Department of Energy

ROCKY FLATS PROJECT OFFICE
12101 AIRPORT WAY, UNIT A
BROOMFIELD, COLORADO 80021-2583

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Mr. Carl Spreng
Rocky Flats Cleanup Agreement Project Coordinator
4300 Cherry Creek Drive South
Denver, Colorado 80246-1530

Mr. Mark Aguilar
Rocky Flats Cleanup Agreement Team Lead
U.S. Environmental Protection Agency, Region VIII
999 18th Street, Suite 500
Denver, Colorado 80202-2405

Dear Gentlemen:

Enclosed please find a copy of the report entitled *Summary of Hydrologic Flow and Transport Modeling Conducted at the Rocky Flats environmental Technology Site* for your information.

Please call me at (303) 966-6246 if you have any questions regarding this report.

Sincerely,

John J. Rampe, Director
Rocky Flats Closure Project Management

Enclosure

cc w/Encl.:
Administrative Record
S. Surovchak, LM, DOE

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SW-A-005222

Summary of Hydrologic Flow and Fate and Transport Modeling Conducted at the Rocky Flats Environmental Technology Site, Golden, CO

For Kaiser-Hill Company, LLC

by
Integrated Hydro Systems, LLC
September 2005

Summary of Hydrologic Flow and Fate and Transport Modeling Conducted at

the Rocky Flats Environmental Technology Site, Golden, CO

For Kaiser-Hill Company, LLC

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Integrated Hydro Systems, LLC
September 2005

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1.0 INTRODUCTION

This report presents two separate tables compiled for this report, included as Appendix A and B. They summarize current and past flow and fate/transport reports used at Rocky Flats Environmental Technology Site (RFETS or Site). Table A.1 (Appendix A) includes information on all recent physically-based, fully-distributed, integrated flow modeling and related fate and transport modeling. Integrated codes are capable of simulating the dynamic coupling of surface and subsurface hydrologic flow processes. Table B.1 (Appendix B) includes details of all other former hydrologic/hydraulic flow and fate and transport modeling studies conducted at RFETS. In each table, the following information was compiled for each model:

- The model code(s);
- Specific objectives;
- Model details;
- Key conclusions;
- Modeling completion date; and
- Reference reports.

The content of this report includes only brief summaries of key information related to each modeling study. Where individual modeling work has been previously well documented in other reports, the reader is directed to these reports for more detailed information. In these cases, only the most important findings are included in this report. In other modeling studies, where results were only compiled into PowerPoint presentations, more information is provided in sections below. This report does not include any information on air modeling conducted at RFETS.

The report is organized into the following sections:

- Recent Integrated flow modeling (Section 2.0) including:
  - Site-Wide Water Balance Model (SWWB) (Section 2.1),
  - Industrial Area (IA) Model (Section 2.2),
  - Landfill Models (Section 2.3),
  - Local Building-specific Closure-Condition Models (Section 2.4), and
  - Accelerated Action Models (Section 2.5);
- Recent Related Fate and Transport Models (Section 3.0); and
- All other Former Models (Section 4.0).

The integrated hydrologic flow and related fate and transport models are mostly presented in the order that they were developed. Most of these models use information from the original SWWB described first.

2.0 INTEGRATED HYDROLOGIC FLOW MODELING

A number of integrated hydrologic flow models have been constructed since 2000 to simulate a variety of hydrologic flow conditions at the RFETS. These models include:

- SWWB flow model;
- IA (IA) – Volatile Organic Compound (VOC) flow model;
- A and B Pond model;
- Landfill flow models:
  - Present Landfill model and
  - Original Landfill model;
- Local building closure configuration modeling:
  - Building 991 (B991) model,
  - Building 771 (B771) model,
  - Building 883/881 (B883/881) model,
  - Building 371 (B371) model,
  - Building 776/777 (B776/777) model – dust suppression model,
  - Building 444 (B444) model, and
  - Building 460 (B460) model;
- Accelerated action modeling:
  - Mound Plume Treatment System and
  - Individual Hazardous Substance Site (IHSS) 118.1 – Dewatering Model.

Two figures were prepared to show the locations of each of these model areas. Figure 2.1 shows a three-dimensional perspective view of the pre-closure (year 2000) RFETS surface topography and boundaries of the regional, or Site-wide, the IA VOC, and A and B Pond integrated flow models. Figure 2.2 shows boundaries for each local-scale integrated flow models.

2.1 Integrated Flow Model Objectives

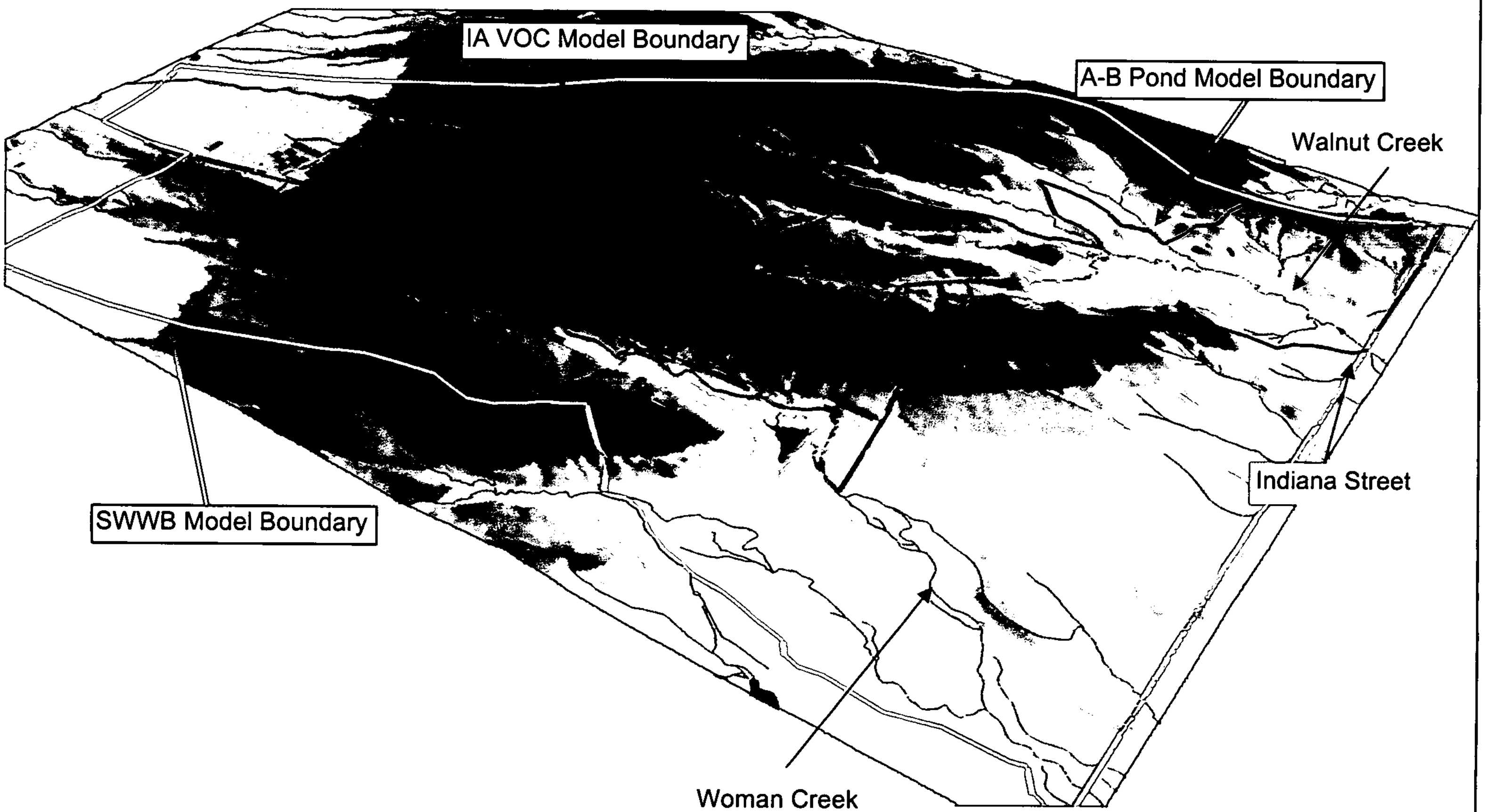
Each integrated flow model had similar, but in some cases different, specific objectives. One key objective for each model was to develop a management tool to aid in making decisions that support proposed Site closure modifications. Other model-specific objectives include the following:

Regional models (SWWB):

- Better understand current integrated system dynamics/integrated flows;
- Evaluate downgradient (Buffer Zone) effects of closure modifications;
- Assess pond operation effects/performance for closure modifications; and
- Focus of this model was on larger-scale hydrologic response (the coarser resolution was not capable of simulating local scale effects).

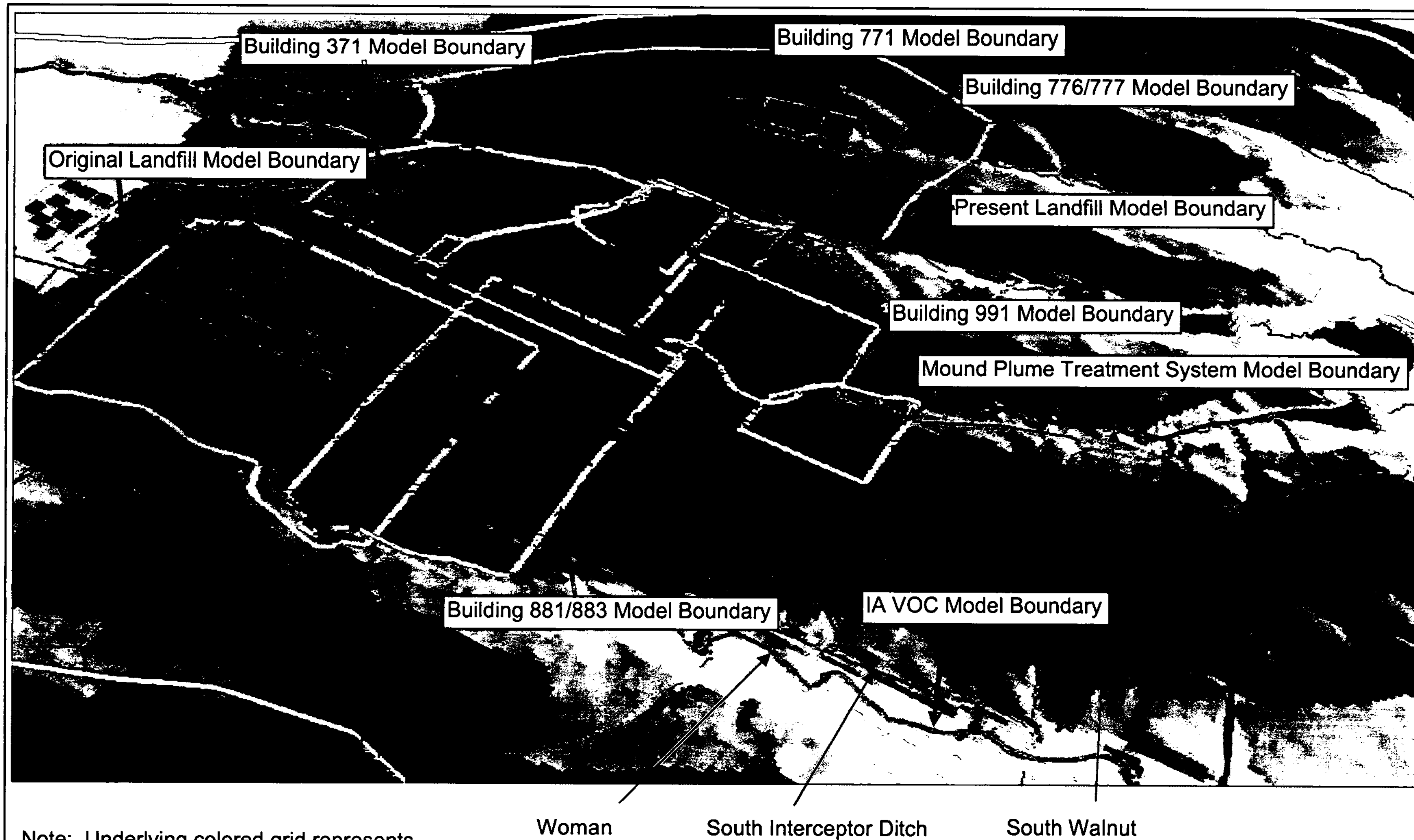
IA VOC flow model:

- Simulate current and closure configuration integrated flows in localized areas impacted by VOCs in groundwater; and



Note: Underlying colored grid represents current surface topography. Colors are constant topographic elevation bands.

