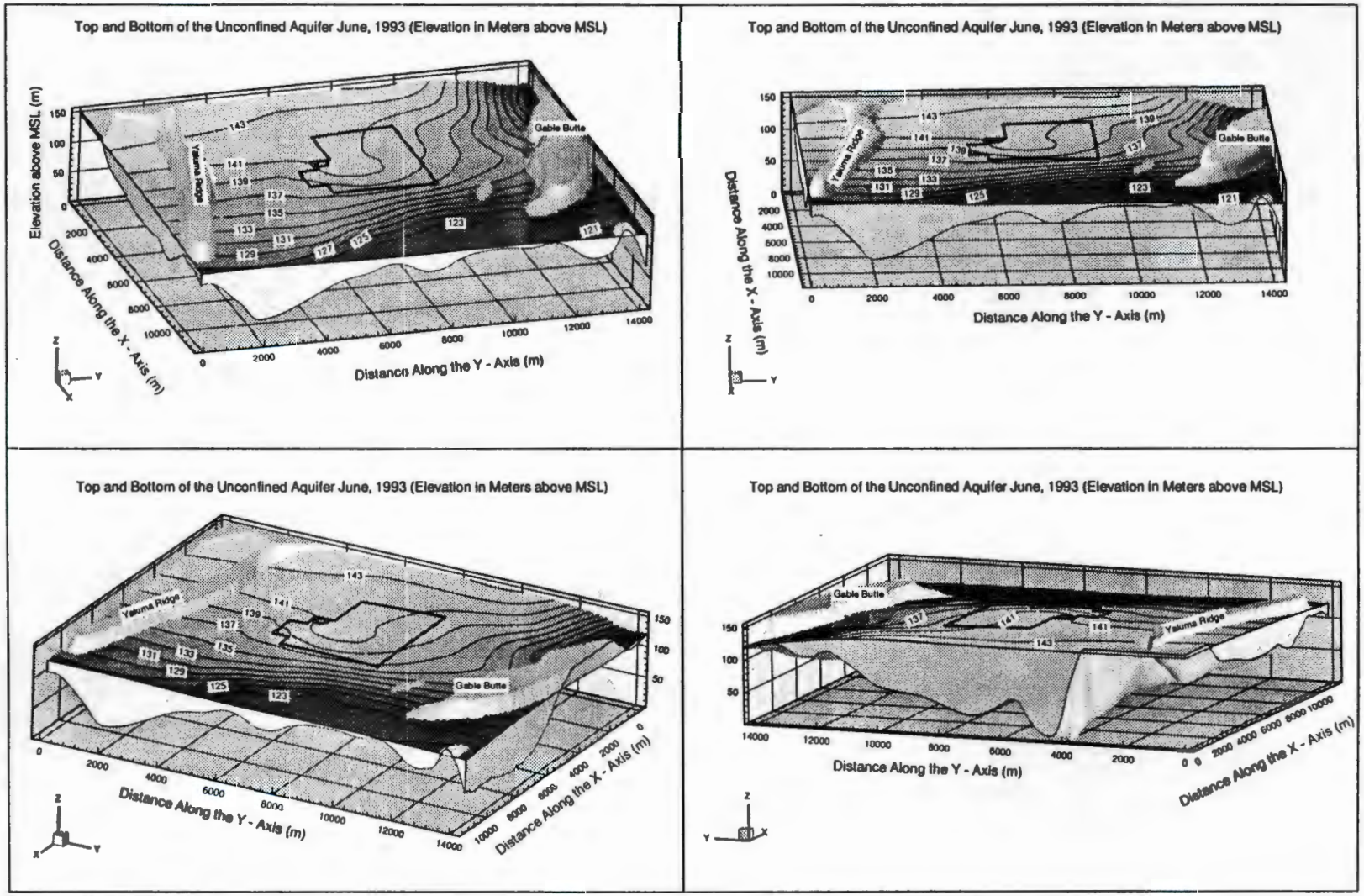

Figure 2-4. Four Perspective Views Showing the Shape of the Regionally Unconfined Aquifer. The X-direction axis is East - West; the Y-direction Axis is North - South.

3.0 NUMERICAL MODEL

This section describes the geometry, numerical discretization, material properties, initial conditions, boundary conditions and source terms used in the numerical model.

3.1 GEOMETRY AND NUMERICAL DISCRETIZATION

The model dimensions and geometry were chosen to incorporate the major hydrologic boundaries surrounding the 200 West Area. The grid was discretized to provide finer resolution near 200-ZP-1 and 200-UP-1 PSPTTs. The dimensions of the numerical grid were 10,700 m in the E-W direction and 13,700 m in the N-S direction. A quadrilateral, rather than rectangular, grid shape was used because the boundaries of the area of interest parallel the axis of Yakima Ridge to the south and Gable Butte to the north.

In plan view, the grid was first discretized into 361 nodes and 324 elements. For this coarse discretization, the element size was approximately 600 m by 600 m. This grid was locally refined by successively dividing the elements in half in the x- and y-directions until element size near the PSPTT was approximately 9.5 m by 9.5 m (Figure 3-1). The smaller elements provided detail around PSPTT wells. The two-dimensional grid, in plan view, had 2,769 nodes and 2,556 elements.

After creating the planar, two-dimensional finite element mesh, the location of the nodes in the z-direction was calculated by interpolating the bottom and the top of unconfined aquifer to the plan view nodal locations and then dividing the distance between the top and the bottom of the aquifer into six elements (Figure 3-2). The final finite element mesh used for the capture zone analyses of the PSPTT wells had a total of 19,383 nodes and 15,536 elements. Although the numerical grid for the 200 West Area appears complicated, the nested grid capabilities of VAM3DCG allow a coarse grid to be readily modified for a specific problem, while retaining the same boundary conditions for each modification.

3.2 HYDROLOGIC PROPERTIES

In the deterministic model used for this analysis, each finite element cell was assigned a discrete material property value. This value cannot represent the wide variability observed in these sediments, and was only an approximation based on field characterization (i.e., aquifer testing). The range in observed hydraulic conductivity the unconfined aquifer in the 200 West Area is 0.3 m/d (1 ft/d) to 1,554 m/d (5,100 ft/d). Using the results from constant discharge, well development and slug tests, Connelly et al. (1992b) produced a hydraulic conductivity map showing the range of hydraulic conductivities in plan view (Figure 1-6). Additional conductivity data were collected in 1993 and an updated hydraulic conductivity map was generated for these analyses Figure 3-3).

Once this updated map was generated, the hydraulic conductivities were back-interpolated to the finite element node locations. To assign a hydraulic conductivity to an element, the geometric mean was calculated using the hydraulic conductivity at the four nodes of the element. The geometric mean was assigned an integer value based on the following ranges:

Material Property Designation	Conductivity Range	Hydraulic Conductivity Value Assigned for the PSPTT Simulation
-2	15.24 m/d (50 ft/d)	15.24 m/d
-1	30.48 m/d (100 ft/d)	30.48 m/d
0	0	dead element
1	.3048 - 1.524 m/d (1-5 ft/d)	0.762 m/d
2	1.525 - 3.048 m/d (5-10 ft/d)	2.290 m/d
3	3.049 - 15.24 m/d (10-50 ft/d)	9.144 m/d
4	15.25 - 30.48 m/d (50-100 ft/d)	22.90 m/d
5	30.49 - 152.4 m/d (100 -500 ft/d)	76.20 m/d
6	152.5 - 304.8 m/d (500 - 1000 ft/d)	229.0 m/d
7	304.9 - 1524. m/d (1000 - 5000 ft/d)	762.0 m/d
8	> 5000 m/d	2290.0 m/d

If the geometric mean for the element corners was within a specified range, that element was assigned the corresponding material property designation number and hydraulic conductivity. The -2 property designation is for Ringold Gravel Unit E in areas for which there were no aquifer test data. In such areas, Ringold Gravel Unit E was assigned a hydraulic conductivity of 15.24 m/d, which is the geometric mean over the area in which there are measurements (Figure 3-3). The -1 property designation is for areas in the model that contain undifferented Hanford gravels and Ringold Formation. Because the undifferentiated Hanford gravels and Ringold Formation have a higher hydraulic conductivity than the Ringold Formation (Gephart et al. 1979), these areas were assigned a hydraulic conductivity that is twice that of the geometric mean of the Ringold gravel unit E. Each element was considered to be isotropic in the x-y plane and to have a 10:1 anisotropic ratio in the z-direction.

In the northeast corner of the model domain, the aquifer becomes progressively thinner until the aspect ratio became too large for the VAM3DCG to accommodate. Therefore, the bottom four layers of elements were assigned a null-value designation (Figure 3-4a), while the overlying elements remain active (Figure 3-4b).