Figure 2.1. Integrated Flow Model Boundaries - Large Scale



Note: Underlying colored grid represents current surface topography. Colors are constant topographic elevation bands.

Figure 2.2. Integrated Flow Model Boundaries - Local

- Estimate long-term, closure-configuration groundwater flow conditions for use in VOC fate and transport modeling.

Building models:

- Assess the short-, and long-term localized hydrologic effects of leaving deep building basement slabs/walls in place, for typical and extreme annual climate conditions;
- Assess the short-term hydraulic/hydrologic effects of continuous application of dust-suppression water during building decommissioning; and
- The most refined grids capture vertical/horizontal details at appropriate level.

Landfill models:

- Better understand current integrated system dynamics/integrated flows;
- Assess the performance of current hydraulic controls on hydrologic flow conditions;
- Assess the short-, and long-term hydrologic effects of proposed closure modifications; and
- Use high resolution models to capture local flows/details.

Accelerated action models:

- Assess the performance of the Mound Groundwater Treatment System, and
- Assess hydrologic conditions and the performance of proposed Mound system modifications.

2.2 Proposed Closure Configuration Details

One of the most important objectives of each integrated flow model was to evaluate the change in hydrologic conditions due to closure modifications. Although most of the original proposed closure modifications were well documented in the SWWB modeling study (K-H, 2002a), many of these have changed as closure has progressed. As a result, the estimated hydrologic conditions for the new closure configuration have also changed. In developing each new model since the SWWB flow model, attempts were made to obtain and include the most current information on closure configurations. In some cases (mostly local building models) the final closure configuration depended on results obtained from the integrated flow modeling. In other cases, the most recent model does not reflect the latest closure configuration.

A brief overview of closure configuration details considered in developing the integrated flow models is presented below. The following closure configuration modifications were considered:

- Regrade of surface topography;
- Modification of surface drainage network;
- Disruption of subsurface drains (footing, storm, and sanitary);
- Discontinued imported water:
    - Eliminated leakage from water supply lines, and
    - Eliminated downstream discharge from sanitary waste water plant;
- Disruption of permeable backfill material associated with subsurface utility corridors (footing, storm, sanitary, process waste, water, electric, alarm, communications, and gas);
- Reconfiguration of portions of deep building basement slabs/walls left in place;
- Conversion of impervious areas to permeable soils;

- Conversion of non-vegetated areas to vegetated areas; and
- Modification of soils distributions:
  - Within former deep building basement footprints, and
  - In regraded areas (some areas required fill material).

Key features, assumptions, and conclusions for each model are described in further detail below.

2.3 Site-Wide Water Balance Modeling

The RFETS is being closed and converted from a nuclear weapons component production facility into a National Wildlife Refuge. Closure activities involve reconfiguring portions of the existing Site, which impact the current surface and subsurface hydrology. The hydrologic system at RFETS is strongly influenced by surface-groundwater flow interactions and vadose zone processes, including evapotranspiration (ET), due to the semi-arid climate. The surface-subsurface hydrologic flow system is further complicated by many surface and subsurface industrial structures within the IA.

Between 2000 and 2002, in order to better understand the current hydrologic flow system and the long-term changes due to closure modifications, a more sophisticated and comprehensive approach than previous modeling was undertaken. A continuous, fully-integrated, distributed-parameter, and physically-based hydrologic SWWB model (K-H, 2002a) was developed and applied as a decision management tool to assess hydrologic changes due to closure. The model is fully-integrated because the important hydrologic processes are dynamically coupled. For example, surface flows consisting of overland flows directed into channelized flows are coupled with subsurface flows consisting of both saturated and unsaturated zone flows. Most model input parameters are distributed either spatially, and/or temporally. The model is physically-based because each flow process and the interaction between flow processes are based on rigorous physical and mathematical equations. The model is 'continuous' because it continuously (hourly or less) simulates the system's transient hydrologic response to spatially and temporally varying input (i.e., precipitation, potential ET, and temperature).

Previous Site modeling, described further in Section 4.0, either considered only single processes, or simple couplings, or used less-rigorous physical equations to describe flows in the system. The fully-integrated SWWB modeling work represents a significant advancement over previous modeling in understanding the current flow system dynamics and interactions, as well as more realistically estimating system response to future closure modifications.

A brief overview of the development and applications of the SWWB model is presented below, starting with the main objectives (Section 2.3.1). A general approach, development of a conceptual model, a numerical modeling approach, and a calibration strategy are presented in Sections 2.3.2 to 2.3.5. The numerical model design, model performance, hypothetical model closure scenarios, and implications to site closure are presented in the following sections (2.3.6 to 2.3.9).

Following development of the SWWB model, the integrated hydrologic responses for several additional scenarios were evaluated with the model. A brief overview of additional scenarios and results are summarized in Section 2.3.10. In addition, the most recent changes to the June 2005 SWWB model (herein called 'the updated SWWB') are briefly discussed at the end of Section 2.3.10.

2.3.1 Objectives

The primary objective of the SWWB study was to create a decision tool to quantitatively assess the integrated hydrologic conditions at the RFETS. Specifically, this integrated model was used to: (1) comprehend and simulate current Site hydrologic conditions; and (2) assess the hydrologic impacts caused by hypothetical modifications to the current Site configuration.

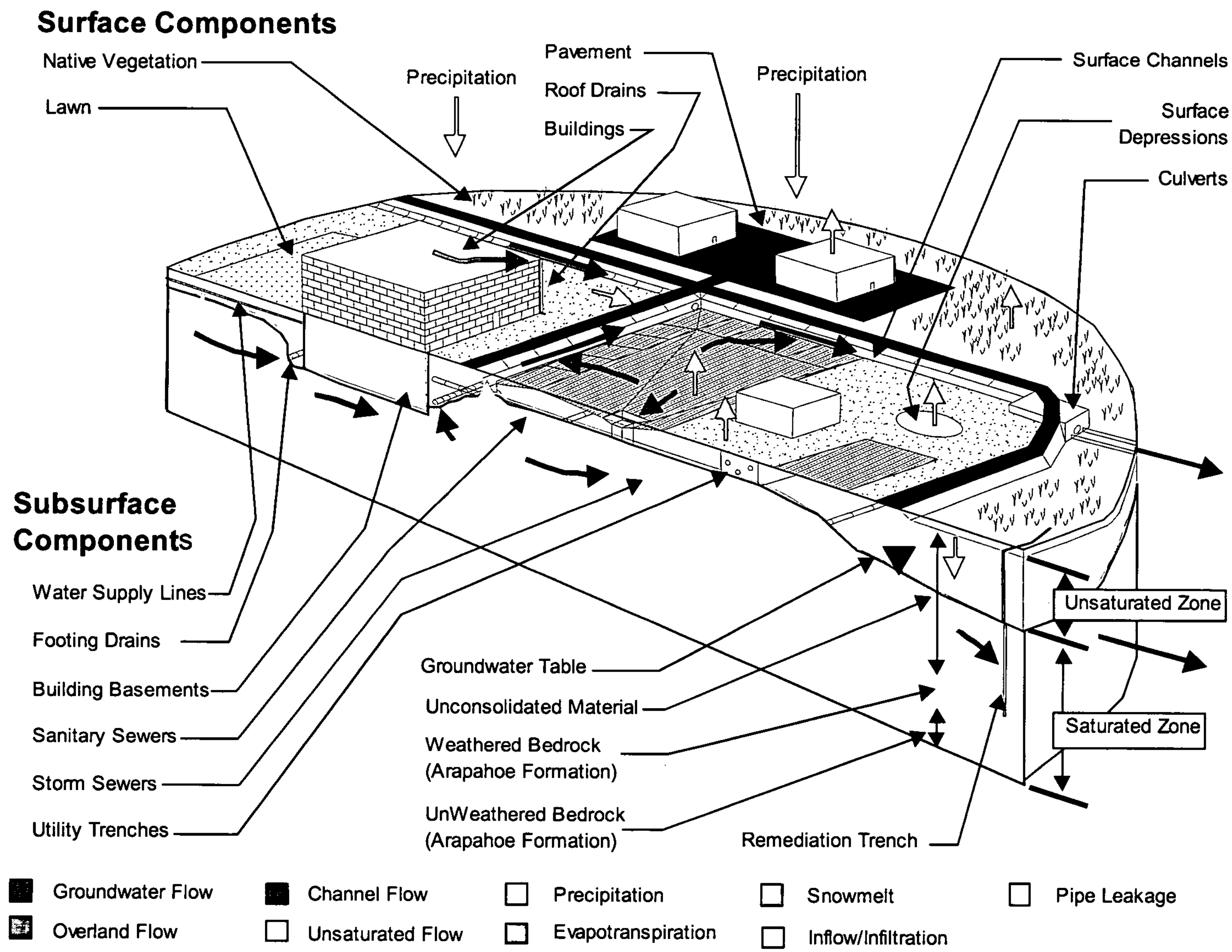


Figure 2.3a IA Conceptual Flow Model.

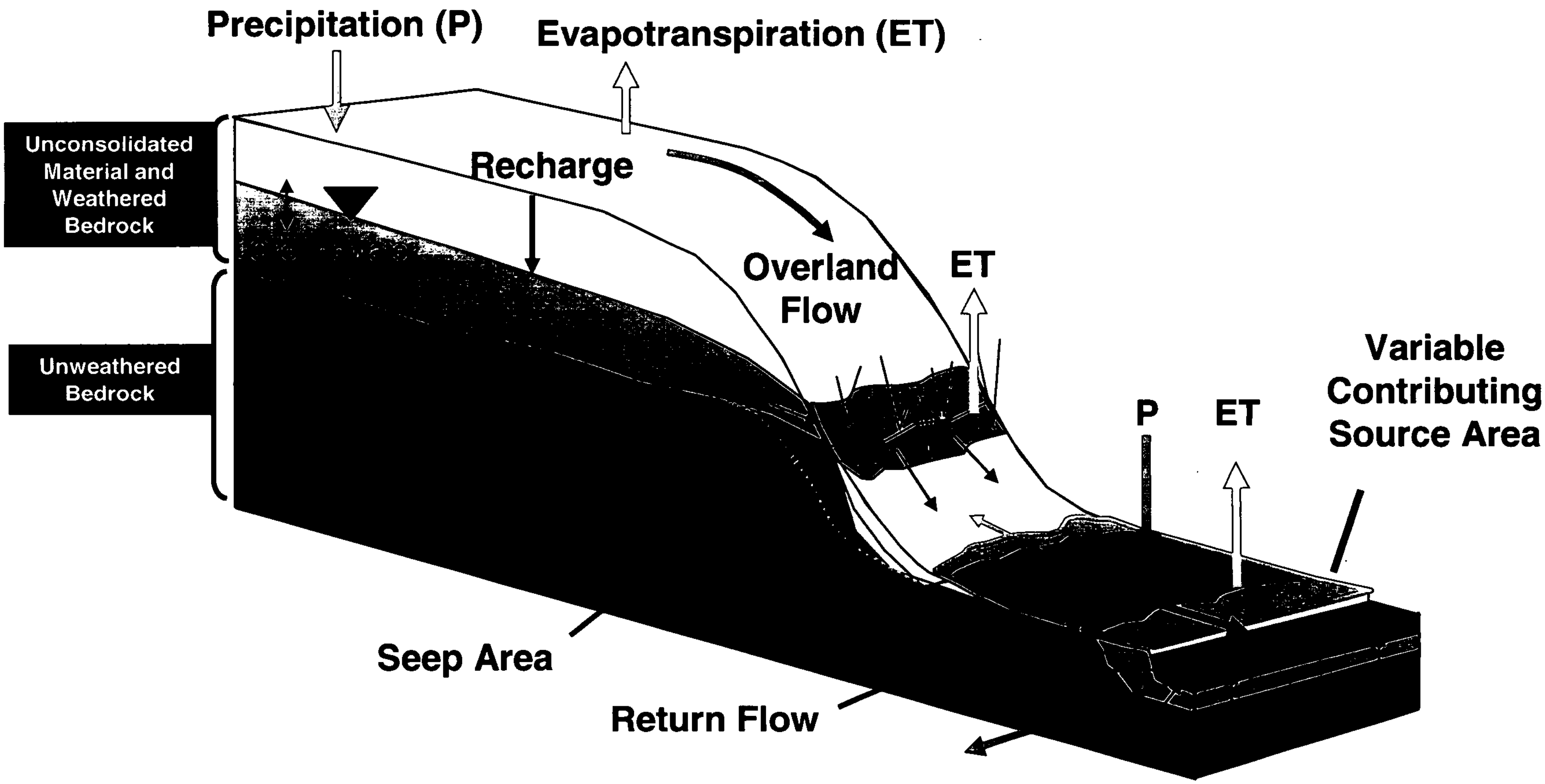


Figure 2.3b Conceptual Hillslope Flow Model

processes and to aid in parameterization of model components, prior to simulating the fully-integrated Site-wide model.

A model code verification study (Illangasekare, Prucha, and DHI, 2001) showed that MIKE SHE was the most appropriate available code for simulating the dynamic and integrated semi-arid zone hydrologic processes at RFETS.

2.3.5 Calibration Strategy

Critical parameters and performance targets were identified and prioritized for the model calibration. Focus areas were specified where key decisions or Site hydrology would likely change in response to the hypothetical Site scenarios. Focus areas included: (1) the regional flow system; (2) major surface water drainages; (3) detention ponds; (4) specific contamination areas including the 903 Pad and Lip Area, the Original Landfill and the Present Landfill; (5) *in-situ* groundwater plume treatment systems; and (6) vegetation/habitat areas. Within the focus areas, additional effort was made to minimize the difference between model-simulated results and field measurements of the hydrologic system. The highest priority was given to accurately simulating surface water discharge from the IA to Woman and Walnut Creeks and from those drainages to the eastern Site boundary. They represent significant possible offsite pathways.

2.3.6 Numerical Model Design

The SWWB model consisted of surface flow, unsaturated zone, and saturated zone components at discrete points on a grid. A 200-x 200-foot (ft) (approximately 61- x 61-meter [m]) regularly-spaced model grid was selected as the most suitable compromise between numerical efficiency versus solution accuracy required to meet the project objectives. Figure 2.4 illustrates modeled processes, their coupling, and their dimensionality. In addition, time-step ranges were used in the model to capture the rapid dynamics of the surface hydrologic system (0.5-minute time step) and slower response of the groundwater flow system (6-hour maximum time step). Spatial precipitation distributions were specified from 10 stations every 15 minutes, while potential evapotranspiration (PET) was specified every 2 hours. Figure 2.5 shows the model extent, discretization, and channel network simulated in the fully-integrated calibrated flow model (conditions current as of WY2000).

In the surface flow model, overland and channel flows were simulated in two-dimensions and one-dimension, respectively. The channel flow network included both Walnut and Woman Creeks and most tributary branches. The A-, B-, and C-series Ponds and the Present Landfill Pond were also incorporated into the channel network. Both channel flow and pond water interact directly with saturated zone flow. Drainage basin boundaries were used to define overland flow areas within the model, and detailed cross-sections defined the channel flow network.

One-dimensional unsaturated zone flow and three-dimensional saturated zone flow were simulated in the subsurface flow model. The unsaturated zone model accounted for spatially distributed soils. Effects of the time-varying, spatially-distributed vegetation and ET were simulated through the unsaturated zone. Four layers were used to describe the saturated zone flow within unconsolidated material and weathered bedrock units. Average hydraulic characteristics and properties of subsurface groundwater treatment systems, utility trenches and drains, water supply lines, and building basements in the IA were incorporated into the saturated zone model.

2.3.7 Model Performance

After completing the numerical model design, the fully-integrated regional model was calibrated. Calibration was achieved by adjusting model parameters until the simulated model results compared well with observed data. The calibration data set period was from October 1, 1999 through September 30,

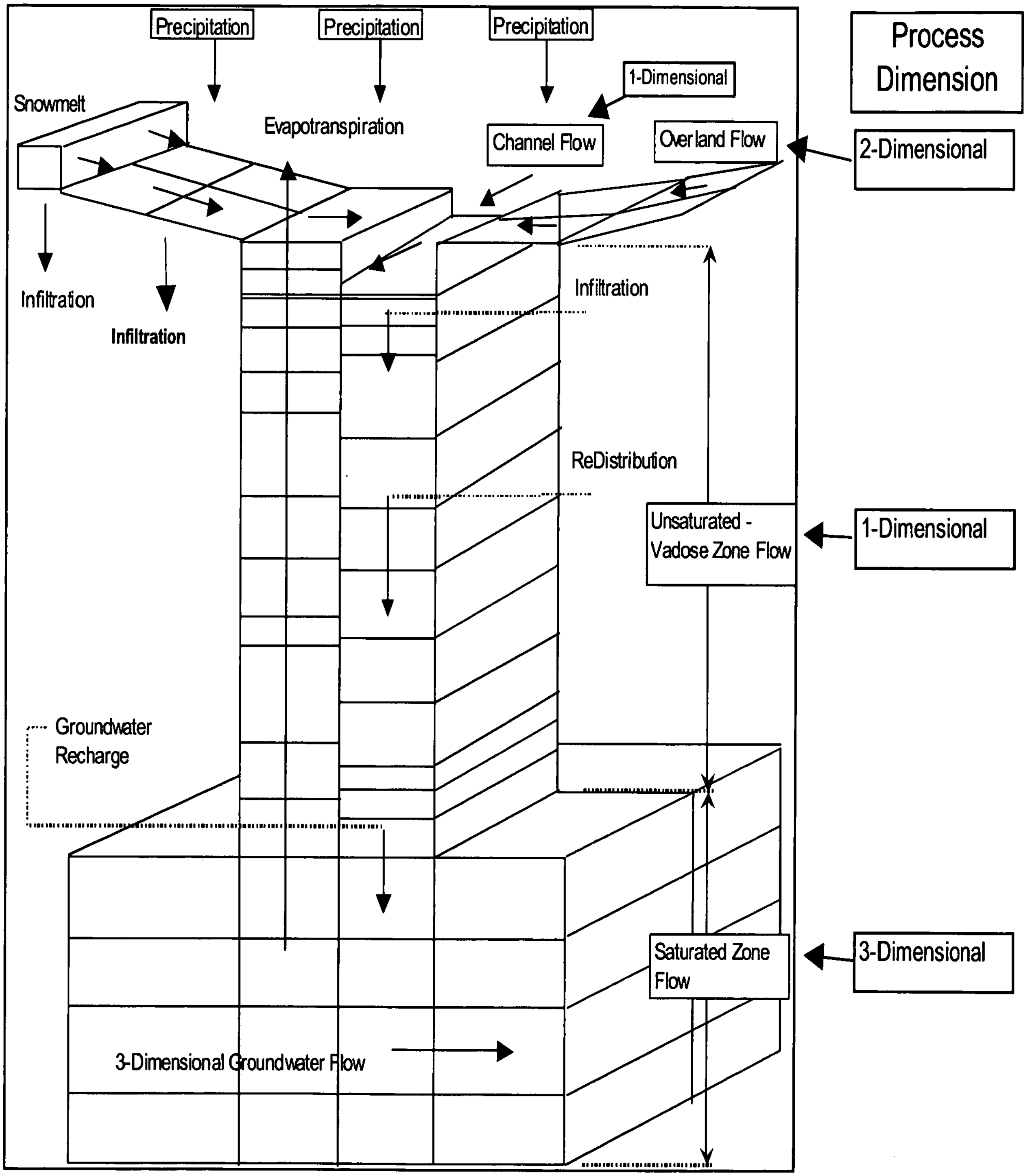


Figure 2.4 SWWB Model Discretization.

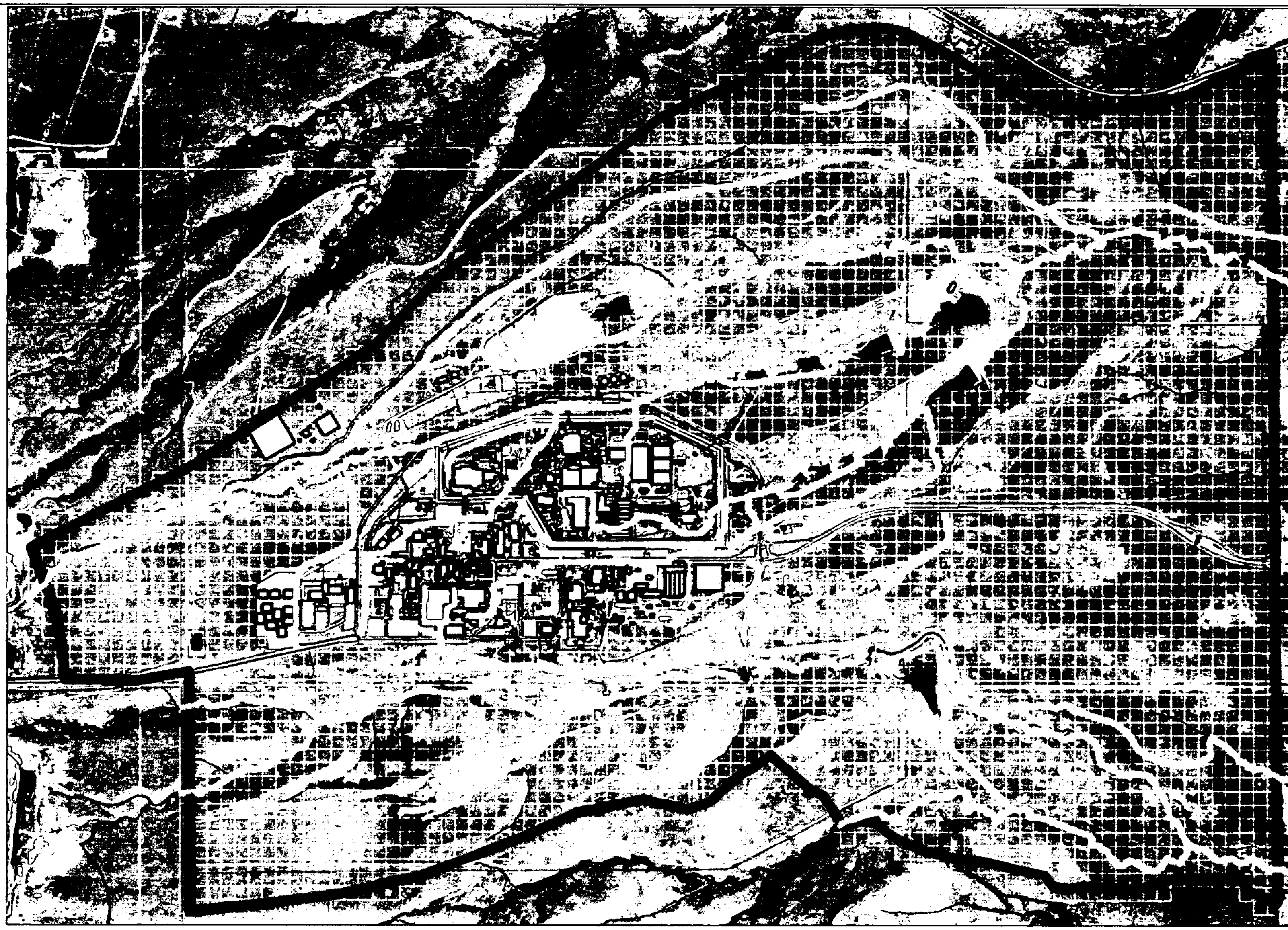


Figure 2.5 SWWB model boundary, grid discretization (200- x 200-ft), and Surface Water Drainage Network.

2000 (Water Year [WY] 2000). The SWWB model simulated observed Site-wide flow conditions at RFETS well. Key findings of the calibrated model included:

- For the current (Year 2000) Site configuration, the water balance differed greatly in the IA as compared to the Buffer Zone. For the WY2000 climate, roughly 90 percent of the precipitation was lost through ET, and less than 1 percent to streams. In contrast, for the IA, roughly 60 percent of the precipitation was lost to ET, with 15 percent running off to streams;
- ET-dominated near-stream groundwater levels strongly affected stream flows. During high ET, groundwater levels declined near Walnut and Woman Creeks at the eastern Site boundary. In Woman Creek, this effectively eliminated stream flow in late spring and summer. During times of the year with low ET, groundwater levels increased. This causes increased base flow contributions to Woman Creek with resulting increases in the total flow and peak flow rates in that drainage;
- In Walnut Creek, flows were dominated by pond releases. However, during non-pond discharge periods, precipitation events rarely caused stream flow in Walnut Creek because of high soil infiltration rates and low near-stream groundwater levels;
- Groundwater level changes were affected most by vertical processes, such as ET and direct recharge from precipitation, rather than lateral groundwater flow. Groundwater flow directions were strongly influenced by local topographic and bedrock surfaces; and
- Simulated IA surface flows consisted of fast runoff, base flow, and drain inflows. Results showed that fast runoff caused rapid hydrograph peaks, while base flow and drain inflows produced continuous low flow rates exiting the IA as surface water.