3.3 INITIAL AND BOUNDARY CONDITIONS

The elevation of the water table in June 1993 was used as the initial condition. This was done by back interpolating to the finite element node locations from the contour map of water table elevations (Figure 2-2). The bottom of the model and the north and south boundaries aligned along Yakima Ridge and Gable Butte were assigned a no-flux boundary condition. The boundaries to the east, to the west, and in the gap between Umtanuum Ridge and Gable Butte were set to a constant head. Those head values were assigned by

interpolating water level measurements at that location from the June 1993 water table map.

The top boundary of the model domain was assigned a no-flux boundary condition, except areas receiving artificial recharge. The natural recharge from precipitation is thought to be small (Gephart et al. 1979) and was ignored. The artificial recharge at the top of the model domain was treated as a constant flux per unit area of recharge. No attempt was made to examine the effects of individual cribs, trenches, or ponds. All discharges to the cribs, trenches, and ponds were grouped together with this total yearly flux being applied at the water table high in the center of 200 West Area. This flux was set to 6.6E+06 m^3/yr (3,290 gpm) until steady-state conditions were achieved. This steady-state condition represented the unconfined aquifer in 1976.

Once the simulation achieved steady-state conditions (in 1976), the total flux was gradually reduced to 1.0E+06 m^3/yr (500 gpm) due to the declining discharge of effluent to the nuclear process facilities, and 2.0E+05 m^3/yr (100 gpm) to the powerhouse pond. The powerhouse pond came on line in mid 1984. The exact amount of water discharged to the powerhouse pond is unknown, but generally is believed to be between 1.0E+05 and 6.0E+05 m^3/yr (50-300 gpm). These reduced values were used for the beginning of the capture zone simulations for the PSPTTs.

The amount of artificial recharge was based on water-use mass balance in the 200 West Area (e.g., Law et al. 1986; Law and Shatz, 1987; and Johnson 1993). Numbers used for the artificial recharge were arrived at by summing the annual volumes of effluent discharged to the nuclear process waste disposal facilities and estimating the recharge to the utility facilities for the years in which data were available.

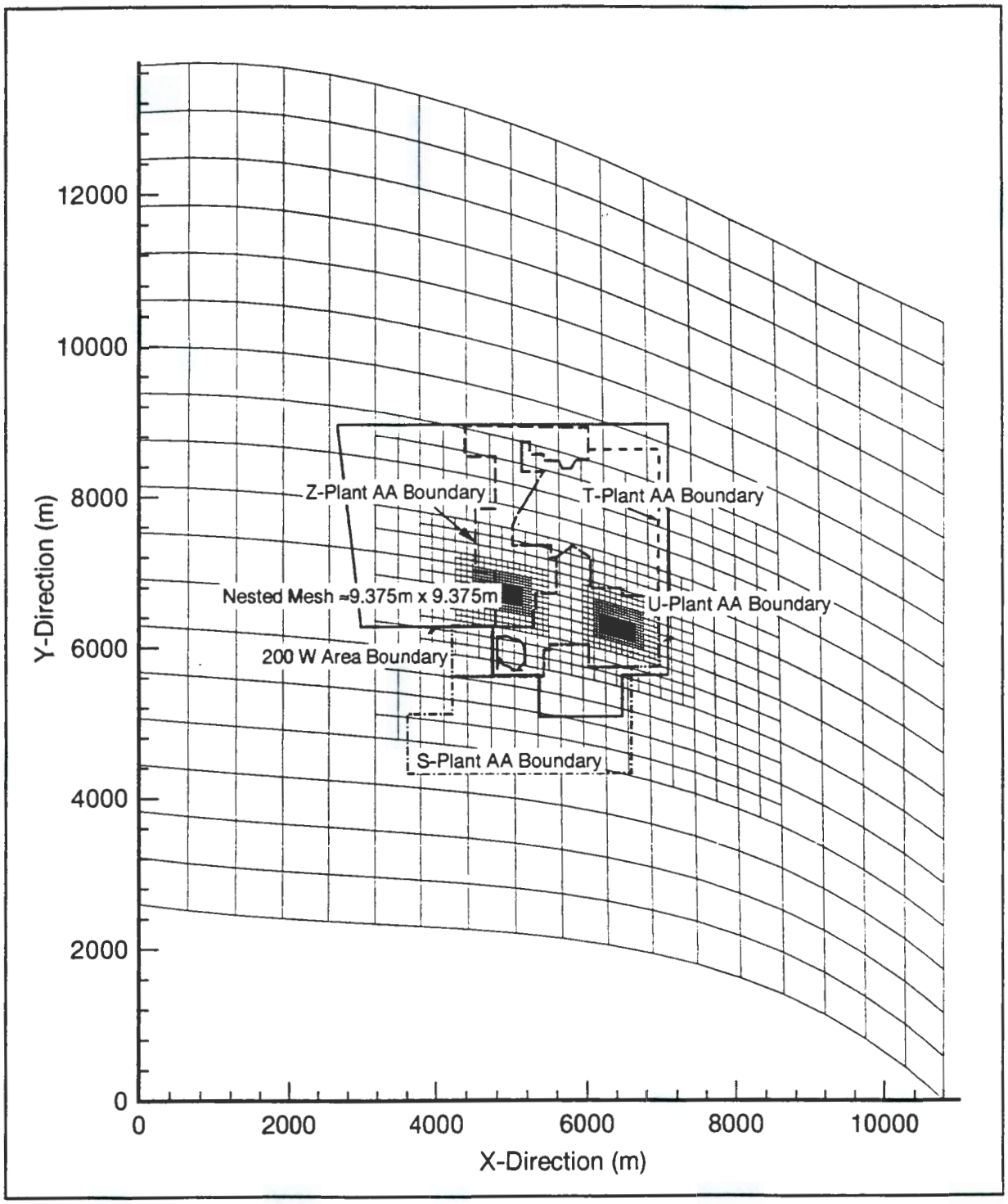

Figure 3-1. Nested Grid with ~9.5 x 9.5 m Elements in the Vicinity of the Proposed 200-ZP-1 and 200-UP-1 Pilot-Scale Pump-and-Treat Test Analyses.

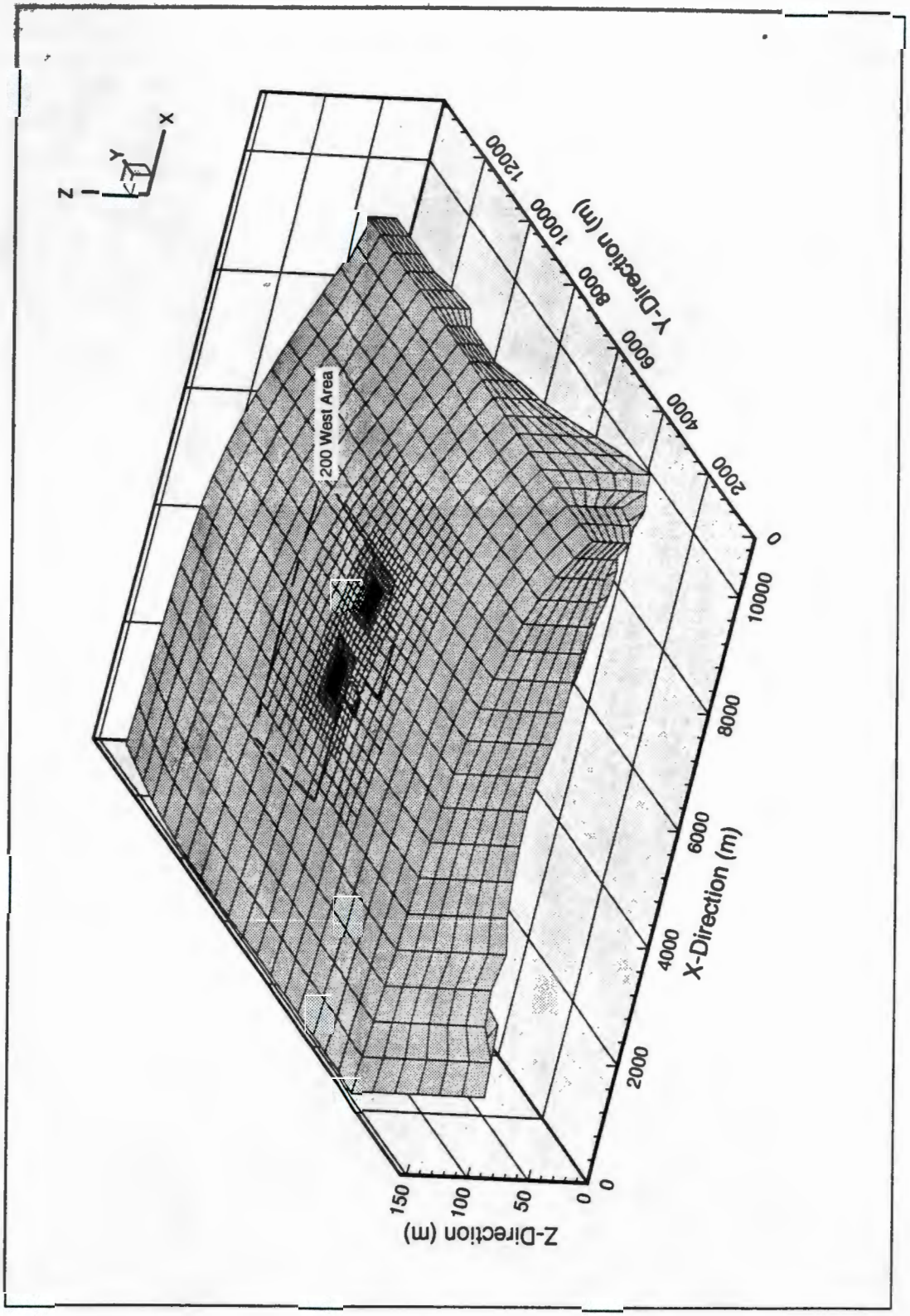

Figure 3-2. Final Three-Dimensional Nested Grid Mesh Used for the Simulations.