The performance of the calibrated model was further assessed through a sensitivity analysis and model validation. The purpose of the sensitivity analysis was to identify key parameters to which the model was most responsive. The system hydrologic response was most sensitive to saturated hydraulic conductivity values. The model validation performance was demonstrated using pre- and post-calibration climatic conditions. These simulations showed that the model performed well in simulating hydrologic conditions of the Spring, 1995 and WY2001 (October 1, 2000 through September 30, 2001).

2.3.8 Model Scenario Evaluations

In 2002, model simulations were conducted for two hypothetical Site closure scenarios to evaluate changes based on WY2000 hydrologic conditions. In the first scenario, the No Imported Water Scenario, imported water from off-Site was discontinued (the Site currently purchased an average of approximately 420,000 cubic meters [110 million gallons or 340 acre-feet] of water annually from the Denver Water Board). The second scenario, the Land Configuration Scenario, also discontinued imported water and included a hypothetical regraded topography in the IA, the Present Landfill, and the Original Landfill. In the second scenario, IA changes included removing buildings, pavement, and subsurface utilities. Figure 2.6 shows the change in surface drainage for the second hypothetical scenario compared to the existing (WY 2000) drainage network.

For each hypothetical scenario, three climate conditions were applied to develop a range of simulated hydrologic responses. The three climate conditions represent average, wet, and dry years of precipitation for the Site. Finally, a Monte Carlo-type uncertainty analysis was conducted on the second scenario to assess the range of uncertainty in predicted output given uncertainty in sensitive model input parameters.

Several key changes observed in hydrologic conditions from the present to the hypothetical Land Configuration Scenario included the following:

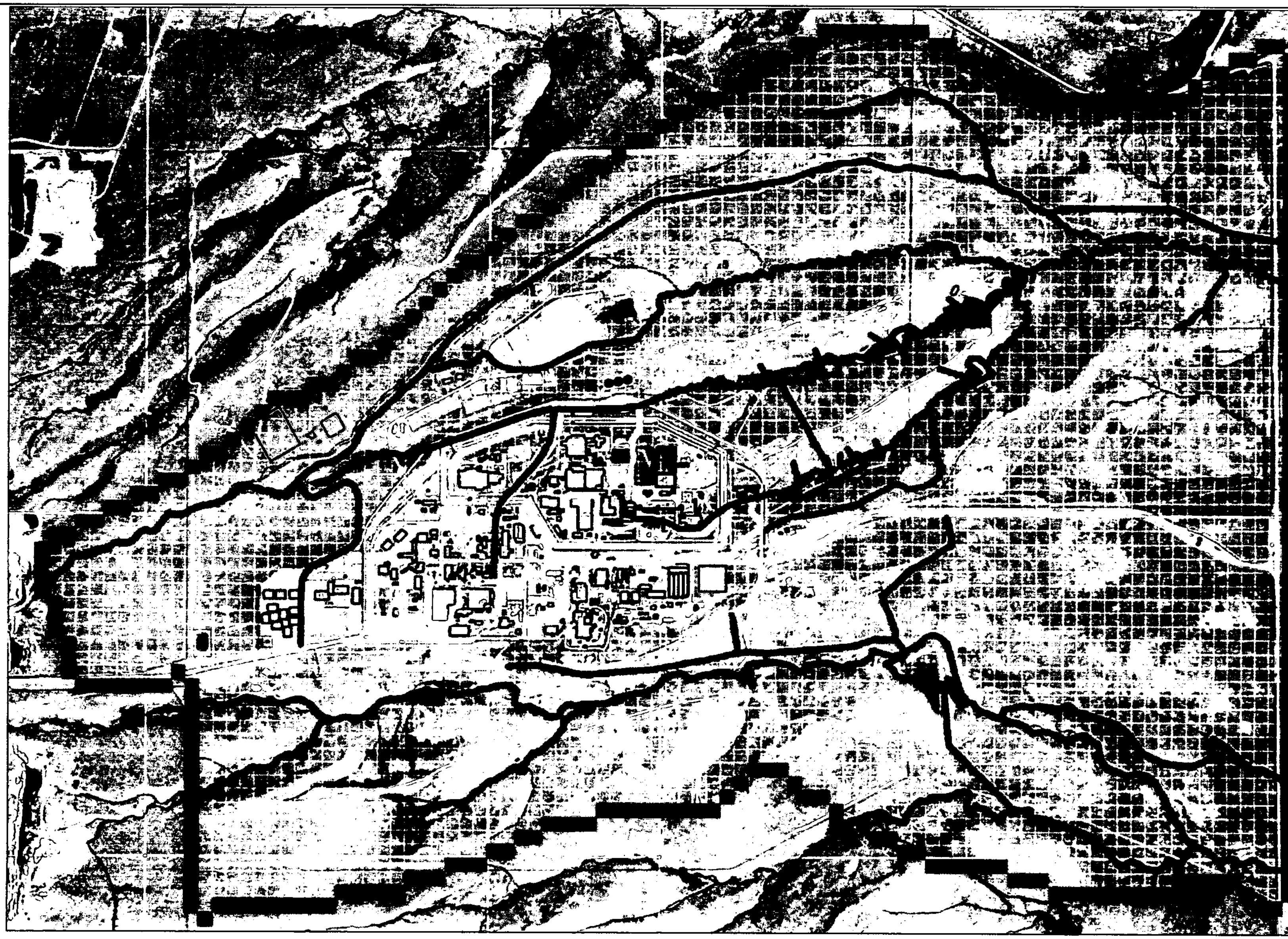


Figure 2.6 Hypothetical Closure Scenario Surface Drainage Network (Light blue – existing WY2000 network).

- Regionally, most of the hydrologic system changes occurred within the regraded IA, the two modified landfill areas (the Original Landfill and the Present Landfill) and to Walnut Creek, east of the IA;
- Surface discharge in Walnut Creek was substantially reduced, while flows in Woman Creek were largely unaffected;
- Walnut Creek discharges decreased for the following three reasons: (1) Waste Water Treatment Plant contributions to Walnut Creek were eliminated; (2) impervious surfaces in the IA were removed, thereby eliminating fast runoff; and (3) drain discharges to IA streams were eliminated;
- The number of required terminal pond discharges decreased in the hypothetical Land Configuration Scenario because of decreased flow from the IA;
- Average groundwater levels in the IA increased. Removing drain discharges and impervious areas caused groundwater to rise, whereas removing leaky water supply lines caused groundwater levels to decrease. The net effect of these changes was to increase IA groundwater levels; and
- Simulated discharges from groundwater remediation systems decreased slightly.

Updates to the original SWWB flow model described above are presented in more detail at the end Section 2.3.10

2.3.9 Implications to Site Closure

Modeling results suggested that significant impacts to the Site's hydrologic system will occur for the hypothetical scenarios. These modeling results have provided valuable insight into Site hydrology that have influenced, and continue to influence the RFETS closure and long-term surveillance and maintenance. Implications based on the simulated scenario results are summarized as follows:

- Surface and sub-surface flows in Woman Creek will be largely unaffected. Therefore, vegetation along Woman Creek will generally not be affected by the Site reconfiguration. An exception to this may occur in the area south of the Original Landfill. This area may experience some localized diminished flows from hypothetical covers and cutoff walls. A more detailed analysis of this area was performed; and
- Surface and sub-surface flows in Walnut Creek, in contrast to Woman Creek, will be substantially reduced. As a result of the diminished surface flows, future hydrologic conditions in Walnut Creek downstream of the IA will be dominated by pond operating protocols and any pond routing or structural modifications. An additional effect of reduced flows in Walnut Creek is the possible impact to vegetation downstream of the ponds caused by lower groundwater levels along the stream channel.

2.3.10 Additional SWWB Modeling

In late 2002, additional SWWB modeling was conducted using both the current calibrated SWWB model and a hypothetical closure configuration model. A white paper was prepared summarizing the findings. Specifically, the following three tasks were performed:

- Task 1 - Assessment of groundwater flow in VOC plume areas;
- Task 2 - Evaluation of remedial designs for groundwater plume treatment systems; and
- Task 3 - Simulation of additional SWWB hypothetical land configuration scenarios.

To accomplish these tasks, observed data were evaluated, previously simulated SWWB modeling results were considered, and additional model simulations were performed (using the SWWB model, with 200-ft. x 200-ft. grid). The findings are presented below.

2.3.10.1 Task 1 Findings: Groundwater Flow Assessment in VOC Plume Areas

Based on an initial review of data availability, certain data limitations presented challenges to the VOC modeling. Few historical measurements of groundwater level, water quality, and climate variables exist from 1952 to the late 1980s which complicated efforts to simulate observed plumes from spill date to 2002 (planned approach for model calibration). Further, the historical release information lacked information on spill concentrations, volumes, and specific release dates (K-H, 2000b).

Many factors affect groundwater flow paths. On a regional scale, flow paths are largely controlled by the bedrock surface. Therefore, on a regional scale, groundwater flow paths don't change significantly due to Site closure modifications. However, on a local scale, groundwater flow directions (and hence transport) can also be strongly influenced by other factors. These factors include ET, building basements, subsurface utilities, precipitation, saturated zone hydraulic conductivity, storage, Arapahoe Sandstone lenses, unsaturated zone heterogeneity, and historical Site development. These local-scale factors needed detailed consideration for flow and transport modeling.

2.3.10.2 Task 2 Findings: Accelerated Action Design Simulations

Slurry walls in the Original Landfill area

Two simulations were conducted in 2003 to evaluate the effects of a single slurry wall extending through the weathered bedrock at the Original Landfill. Results showed the following:

- The lateral extent of slurry wall effects on groundwater levels was limited to several hundred feet;
- The magnitude of change to upgradient or adjacent groundwater levels was less than about a meter. Groundwater levels increased on the upgradient side of the slurry wall, but decreased within the Original Landfill waste material downgradient of the wall. The increase in water levels caused flow directions to change slightly, upgradient of the wall. This change in flow directions would likely cause the southern extent of the IA plumes to be redirected from the current pathway;
- Recharge could not be entirely eliminated with the hypothetical geotechnical cover parameters specified by the Land Configuration Project. As a result, the waste material could not be entirely dewatered; and
- Dewatering would likely take decades to occur within the Original Landfill area, given the relatively low saturated hydraulic conductivities.

Solar Pond Plume Groundwater Treatment System

In 2003, based on an evaluation of the observed data and SWWB simulation results (note: model resolution limited to grid size of 200- x 200-ft.), it is possible that the current Solar Pond Plume groundwater treatment system captures the present VOC plumes in this model area. However, more localized modeling, combined with careful monitoring of hydrologic response in the area, would be required to fully evaluate the performance of the system.

Hypothetical Interceptor Trenches

In 2003, two hypothetical interception trench scenarios (one oriented north-south through the center of the IA, and the other was "L-shaped" around the south and east part of the 903 Pad) were simulated in the IA to evaluate their effects on subsurface flows. Results showed the following:

- The influence of these systems on surrounding subsurface flows was limited due to the shallow aquifer, low aquifer permeabilities, and strong localized influence of recharge and ET; and
- Because of the limited capture zone of collection trenches, they would need to extend across the entire lateral extent of any plume migration pathway to effectively capture VOCs.

2.3.10.3 Task 3 Findings: Additional Land Configuration Scenarios

This task involved simulation of four additional scenarios using the regional SWWB model. Specifically, in 2003 the SWWB model was applied to simulate the following:

- Effects of minimal topography change at closure;
- Effects of leaving most drains in place at closure;
- Effects of upgradient gravel mining activities at closure; and
- Hydrologic response to a 100-year precipitation event (currently and at closure).

Results of these simulations showed the following:

- The current topography did not produce significantly different surface water discharge volumes as compared to the engineered topography. Groundwater levels were higher in some areas and lower in others, relative to simulation of the engineered topography at closure. Though groundwater elevations varied, groundwater depths remained fairly constant in the central IA, regardless of topography;
- Leaving drains in place increased surface water discharge from the IA and lowered IA groundwater levels;
- As simulated, upgradient mining activities had no effect on groundwater levels in the IA at closure (which is consistent with the Site conceptual hydrologic model); and
- The simulated runoff volume and flow rates for the 100-year event decreased at closure, as compared to the current configuration. This decrease, however, was smaller than the simulated decrease in annual runoff for a typical year at closure.

2.3.10.4 Updated 2005 SWWB Model Modifications and Simulation Results

The most recent (2005) changes to the SWWB Model include significantly revised closure configuration surface topography and surface drainage across the Site compared to the original hypothetical cases (i.e., Section 2.3.8). Although the model was updated and several simulations made, this information has not been summarized in any white papers. One reason for this is because of continuously changing closure configuration modifications. Recent changes to the closure configuration are described in Section 2.2. Figure 2.7 shows the change to the surface drainage network compared to the original (2000) drainage network. Much of the IA drainage network is removed, while drainage in the Buffer Zone is mostly unchanged. Figure 2.8 shows five key drainage areas that have been re-engineered. The new drainages are called Functional Channels (FC), and are numbered 1 to 5. Two wetland areas were also engineered in FC-2 and FC-4. The wetlands are elevation-tiered, relatively wide, flat areas separated by berms across the width. The berms have trees planted in them. All of these drainage modifications have been incorporated into the original SWWB model along with modifications to the surface topography.

To assess the hydrologic response over the entire Site due to the recent closure configuration modifications, mostly in the IA, required using two models, the updated SWWB model and the updated IA – VOC flow model. The higher resolution updated IA – VOC flow model was used first to more accurately simulate localized integrated flow conditions for the recent closure configuration modifications, mostly within the IA. Results of these simulations are described in more detail in Section

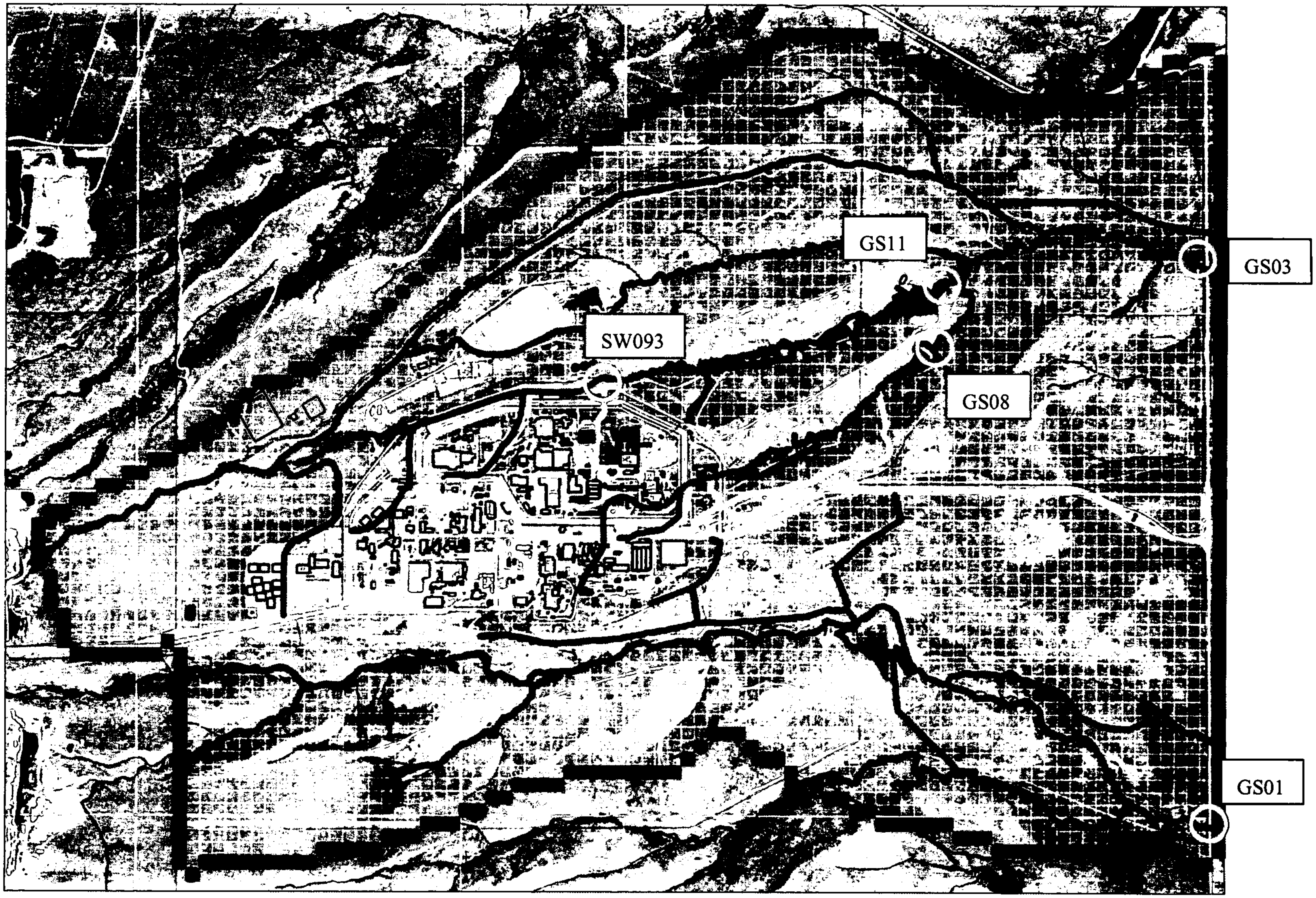


Figure 2.7 Current Proposed (June 2005) Drainage Network (Light blue – existing WY2000 network, Red – Proposed network).

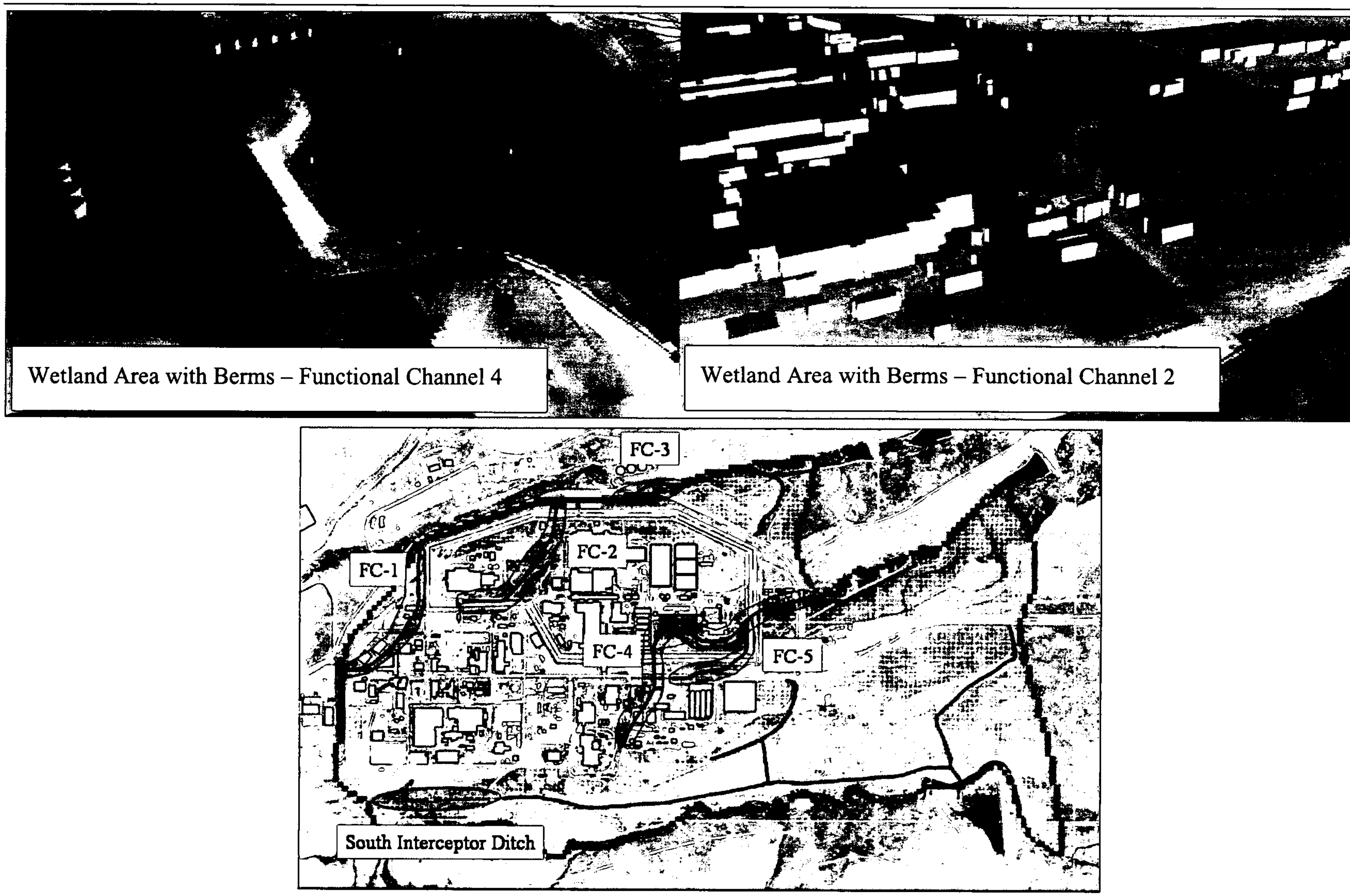


Figure 2.8 Current Drainage Network (June 2005) - Functional Channels and Wetlands (Proposed – Dark Blue, Current (2000) – Light Blue).

2.4.5. The hydrologic response downgradient of the IA (i.e., mostly in the Buffer Zone) was then simulated using the updated SWWB model. Results of this modeling are described in further detail below. Simulated results of the closure configuration using the IA – VOC model were subsequently used as input to the updated SWWB model closure configuration simulations.

Like the original SWWB Modeling Report (K-H, 2002a), results of both the simulated closure surface and subsurface flow conditions downgradient of the IA can be described. However, changes in the subsurface groundwater flow conditions downgradient of the IA are minimal and therefore not described further in this section. Within the IA, changes to subsurface flows are more significant and as such are described later in Section 2.4.5. Because most of the change in hydrologic response downgradient of the IA occurs in surface water flows, only surface water impacts are discussed further here.

Several scenarios were simulated to assess the hydrologic response for the closure configuration, including:

- a typical-year climate sequence (WY2000);
- a wet-year climate sequence (based on 100 years of data); and
- a dry-year climate sequence.

Cumulative annual surface flows at four of the five gaging stations (GS01, GS03, GS11, and SW093), shown on Figure 2.7 for these different climate sequences are summarized on Figures 2.8a through 2.8d. Flows at GS08 (below Pond B-5) and at GS02 (Mower Ditch at Indiana) were negligible and therefore not shown here. Simulated results are compared against annual measured pre-closure configuration flows (i.e., 2000), previous calibrated model flows, and the original SWWB closure configuration. The latter comparison illustrates the change from previous simulated closure condition flows due to updated configuration modifications in the model.

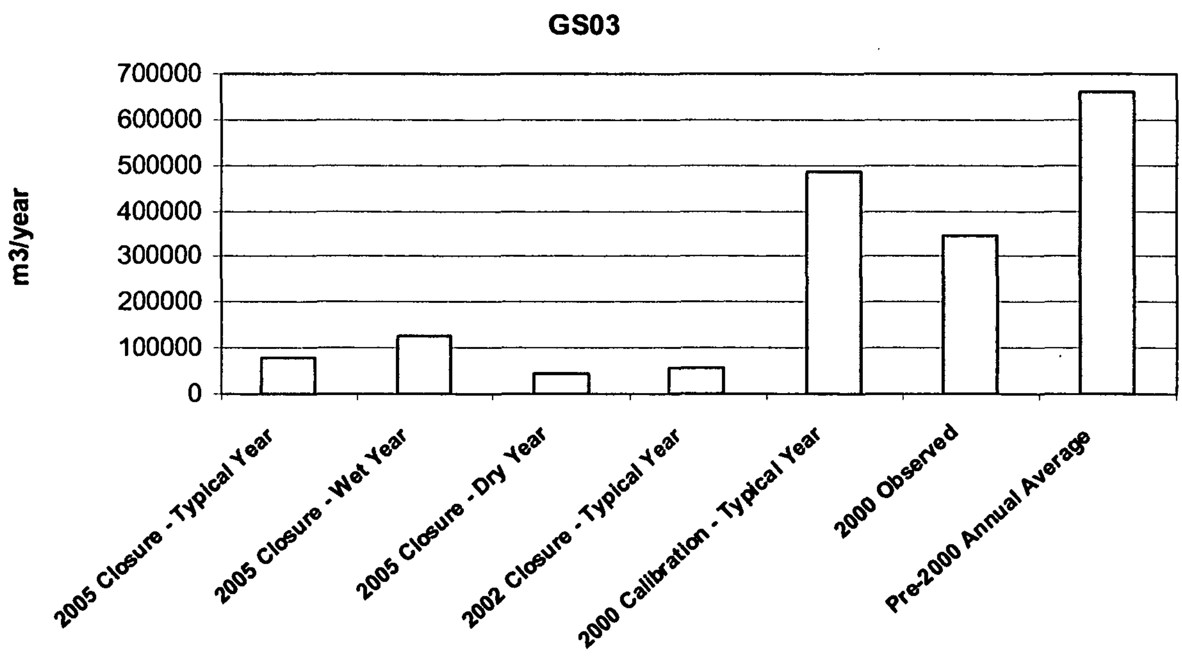


Figure 2.8a Simulated annual surface water flow (m3/yr) at GS03 (Walnut Creek at Indiana).