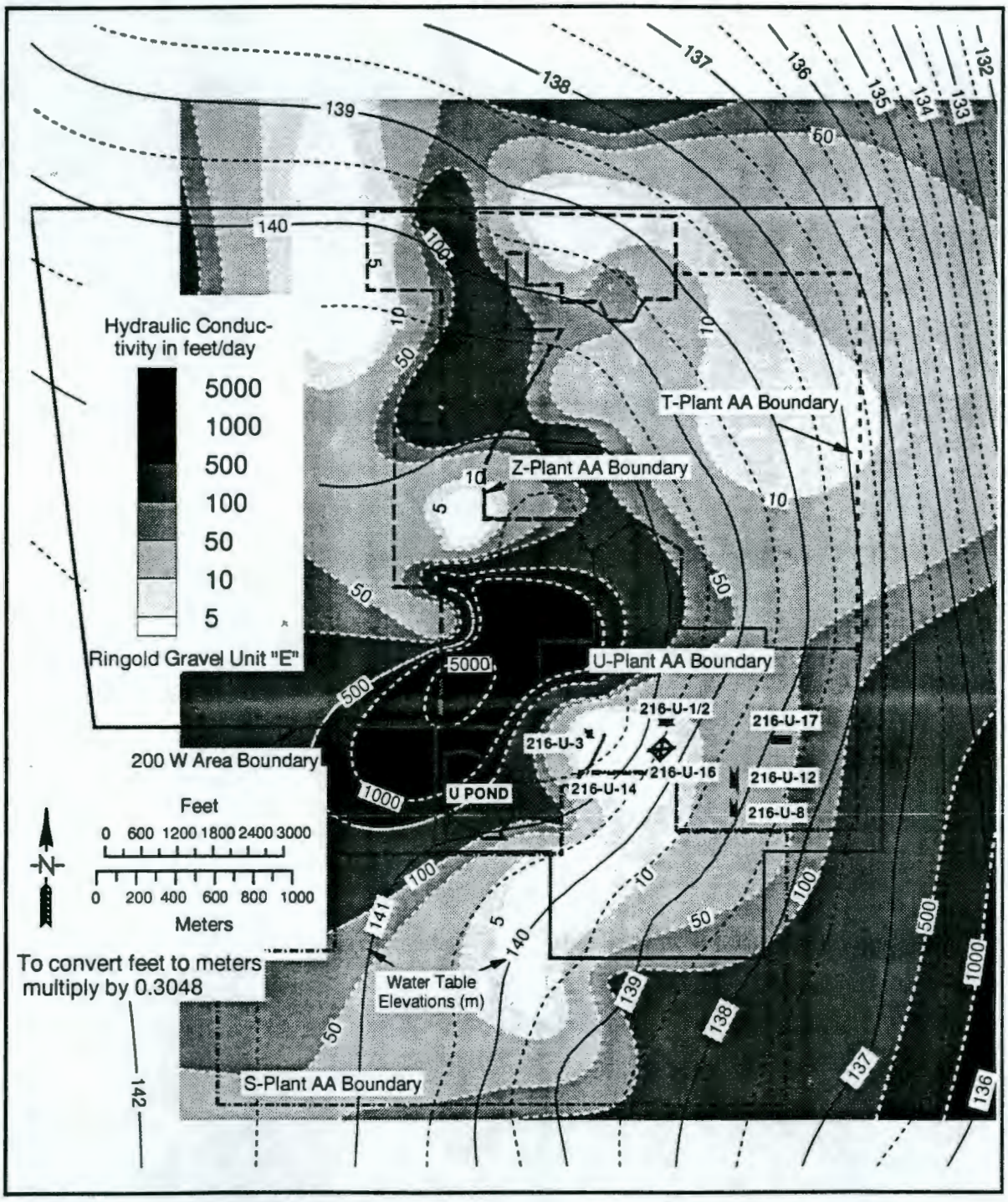

Figure 3-3. Modification of Hydraulic Conductivity Map Constructed Using Data Collected in 1993.

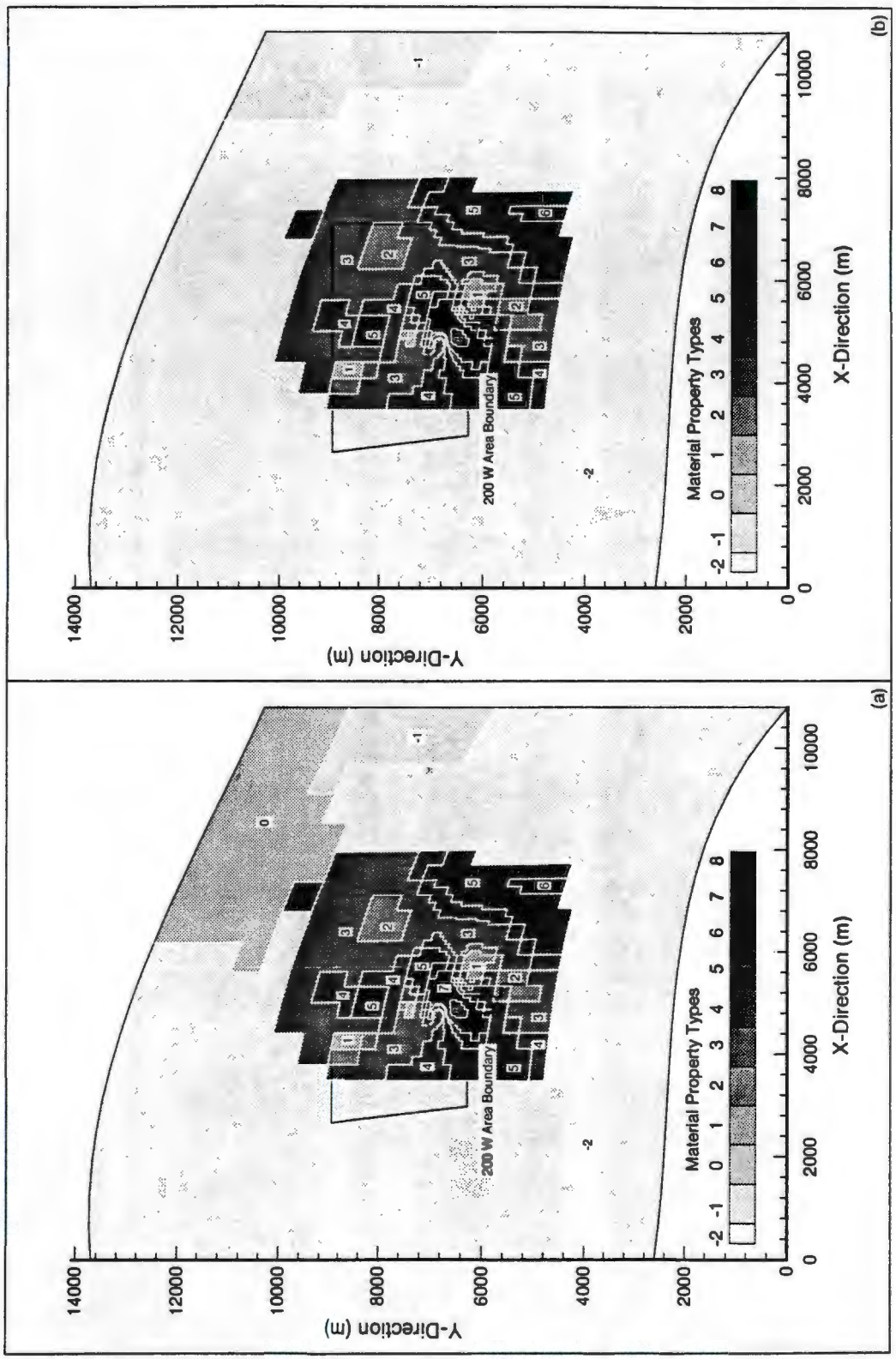

Figure 3-4. Material Property Designations for Each Element within the Model Domain. Figure a is for the lower four elements in the Z-direction; Figure b is for the upper two elements in the Z-direction).

4.0 SIMULATION RESULTS

4.1 STEADY-STATE SIMULATION

The water table in the 200 West Area was at its highest elevation in the late 1970's. To simulate the currently falling water table, a steady-state water table was simulated for 1976 by applying an artificial recharge at the top of the water table mound and running the model until the change in storage was negligible. Figure 4-1 shows the results from the start of the simulation until a steady-state solution was reached. During this part of the simulation, a flux of 6.6E+06 m^3/yr (3,290 gpm) was applied to the area at the top of the mound (i.e., to those nodes that have a water table elevation greater than 141.5 m, Figure 4-1a).

The simulated water table rose a maximum of 2.3 m by the end of 10 yr (Figure 4-1b), 2.7 m by the end of 22 yr (Figure 4-1c), and 3.0 m (Figure 4-1d) by the time steady-state conditions occurred after approximately 40 yr. These results were used as the initial conditions for subsequent simulations of the falling water table through the 1980's and early 1990's.

4.2 SIMULATIONS OF CONDITIONS FROM 1977 TO 1993

Figure 4-2 shows the water table elevations simulated for 1977 to 1992. The artificial recharge rates used for the simulations were 5.95+06 m^3/yr from 1977 to 1979, 4.5+06 m^3/yr from 1979 to 1982, 3.5E+06 m^3/yr from 1983 to 1985, 2.0E+06 m^3/yr from 1986 to December 1993. From 1972 to December 1993, the simulated elevation of the water table at the highest point of the mound dropped from 144.31 to 140.62 m. This change is seen in Figures 4-2a to 4-2d as the gradual contraction and disappearance of the 141-m through 144-m contour lines in the center of 200 West Area. The 144-m contour line disappears by 1980, the 143 m by 1984, the 142 m by 1986, and the 141 by 1992. It is evident from these figures that as artificial recharge was reduced the elevation of the water table dropped.

Figure 4-3 compares the observed water table elevations for June 1993 to those predicted by the model. It is apparent from this figure that the model predicted water table elevations too high to the north and northeast, and too low at the center of the artificial recharge mound and in the southeast corner of the 200 West Area. However, the predicted hydraulic head gradient and groundwater flow direction are similar to measured conditions. The differences between predicted and measured water table elevations can be ascribed to several factors that include, but not limited to, the following:

- The water table elevations based on borehole-measured data was calculated by a program that interpolates between well locations. In areas with a large data population, the interpolation is accurate. However, where data were sparse, the interpolation between data points became less accurate.

- The estimates of annual artificial recharge for each year were approximate and averaged over an area, rather than for a specific disposal facility.

- Artificial recharge was based on multi-year estimates (i.e., the same flux rate assumed for several years).

- Use of an average hydraulic conductivity for areas outside the 200 West Area.

4.3 CAPTURE ZONE ANALYSES

A t-day capture zone in a three-dimensional flow regime is the bounded volume described by the set of all flow paths that intersect a hydraulic sink within a specified number (t) days. Injection zones are described as all flow paths emanating from a source with in a specified number (t) days. For two-dimensional horizontal flow, the vertical flow component is ignored and the capture zone becomes the planar area described by the set of all horizontal path lines with t-day travel time to the sink.

For these capture zone analyses, the artificial recharge into the top of the model was reduced to 1.2E+06 m^3/yr (600 gpm). This reduction was based on projections of future discharges to the 216-U-14 ditch and powerhouse pond. The model was run for 150 days with the water table elevations and darcy velocities at the element centroids calculated every 3 days of simulation time. The post-processor TECPLOT (a trademark of) read these data files and calculated forward (injection well) and reverse pathlines (pumping well). The effective porosity used to calculate the pathlines was 0.1.

Once the water table elevations for 1993 were satisfactorily simulated, the calibrated model was used to predict the effect on the aquifer of the proposed 200-ZP-1 and 200-UP-1 PSPTT.

4.3.1 200-ZP-1 Pilot-Scale Pump-and-Treat Tests

The initial planning called for well 299-W18-5 to be used for pumping and 299-W18-2 to be used for injection. Water was to be pumped at a rate of 3.4E+04 m^3/yr (17 gpm), treated, and then injected into the other well. Determining when the pumping-well capture zone would overlap the injection zone of the injection well was the purpose for this simulation. The PSPTT operations are scheduled to last 90 days, but could last longer.

Four capture-zone analyses (for 30, 45, 60, and 90 day durations) were completed for two different scenarios. Well 299-W18-5 was the pumping well and 299-W18-2 was the injection well for the first scenario. These wells are aligned SSE to NNW and are approximately 76 m apart. Well 299-W18-5 is located regionally downgradient from the injection well. The second scenario placed the pumping and injection sites 76 m apart along a line running E-W, approximately -30 across the regional gradient. This second scenario illustrated the effects resulting from cross gradient sites near well 299-W18-5. Such effects may occur if well 299-W18-1 is used in place of well 299-W18-2 for the PSPTT. The well sites for the second scenario are fictitious and are close to but not related to any existing wells. On Figures 4-4 (downgradient scenario) and 4-5 (cross gradient scenario) the capture and

injection zone for each analysis has been superimposed on the water table elevations and pore velocity vectors.

The shape, location, and areal extent of the capture zone were highly dependent on the magnitude and direction of the regional gradient and the hydrologic properties. Therefore, it should be noted, these injection and withdrawal sources are located close to the highest part of the groundwater mound and are in an area with a low hydraulic gradient. The changes in water table elevation in this area are on the order of millimeters, with a regional gradient in the area of these wells of approximately 5.0E-5 m/m. The pumping and injection centers for both scenarios occur in material type 7 (Figure 3-5), which was assigned a hydraulic conductivity 762 m/day. The natural gradient, in combination with the hydraulic conductivity and effective porosity, results in a pore velocity of approximately 0.4 m/d near the wells. The areal extent of the capture zones were approximately 1,600 m^2, 2,300 m^2, 2,860 m^2, and 4,200 m^2 for the 30-, 45, 60- and 90-day time periods, respectively.

One question these analyses were directed toward was whether recirculation cells were likely to develop during the PSPTT. For the downgradient scenario, this simulation implies the well pairs will communicate hydrologically, with the capture and injection zones overlapping after 55 days (Figure 4-4c. However, at the end of 90 days the treated water still has not arrived at the pumping well (Figure 4-4d). For the cross-gradient scenario, there is no hydrologic communication between the pumping and injection sites.

4.3.2 200-UP-1 Pilot-Scale Pump-and-Treat Tests

For the 200-UP-1 PSPTT, well 299-W19-24 was called out in the initial planning to be the pumping well with well 299-W19-25 to be used for injection. Well useability tests indicated that well 299-W19-25 had a capacity of 3.2E+04 m^3/yr (16 gpm), and well 299-W19-24 had a capacity 3.4E+04 m^3/yr (17 gpm). These were the rates used for the capture zone analyses for this PSPTT. Although the PSPTT is scheduled to last only 90 days, there is a possibility that it could be continued for 150 days. Therefore, four capture zone analyses (60, 90, 120, and 150 days) were completed for this PSPTT (Figure 4-6).

The two wells are aligned east-west, approximately 105 m from each other. The pumping well is regionally upgradient from the injection well. The overall regional gradient in this area is approximately .004 m/m. The results of these capture zone analyses are shown (Figure 4-6) together with the concentrations of uranium and ^{99}Tc, and the elevation of the water table. The areal extent of the capture zones are approximately 3,200 m^2, 4,550 m^2, 5,800 m^2, and 6,900 m^2 for the 60-, 90-, 120- and 150-day time periods, respectively. As with the 200-ZP-1 PSPTT, these analyses were directed toward determining whether a recirculation cell would to develop between these wells. The simulations indicate that there will not be any hydrologic communication between these wells.

A second scenario was simulated with the pumping and injection wells reversed, because potential concerns with injecting treated water downgradient from the pumping well and a consequent potential for driving the plume to the

east (i.e., well 299-W19-24 becomes the injection well and well 299-W19-25 became the pumping well). The results of this analysis are given in Figure 4-7. The results showed that the capture and injection zones would overlap after 60 days of pumping and that treated water from the injection well would arrive at the pumping well after 130 days. Tracer tests could be used to determine exactly when this communication would begin if this well configuration is used for the PSPTT.

4.3.3 Effect of Heterogeneity on Capture Zone Analysis

The Ringold gravel unit E is a semi-indurated clast-supported gravel to cobble gravel with a sandy matrix possessing highly variable hydraulic properties. The hydraulic conductivities used in these simulations are extrapolated from areas that contain aquifer testing data to areas that do not. The resulting contour map (Figure 1-6) has both the 200-ZP-1 and 200-UP-1 PSPTTs pumping and injection centers wholly contained within the same material property and away from any material property boundaries.