Simulated annual flows at GS03 (~79,000 m3/year) for a typical climate year (shown on Figure 2.8a) are slightly greater (~37%) than the former 2002 closure configuration scenario, but still significantly lower than pre-closure conditions (observed 330,000 m3/year, and average annual observed 660,000 m3/year). Only one pond release occurs throughout the year from Pond A-4 using current operating protocol (i.e., see original SWWB modeling report for details (K-H, 2002a). The B-pond series do not release, even for a wet year climate sequence (i.e., negligible flows at GS08 gage, immediately downstream of Pond B-5).

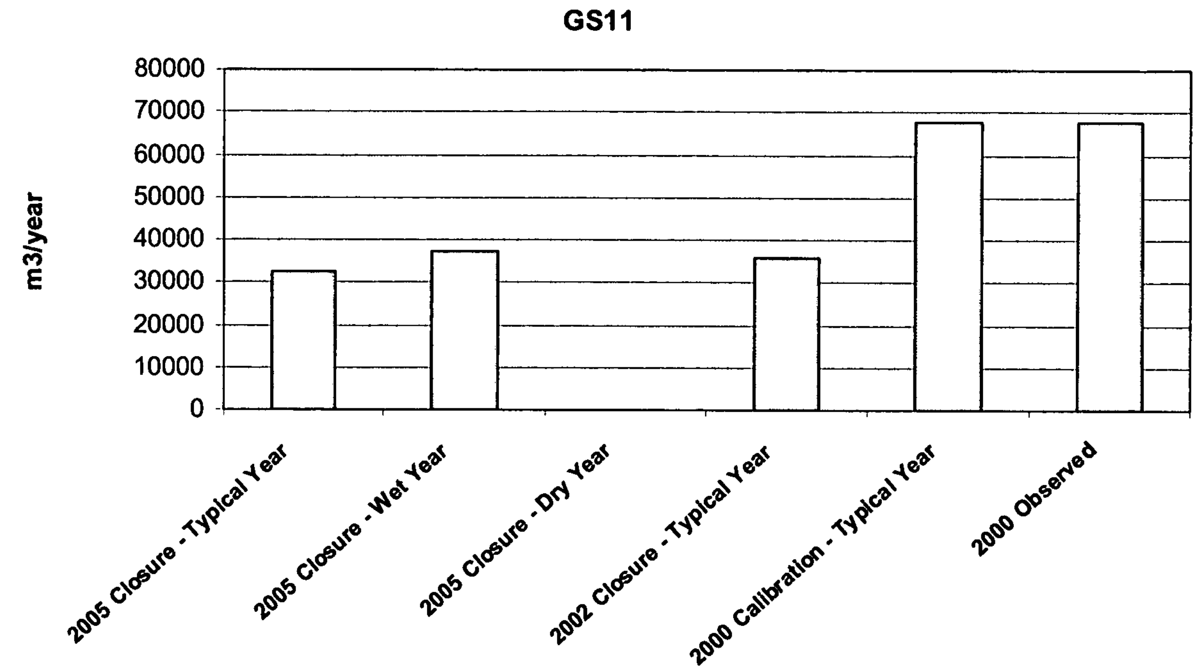


Figure 2.8b Simulated annual surface water flow (m3/yr) at GS11 (Just below Pond A-4).

Simulated annual flows immediately downgradient of Pond A-4 for the updated closure configuration are similar to those estimated for the 2002 closure configuration (Figure 2.8b). Although flows increase only slightly for a wet year, they become negligible for a dry year because inflows to Pond A-4 do not cause pond levels to trigger a release. Much of the inflow to the A-pond series is from the North Walnut Creek drainage, which was not modified significantly in the updated closure configuration, except for a slight rerouting of the channel near SW093 (i.e., FC-3 area shown on Figure 2.8).

The updated closure configuration had only a minor effect on simulated flows at the SW093 gage on North Walnut Creek as shown on Figure 2.8c compared to previous closure simulations in 2002. This is because inflows from FC-1 and FC-2 only constitute a small fraction of the total flow in North Walnut Creek. Flows are slightly lower than the previous closure simulation in 2002, but that are still more than three times lower than the pre-closure configuration. The notable decrease in flows from pre-closure conditions is due to the removal of footing drains and pavement within the IA.

Simulated annual flows in Woman Creek at Indiana (GS01) do not change significantly due to the updated closure configuration. The only significant change to the Woman Creek drainage was the removal of part of the South Interceptor Ditch in the area of the Original Landfill, and removal of the storm drain discharge from the former Building 460/444 area (i.e., drainage at former GS22 gage). The change in groundwater flows due to these updates is negligible compared to the total surface flow in Woman Creek. Therefore, the change in surface flow response in woman Creek (and GS01) is negligible.

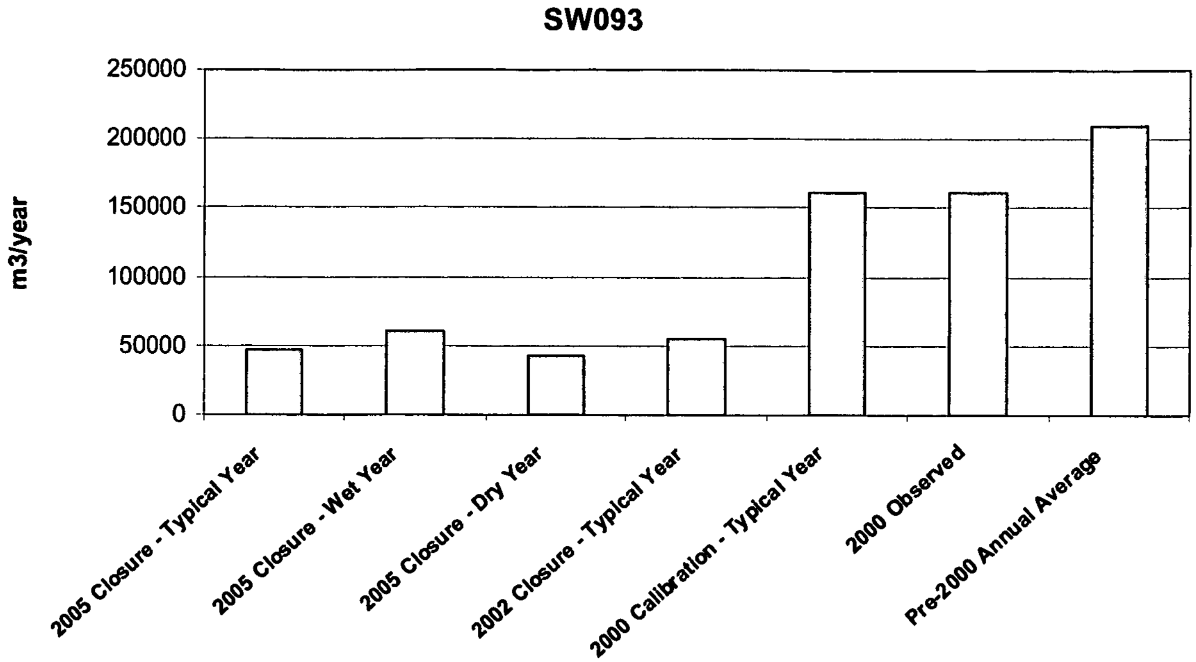


Figure 2.8c Simulated annual surface water flow (m3/yr) at SW093 (North Walnut Creek).

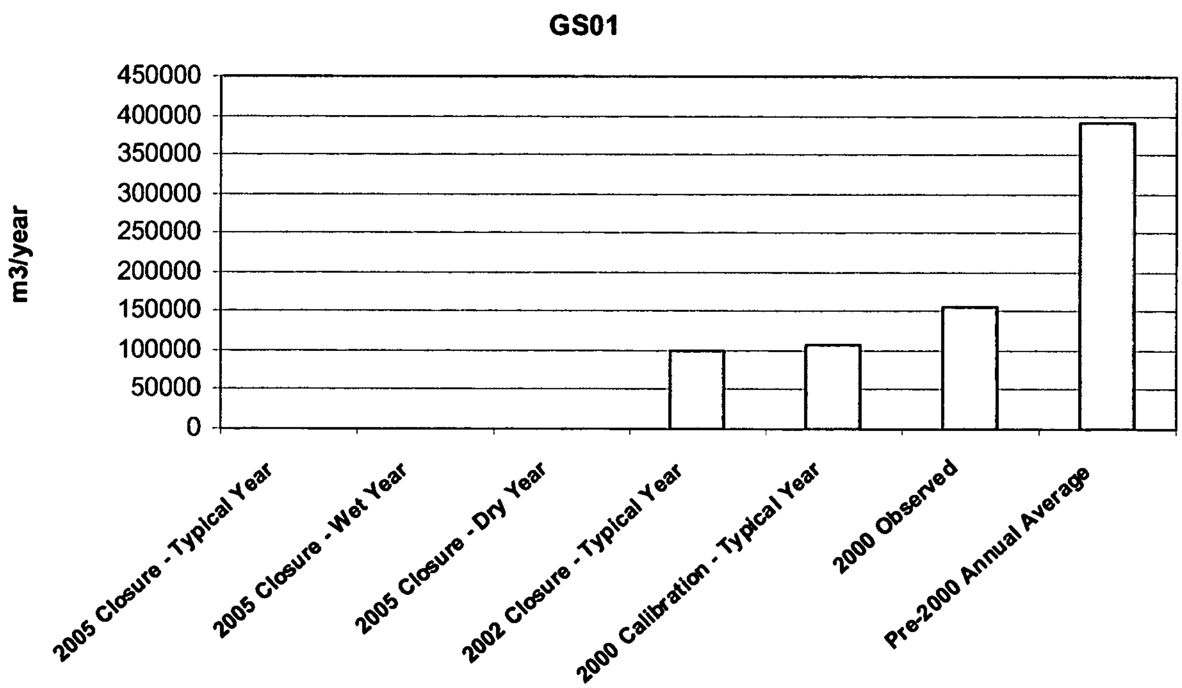


Figure 2.8d Simulated annual surface water flow (m3/yr) at GS01 (Woman Creek at Indiana).

2.4 IA – VOC Flow Model

Following development of the SWWB model, a more refined, local-area integrated flow model was developed in 2003 to support decisions about the fate and transport of VOCs in groundwater for the Comprehensive Risk Assessment (CRA) in the Site Remedial Investigation/Feasibility Study (RI/FS). The development and results of the IA VOC flow model are summarized in this section. Long-term, three-dimensional groundwater flow conditions from the IA VOC model were subsequently used in fate and transport modeling. Results of the reactive fate and transport model are described in more detail in Section 3.0.

The modeling scope considered in this study is described in Section 2.4.1. The approach, though similar to that used for the SWWB model, was more involved, and is discussed in Section 2.4.2. Current condition (2000) and proposed closure configuration simulation (proposed configuration in 2003) results are presented in Sections 2.4.3 and 2.4.4, respectively. The most recent (June 2005) updates to the IA VOC flow model are presented in section 2.4.5.

2.4.1 Modeling Scope

The modeling scope included the following steps:

- collected, synthesized, and reviewed all historical VOC data;
- developed a flow and transport model of historical conditions to determine appropriate parameter values; and
- developed a flow and transport model to predict long-term (or probable maximum) groundwater VOC concentrations for a proposed closure configuration that could discharge to surface water.