The material property designation for the 200-ZP-1 wells was 7 (Figure 3-4) resulting in an assigned hydraulic conductivity of 762 m/day. The material property designation for 200-UP-1 wells was three with an assigned hydraulic conductivity of 9.144 m/day. The resulting capture zones given in Figures 4-4 through 4-7 were symmetrical with respect to the regional gradient and the assigned hydraulic conductivity. The effective porosity for all material property types was 0.1. Differences in these hydraulic properties could affect the shape of the predicted capture zones.

Therefore, to investigate the effect of heterogeneity on the capture zone, the model was modified by placing two sources (one pumping, one injection) in different material types close to a material boundary in the vicinity of 200-ZP-1 PSPTT. This simulation was run for 150 days to calculate the resulting capture and injection zones. It is apparent from an inspection of Figure 4-8 that heterogeneity causes the capture and injection zones to change shape drastically. If there is a change in material properties (i.e., hydraulic conductivity or effective porosity) close to the PSPTT wells that is not accounted for in the model, the shapes of the capture zones could appreciably different from those shown in Figures 4-4 through 4-7. Consequently, if these PSPTTs are to be expanded, additional hydrologic data should be locally collected during the operation of these tests to help optimize the placement of additional extraction, injection, and monitoring wells.

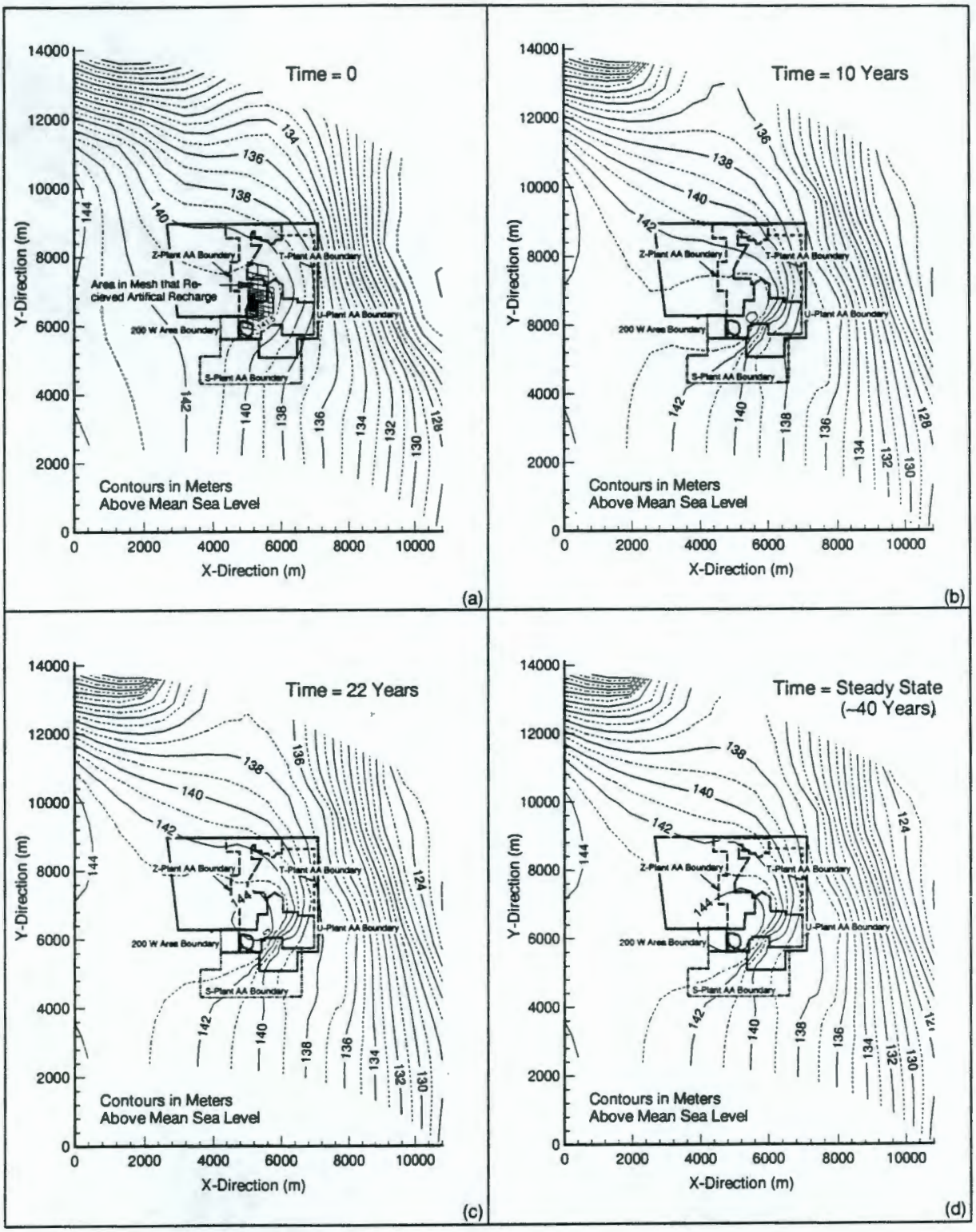

Figure 4-1. Simulation to Steady-State Conditions in 1976. The upper left figure shows the initial water table elevations for the June, 1993. Upper right Figure (b) shows the results after 10 years; lower left (c) after 22 years; and lower right (d) is the steady-state flow field at approximately 40 years.

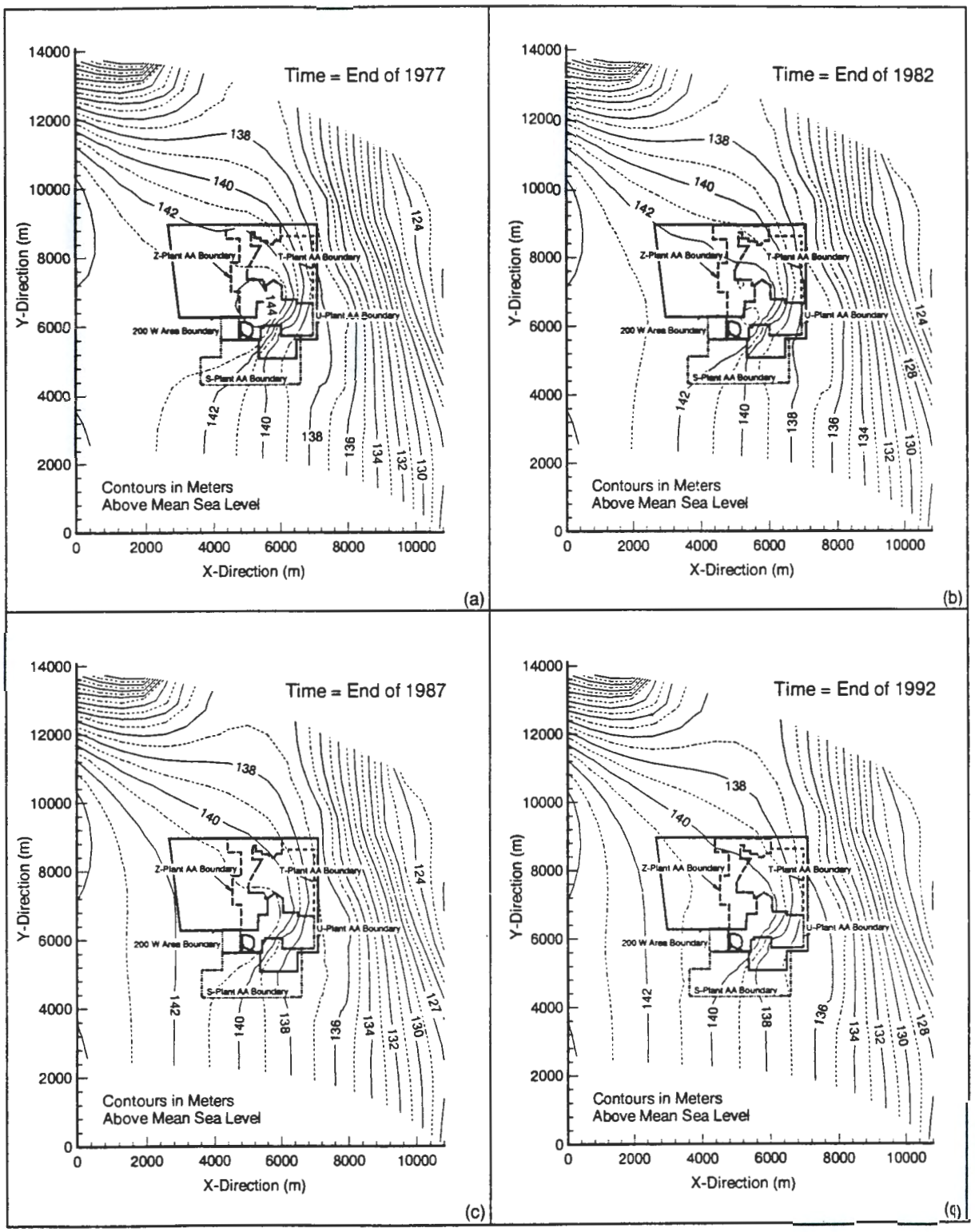

Figure 4-2. Model-Predicted Water Table Elevations for 1977 (a), 1982 (b), 1987 (c) and 1992 (d). These figures show the gradual fall in water table elevations as artificial recharge to both nuclear process and utility effluent disposal facilities decrease.

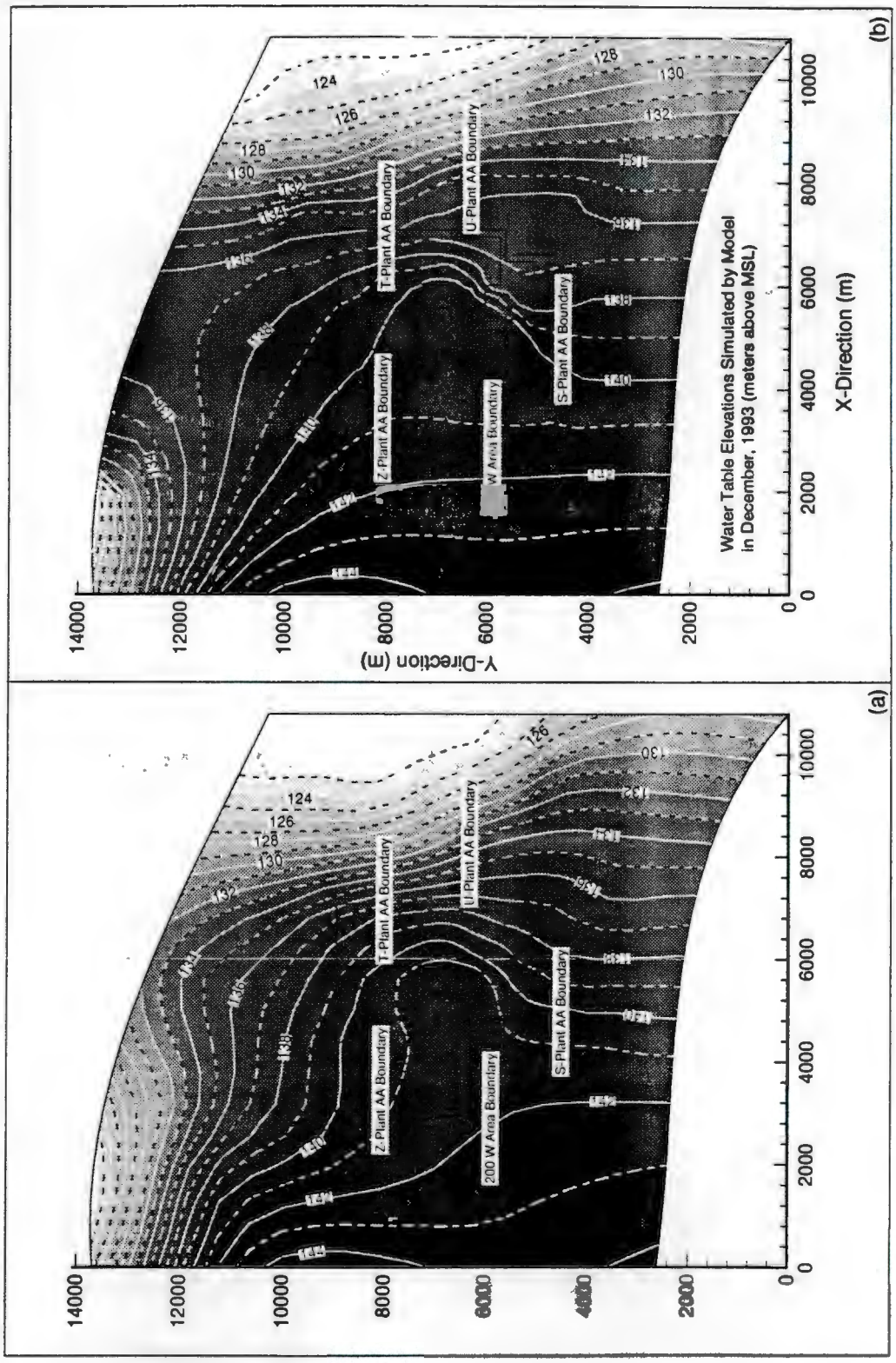

Figure 4-3. Comparison of the Observed Elevation of the Water Table (a) in 1993 with the Elevation Predicted by the Numerical Model (b).

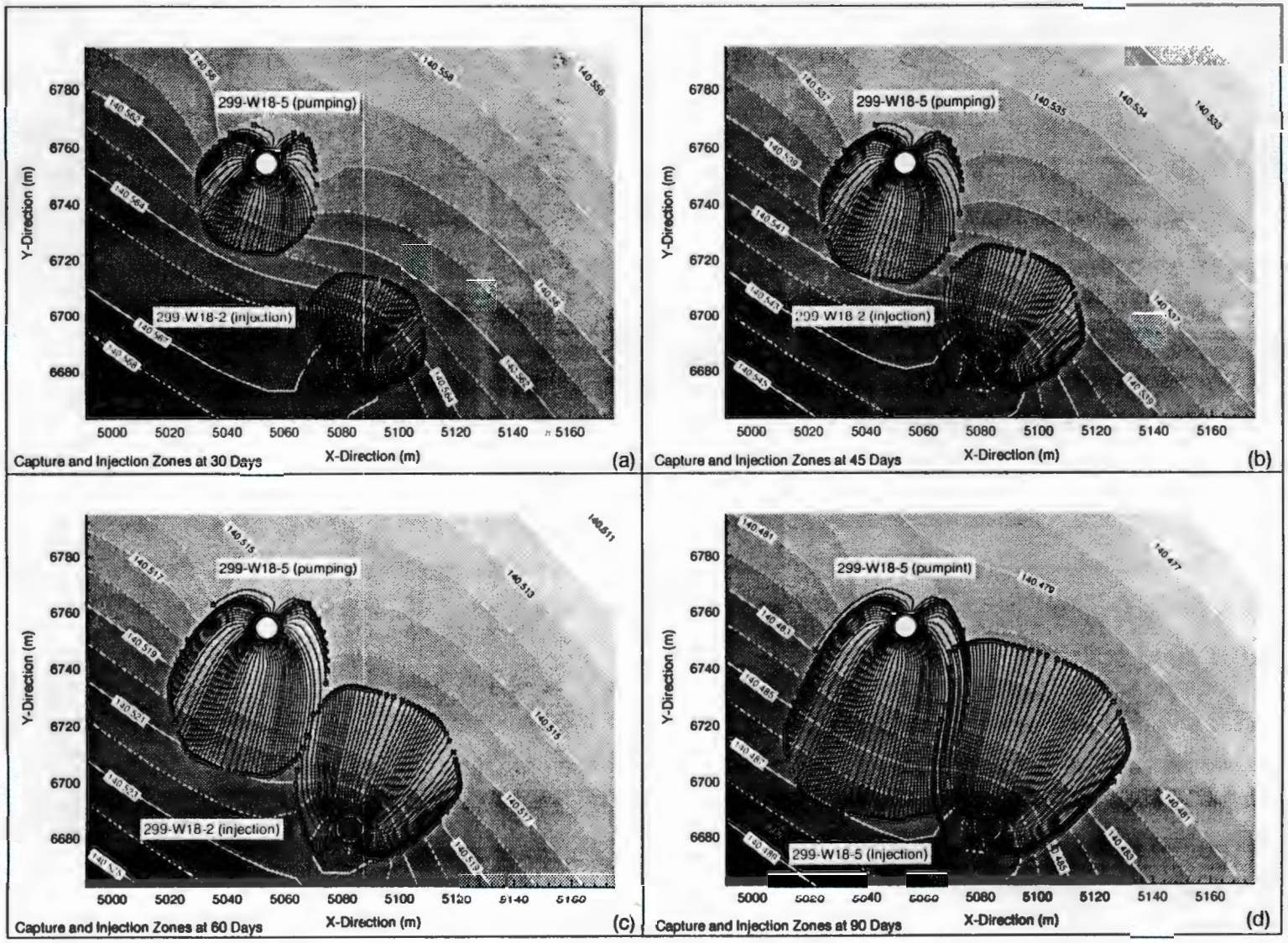

Figure 4-4. Capture and Injection Zone Analyses for 200-ZP-1 PSPTT Wells 299-W18-5 and 299-W18-2 after 30 (a), 45 (b), 60 (c), and 90 (d) Days. The water table elevations (meters above MSL) have also been superimposed on these maps.