The modeling scope included simulation of saturated zone transport only within unconsolidated material and weathered bedrock that define the Upper Hydrostratigraphic Unit (UHSU) at RFETS. The integrated flow model boundary is shown relative to the SWWB model boundary on Figure 2.1. VOCs in the UHSU do not migrate downward through the much lower permeability unweathered bedrock of the Lower Hydrostratigraphic Unit (LHSU) and into the underlying regional Laramie-Fox Hills Aquifer (RMRS, 1996).

Simulation of VOC fate and transport within the unsaturated zone or surface streams was not considered in this study. Surface water impacts from groundwater VOCs were not modeled or assessed. The scope also did not include the simulation of the fate of any contaminants other than VOCs. Rather than simulating the fate and transport of total VOCs in groundwater, individual VOCs were modeled because differences in their chemical properties cause them to transport at different rates. Finally, this study did not evaluate the performance of current groundwater plume treatment systems.

VOCs associated with the PU&D Yard Plume, south of the Present Landfill, were not considered in this modeling. They were addressed in separate reports.

2.4.2 Modeling Approach

The approach used to develop flow and transport models involved several steps. First, historical VOC groundwater concentration data were collected and analyzed. Then Historical Release Report (HRR) information was evaluated and incorporated into a database/Geographical Information System (GIS) so this information could be further assessed in conjunction with available hydrologic and hydrogeologic information to identify possible groundwater VOC sources. Using the GIS, observed groundwater VOC concentration data were spatially linked with historical release information to identify likely sources. In general, VOCs detected in the greatest number of groundwater sample locations exhibited the highest concentrations. A total of 19 VOC-impacted areas, referred to as plume signature areas (PSAs), were identified where at least one source explained a group of associated groundwater concentration sample locations. PSAs represented an attempt to identify approximate, but distinct, source-plume areas. As such, PSA delineations were estimated due to uncertainties in VOC source information and the complexity of historical groundwater flow pathways. Further discussion of the differences between PSA delineations and current VOC concentrations is presented in the Groundwater Interim Measure/Interim Remedial Action (GW IM/IRA) report (K-H, 2005).

Available data and groundwater flow directions suggest that most PSAs extend to, or near groundwater discharge areas. Moreover, relatively steady VOC concentrations in time observed at most sample locations suggested that PSAs have probably reached stable configurations, though some areas may still be developing (i.e., 903 Pad area). The steady well concentration trends also suggested that VOC sources have probably reached steady concentrations in time. Non-aqueous phase liquid (NAPLs) VOC sources typically produce constant long-term, dissolved phase concentrations in groundwater.

Primary VOCs considered in this study were tetrachloroethene (PCE), carbon tetrachloride (CCl_4), and their daughter products. Successive daughter products of PCE include trichloroethene (TCE), cis-1,2-dichloroethene (cis-1,2-DCE), and then vinyl chloride (VC). Successive daughter products of CCl_4 include chloroform (CCl_3) and then methylene chloride (CCl_2). The occurrence of both parent and daughter product VOCs within most PSAs suggested that biodegradation occurs at RFETS, though an independent study suggested rates are variable but low throughout the model area. Additional evidence suggested that TCE occurred as a source in several areas, though it is probably also a degradation product of PCE.

Draft 2004 CRA surface water PRGs, which define the relative risks associated with each VOC, were used as the basis for determining whether individual PSAs would be modeled. The total number of PSAs modeled was reduced to nine for PCE, 10 for TCE, and seven for CCl_4. Later, the long-term fate and transport of PSA source areas were reassessed to surface water standards. In some cases this required modeling PSAs originally screened out. Details and simulation results for these models are described further in Section 3.0 below.

2.4.3 Modeling Results - Current Conditions

The current distribution of VOCs for each PSA was evaluated using a groundwater flow path analysis and a sensitivity analysis of reactive transport for the PCE and CCl_4 degradation chains. Iterative groundwater flow path analysis was conducted for eight different model areas (at least one PSA in each model). The results confirmed initial assumptions about possible VOC source locations, the number of sources, timing of sources, and groundwater pathways and travel velocities. Results showed that it was reasonable to assume groundwater sources were introduced approximately 30 to 50 years ago. HRR information supported this conclusion. Flow path analysis resulted in 22 different source areas that explained concentration distributions in the 19 separate areas. Several conclusions were made from the reactive transport sensitivity analysis conducted for each PSA model (13). Many factors affected the fate and transport of VOCs from source release time to present.

The most important included:

(1) hydraulic conductivity;

(2) depth of source introduction; and

(3) biodegradation rates.

Factors such as sorption, dispersion, source concentration, diffusion, and porosity affected the fate and transport less significantly. The range of effective source concentrations and source depths, determined through this modeling, reproduced the range of historical time-averaged concentrations within each PSA for both parent and daughter VOCs.

Modeling showed that three-dimensional groundwater flows were important in supporting a detailed flow and transport model for the Site. Groundwater flows downward in upper mesa areas, but then flows upward near the bottom of hillslopes or streams due to the hillslope structure. This is important in the conceptual model because slower flow rates from sources allow for more efficient degradation (mostly within bedrock) before it eventually emerges at stream areas. Because ET dominates near-stream hydrology at RFETS, model results indicated increasing amounts of VOCs in groundwater were lost via ET near streams. This loss to ET was significant because it helped attenuate VOCs in groundwater within most PSAs before discharging as base flow to streams, seeps, ponds, or overland flow.

2.4.4 Model Results – Proposed Closure Configuration

Proposed land configuration modifications (2003 – 2004) were simulated in the local-scale integrated flow model for the IA. The integrated modeling produced a three-dimensional flow field for reactive transport modeling of the closure configuration and was used to identify areas where groundwater discharged to the land surface within the model boundary (Figure 2.9). Discharge frequency and rates were also calculated by the model, but the model was not used to estimate groundwater discharge to streams along North Walnut, Woman Creek, or South Walnut in the B-Pond area. The SWWB model was used to predict actual discharge locations, rates, and frequency in these areas, but the original SWWB closure scenario configuration was modified to reflect the updated proposed land configuration.

Simulated closure-condition groundwater flow velocities changed little from the 2002 SWWB configuration primarily because the strong influence of the hillslope morphology (surface and bedrock topography) doesn't change significantly in the closure configuration. The largest change in flow direction occurred near buildings with deep foundations where footing drains were assumed to be disrupted (B371, B771, B881, and B991); along South Walnut Creek east of B991; and where the proposed channel was re-engineered to eliminate roadways, fenced areas, and associated culverts. Local flow directions near the current Mound Plume Groundwater Treatment System changed notably due to this proposed reconfiguration.

Simulated closure-condition groundwater levels increased throughout the model area due to the proposed land reconfiguration. Results indicated that groundwater seepage, or base flow occurs throughout the year in three of the four modified IA streams (FC 2 – between B371 and B771, FC 4 – south of B991, and in FC 1 - west of B371). Simulated minimum annual groundwater depths for a typical annual climate sequence (WY2000) are shown on Figure 2.10. Seepage areas are depicted by green areas.

The most sensitive transport model parameters were adjusted to produce a range of simulated concentrations that bracketed the distribution of observed time-averaged VOC concentrations within each PSA. This same range of parameter values was then used to simulate multiple closure configuration reactive transport model simulations and to estimate a range of possible groundwater concentrations at groundwater discharge areas. Simulations were run long enough to produce steady concentrations at groundwater discharge areas.

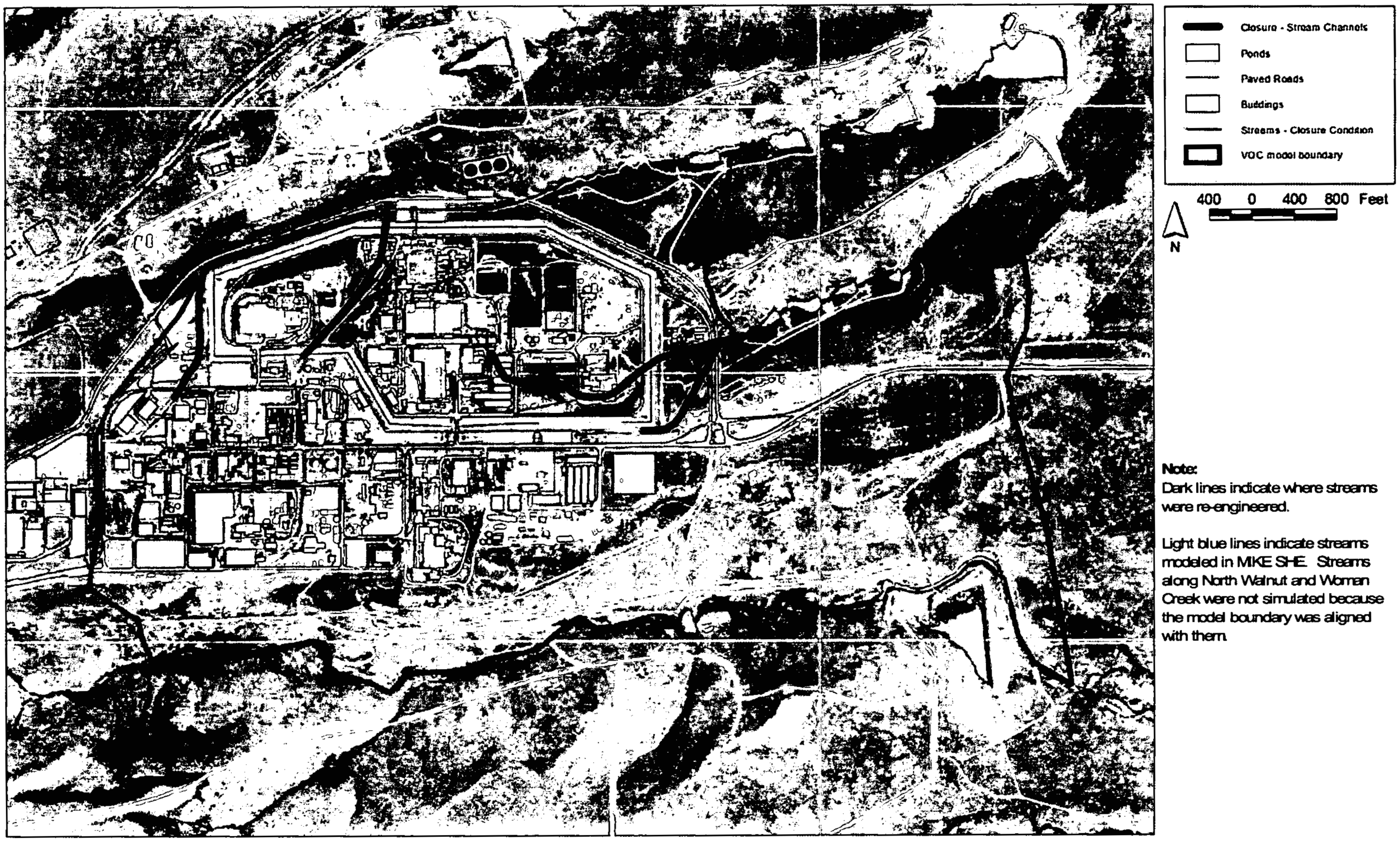


Figure 2.9 Updated IA VOC model surface stream routing - Simulated closure configuration (2003-2004).