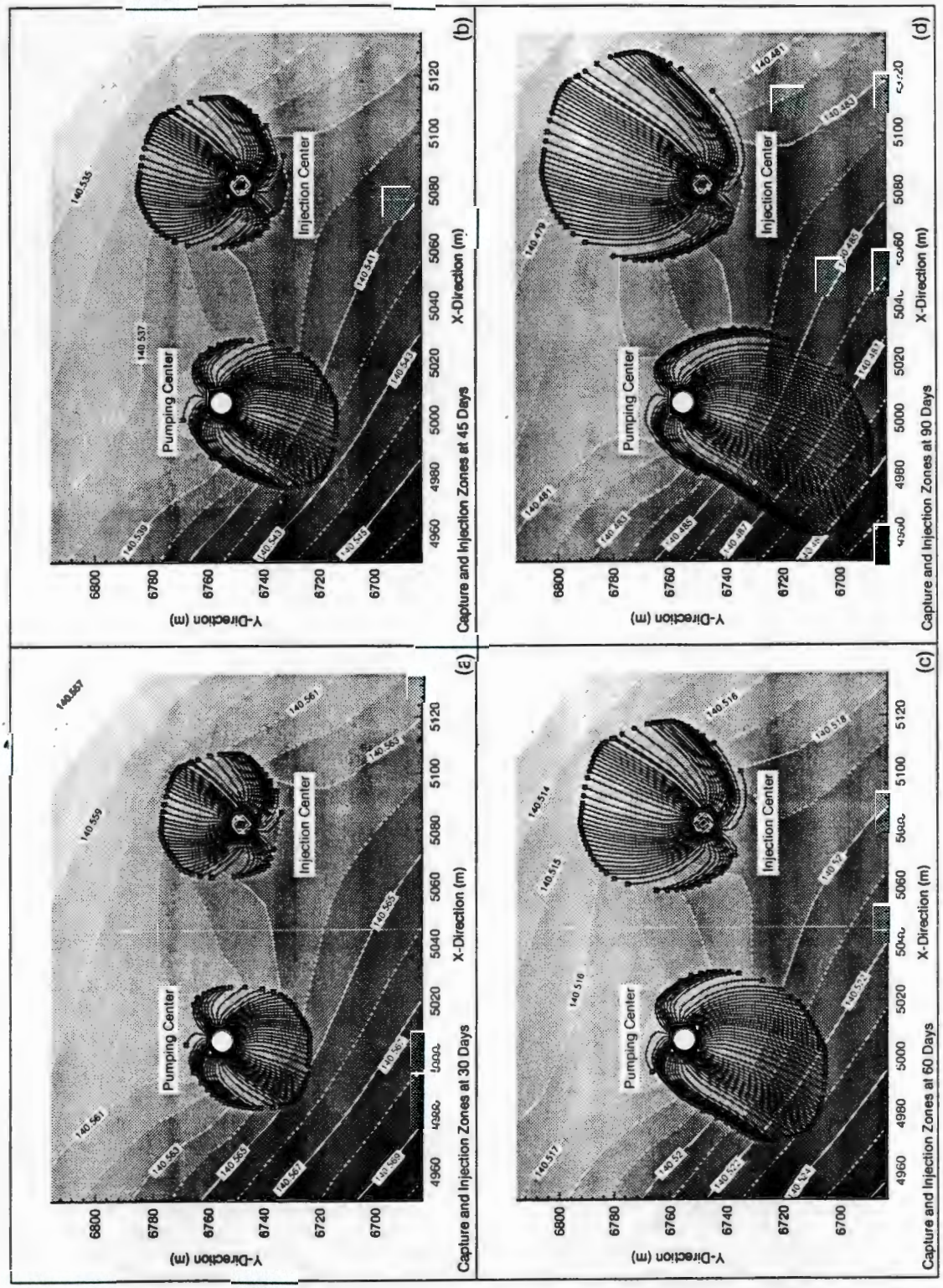

Figure 4-5. Capture And Injection Zone Analyses for 200-ZP-1 PSPTT Pumping and Injection Wells Located Cross Gradient from One Aonother after 30 (a), 45 (b), 60 (c), and 90 (d) Days of Operation. The injection source is placed approximately at well 299-W18-5 location. There are no wells that correspond to the pumping well.

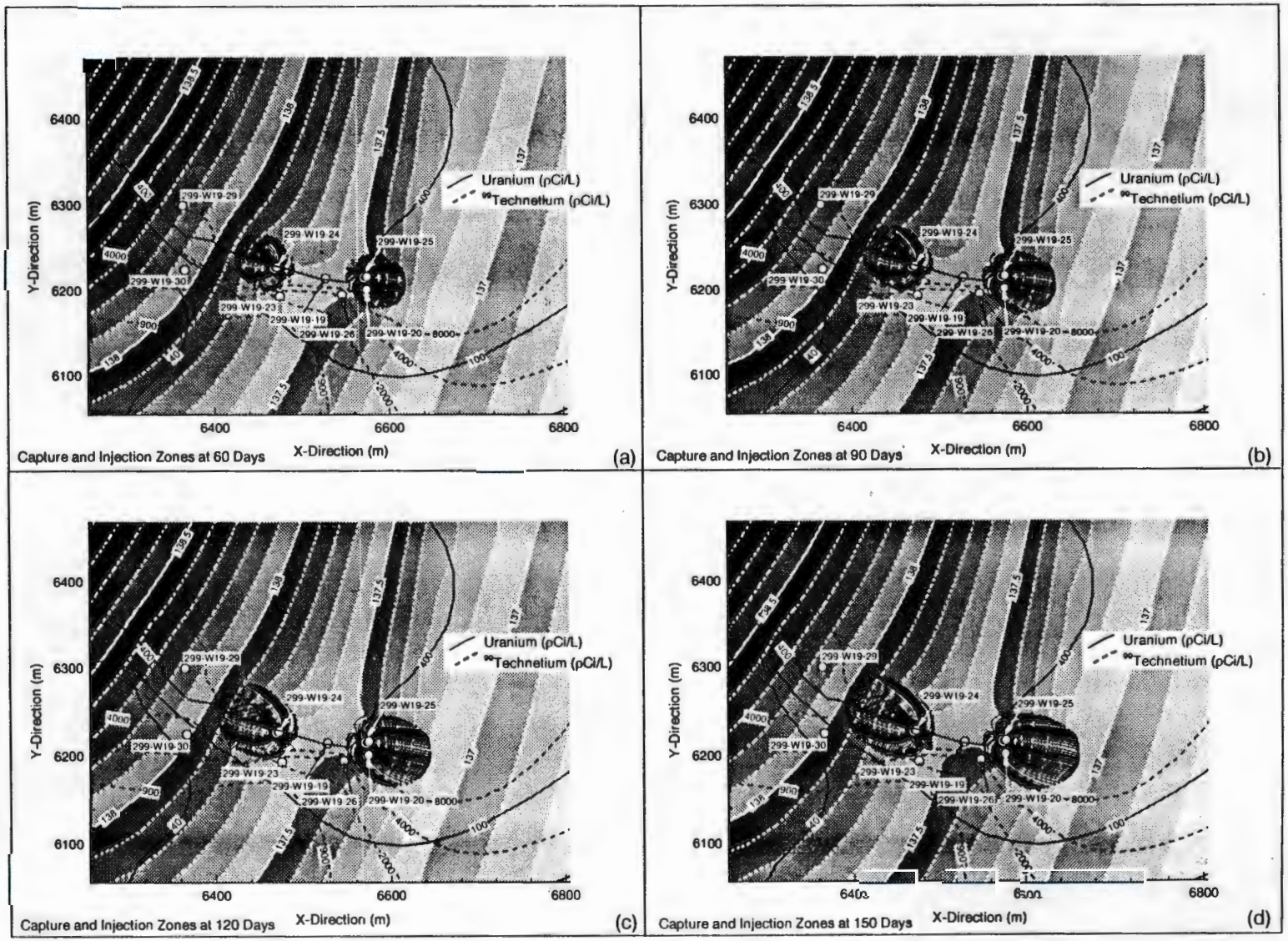

Figure 4-6. Capture and Injection Zone Analyses for the 200-UP-1 PSPTT after 60 (a), 90 (b), 120 (c), and 150 (d) Days of Operation. Pumping is from well 299-W19-24; treated water is injected into well 299-W19-25. The uranium and ^{99}Tc plumes, and the water table elevations (meters above MSL) are superimposed on these figures.

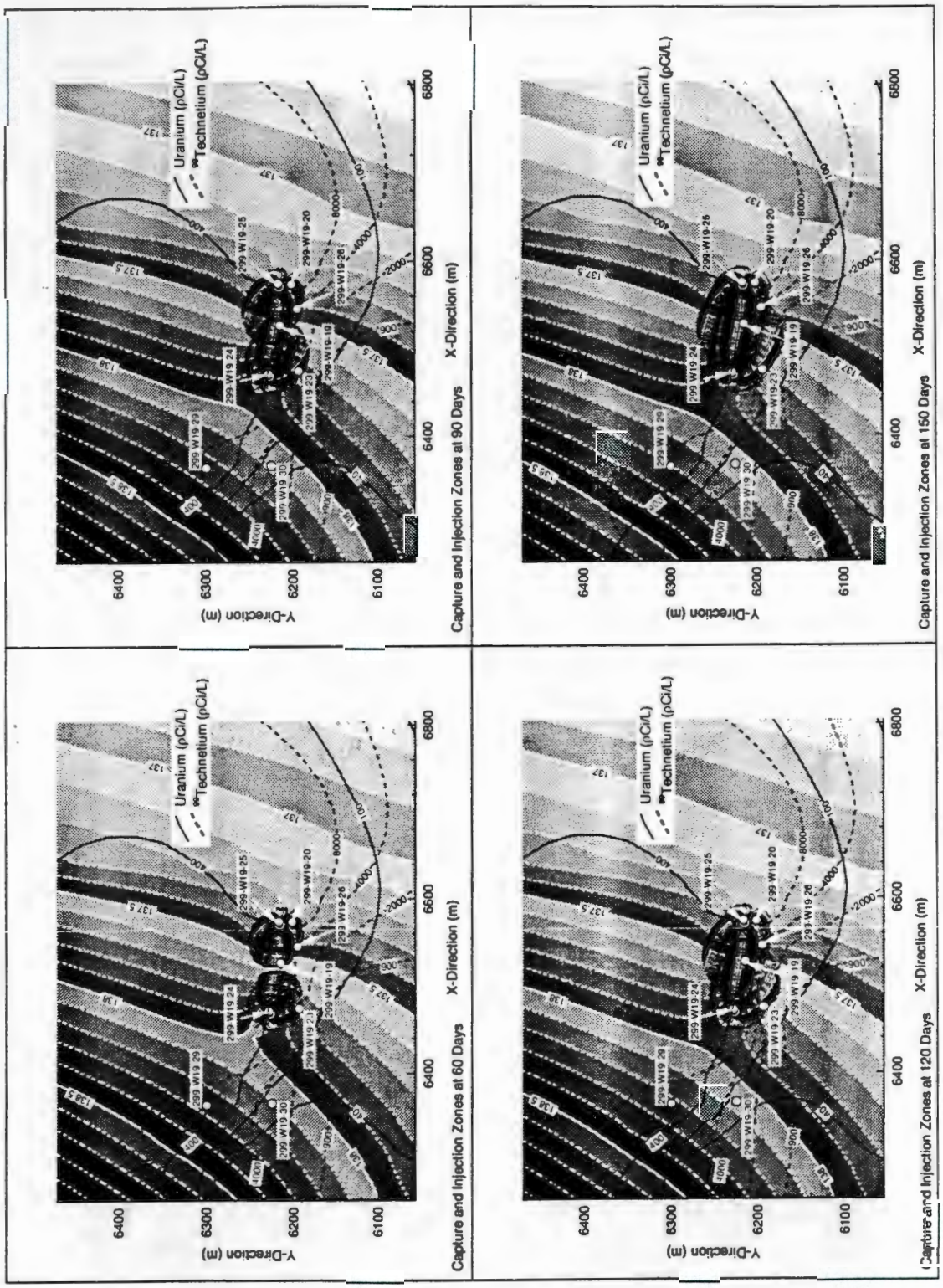

Figure 4-7. Capture and Injection Zone Analyses for the 200-UP-1 PSPTT after 60 (a), 90 (b), 120 (c), and 150 (d) Days of Operation. For this scenario, the pumping is from well 299-W19-25 and treated water is injected into well 299-W19-24. The pumping and injection wells are reversed from the previous figure.

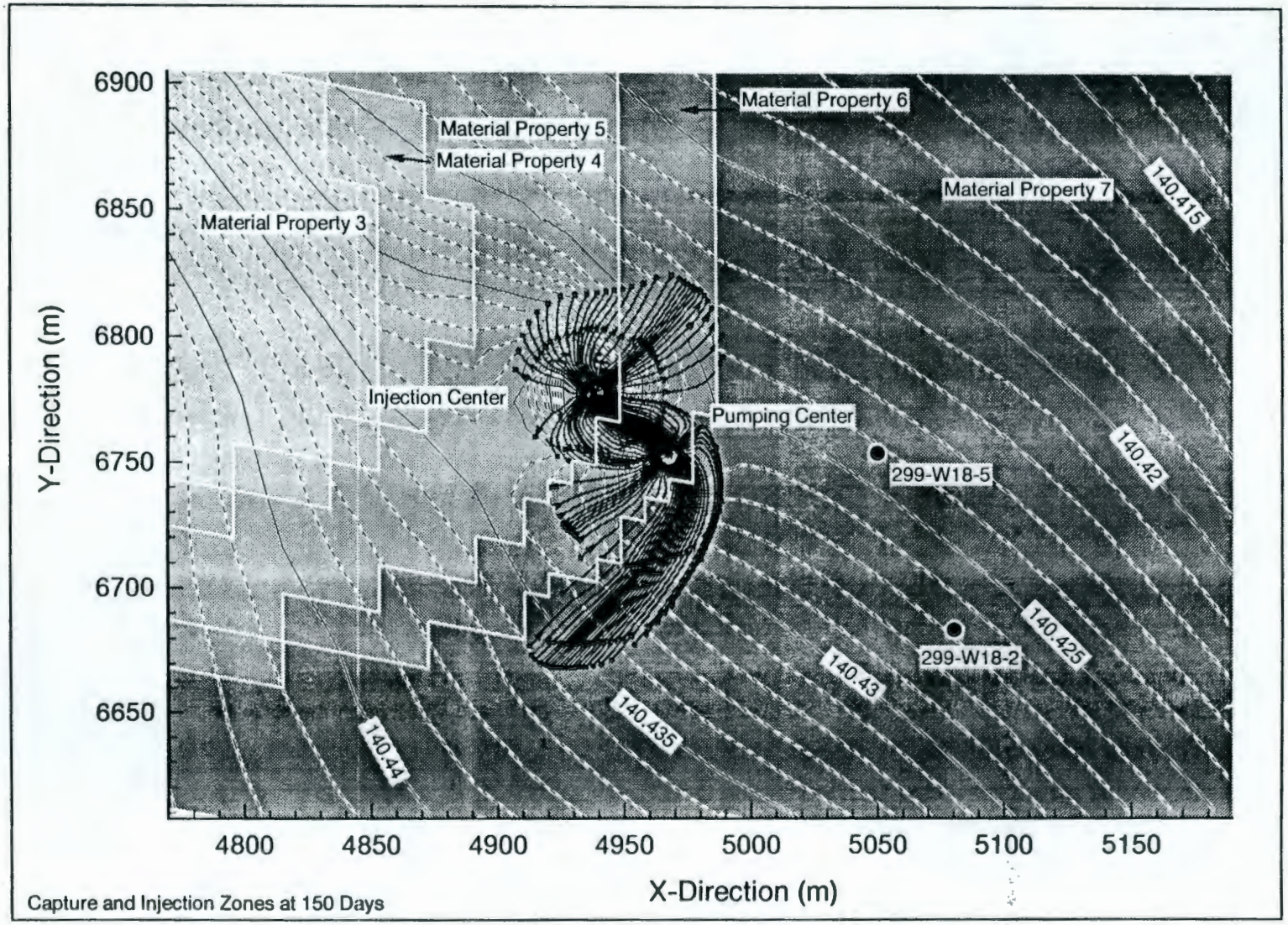

Figure 4-8. Effects of Heterogeneity on the Calculated 150-Day Capture and Injection Zones. The distance a water particle moves depends on the hydraulic properties of the media. Material property 7 has the highest hydraulic conductivity (see Figures 3-3 and 3-4).

5.0 SUMMARY

The 200 West Area groundwater model is operational and was used to predict the capture zones for the 200-ZP-1 and 200-UP-1 Operable Unit PSPTT. The pumping rates and well configurations for the PSPTT can easily be modified and simulated to show the effects of different pumping rates and well configurations.

The analyses presented here assume 10:1 K_H:K_V anisotropy, with no preferential pathways, and that the input parameters and numerical model accurately represents the dynamic hydrogeologic system. However, collecting additional hydrologic data during the PSPTT is required to determine whether or not the model accurately represents the hydrogeologic system. Data collected during the test should, as a minimum, include hydraulic conductivity and effective porosity. This additional data can be used to further refine the model that will be used determine the number and locations of additional extraction, injection, and monitoring wells.

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