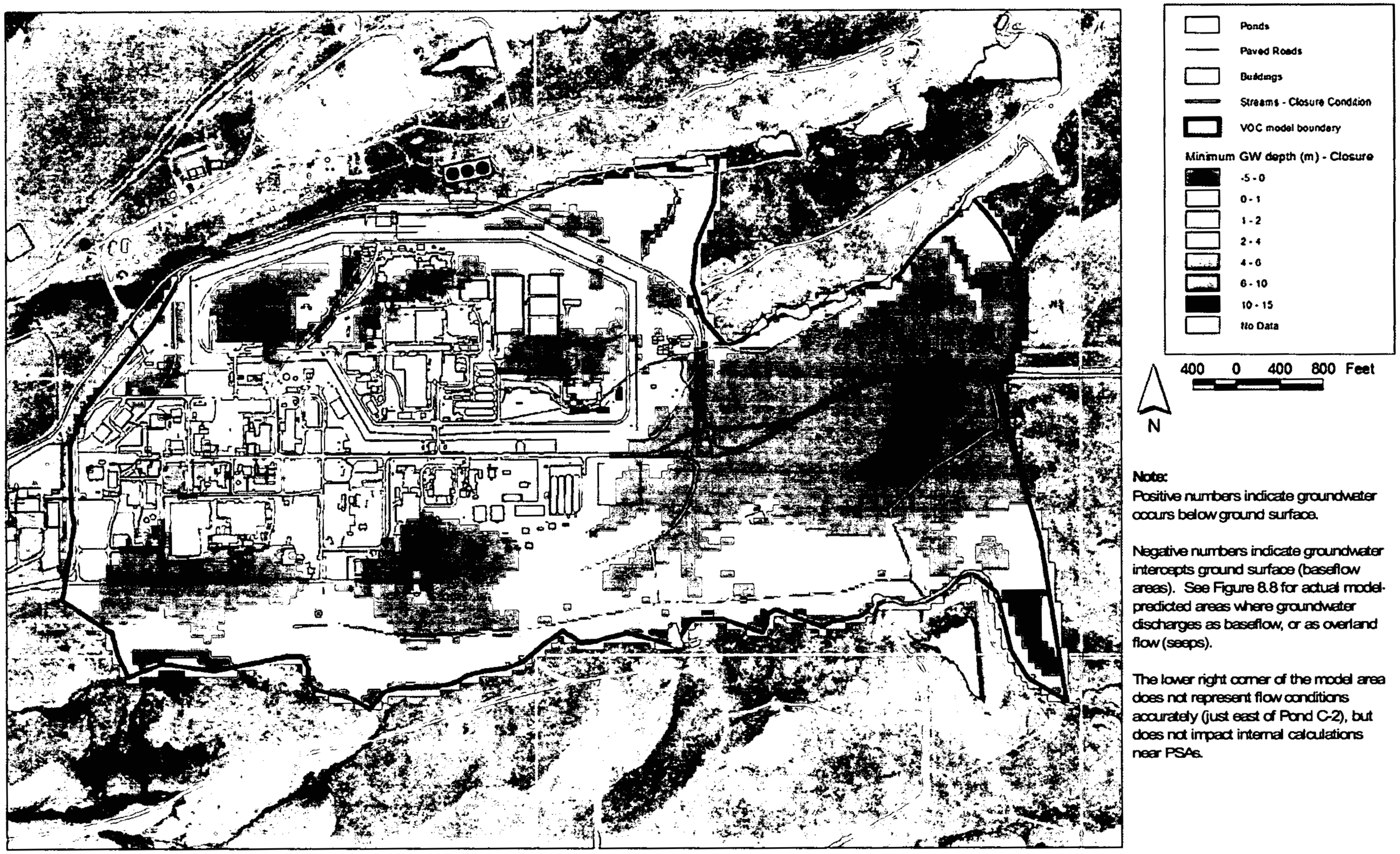


Figure 2.10 Simulated minimum annual groundwater depths (m) – typical climate (WY2000) - 2003-2004 closure configuration.

In four of the eight PSAs modeled, at least one of the closure-condition simulations produced long-term groundwater concentrations for TCE or CCl_4 that were above the draft surface water PRGs at groundwater discharge areas. These PSAs include:

- the East Trenches area;
- the Oil Burn Pit/Mound area;
- B771; and
- Ryan's Pit/903 Pad area.

Of these areas, only B771 had average groundwater concentrations (for all closure-condition simulations) below draft 2004 PRGs at groundwater discharge areas.

Closure-condition integrated flow modeling results indicated that groundwater discharged to several areas. Groundwater discharged to the surface drainage west of the former B771 due to shallow bedrock and the Arapahoe Formation "No. 1 Sandstone" (herein referred to as Arapahoe Sandstone) in the area. Although the Arapahoe Sandstone is only present as shallow, discontinuous lenses throughout the model area and has no connection to the much deeper regional confined aquifer (i.e., Laramie/Fox Hills Aquifer), it is more permeable than the surrounding claystone/siltstone matrix and controls local groundwater flows. For a typical climate, some simulated groundwater discharged into the South Walnut Creek drainage north and downgradient of the Mound Plume Groundwater Treatment System. The discharge area increased during precipitation events. Southeast and downgradient of the Ryan's Pit area, groundwater discharge was also simulated to the South Interceptor Ditch and Woman Creek, but only during larger precipitation events. The integrated flow model did not simulate groundwater discharge to south Walnut Creek, though this probably occurs, for example to Pond B-2.

In general, simulated results indicated that only parent compounds CCl_4 and TCE were above draft 2004 PRGs at groundwater discharge areas. All other daughter products and PCE did not. For the other PSAs not listed above, simulated groundwater VOC concentrations in groundwater discharge areas for closure simulations were below the draft PRGs. This is due to a combination of the following:

- slower groundwater velocities in bedrock (caused by typically unsaturated unconsolidated material in upper hillslope areas);
- the simultaneous combined effect of attenuation processes (such as biodegradation, sorption, volatilization, and ET loss) reduced VOC concentrations in groundwater discharge to surface areas; and
- loss through volatilization (not simulated with the reactive transport model but results in conservatively high concentrations).

In most PSAs, the dominant attenuation process was a combination of biodegradation and ET loss. The percentage lost to ET increased in eastern PSAs (i.e., southeast of the 903 Pad area and in the East Trenches area). Although, parameter values for each closure configuration model were able to bracket the range of observed time-averaged concentrations, some combinations underestimated concentrations, while others over-predicted them. In the latter case, simulated long-term closure concentrations are likely over-predicted in groundwater discharge areas. As such, a single run should not be considered to be an accurate representation of closure concentrations, or even the most reasonable. Rather, the range of predicted output should be used in assessments.

2.4.5 Updated IA VOC Flow Model

Recent updates to the closure configuration (as of June 2005), summarized in Table A.1 (Appendix A), were incorporated into the IA VOC flow model. Details of the closure configuration changes are presented in Section 2.3.10.4. These recent modeling results were not summarized in a separate white paper, but results have been used in more recent local fate and transport models (i.e., see Section 3.0). The fate and transport of VOCs in more recent models were assessed against surface water standards, rather than the PRG values. The same closure configuration updates to the SWWB model (i.e., shown on Figures 2.7 and 2.8) were made to the IA VOC flow model. In addition to changes in the surface regrade and drainage networks, several of the other modifications outlined in Section 2.2 have also been made.

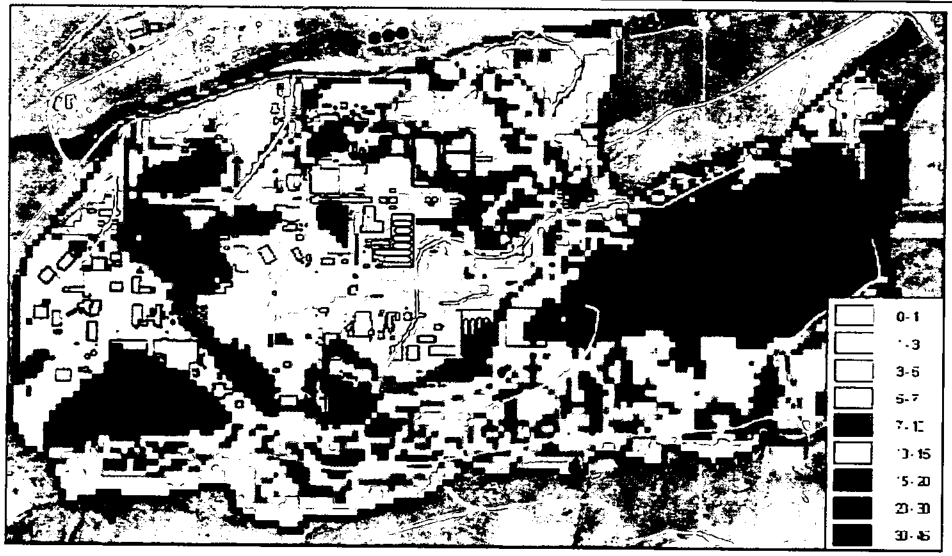
Recent modeling simulation results are graphically illustrated on Figures 2.10a through 2.10e. Simulated average and minimum annual groundwater depths are shown on Figure 2.10a. Results show that groundwater depths in several areas of the IA will be less than 1 meter below grade. This is mostly in response to shallow bedrock. Shallow depth areas include the central IA (along former Central Avenue), FC-1, FC-2 and FC-4, and other hillside areas (i.e., north of former B371) where the final regrade decreased the thickness of unconsolidated materials. The former central avenue area, just south of former B707, appears to revert back to the former pre-1950 riparian area based on a 1937 aerial photo of the Site. Overland flow from groundwater discharge in this area flows into the South Walnut Creek drainage. The areal extent of the shallow groundwater increases for precipitation events as shown for the minimum annual groundwater depth plot. Darker blue areas associated with former deep-basement buildings (i.e., 991, 771, 371 and 881) do not depict accurate depths because groundwater flows are not simulated in these areas (external flows see these basement structures as barriers and flow around them).

The simulated change in groundwater levels from the former pre-closure configuration (i.e., 2000 configuration) is shown on Figure 2.10b. Results indicate that levels mostly increase throughout the central IA, but in some areas decrease. The increase is due to a combination of factors that include a change in ground surface topography, removal of pavement, and subsurface drains. The decrease is mostly attributed to removal of leaky water supply lines and topographic surface modifications (i.e., borrow areas).

Simulated groundwater discharge locations and annual rates are illustrated on Figure 2.10c. Groundwater discharge includes both baseflow into streams, and seep flow in areas not associated with streams. Results indicate that baseflow discharge is most significant in FC-2 (some cells discharge between 10,000 and 100,000 gal/year), and to a lesser extent in FC-1 and FC-4 (annual discharges between 250 and 10,000 gal/year). Some baseflow occurs along the SID, but rates are generally low less than 1000 gal/year). Groundwater also discharges along the East Trenches Groundwater Collection System trench (mostly between 1000 and 10,000 gal/year), and from the SW091 drainage. Simulated seepage only occurs in the area west of FC-4 (South Walnut Creek) in the central IA, and in the borrow pit area associated with FC-1, just west of B371. Simulated rates are much lower than baseflow areas (mostly less than 250 gal/year).

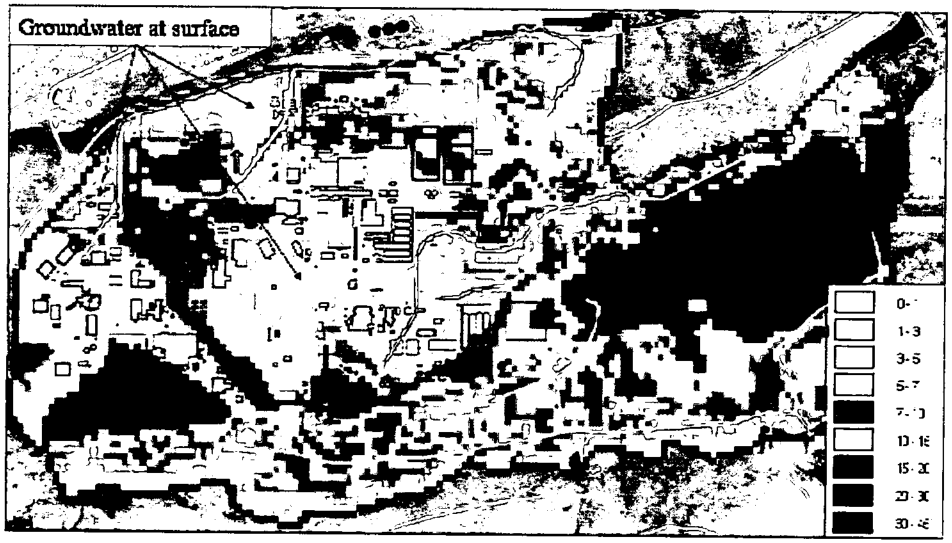
Results of simulated surface water flows at four locations within the IA are presented on Figures 2.10d and 2.10e. A diagram showing the locations of the four locations is included on Figure 2.10d. Simulated flow conditions at Functional Channel 1 and 2 are included on Figure 2.10d, while GS10/Functional Channel 4 and SW027 results are presented on Figure 2.10e.

Results indicate that surface flow from FC-1 will be minimal during a typical year climate (i.e., well below 1 gpm, or ~110,000 gal/year). Ultimately this may be entirely lost to ET as vegetation develops in the area. Simulated flow from FC-2, before it reaches North Walnut Creek, also appears minimal (~180,000 gal/year) compared to the pre-closure



Simulated average annual groundwater depths (feet below ground surface)

Note: Groundwater levels are simulated throughout the model area at 6 hour intervals continuously for a year. Results shown here represent the 'average' depth in time at a given location.



Simulated minimum annual groundwater depths (feet below ground surface)

Figure 2.10a Simulated groundwater depths (ft) – typical climate (WY2000) - 2005 closure configuration.

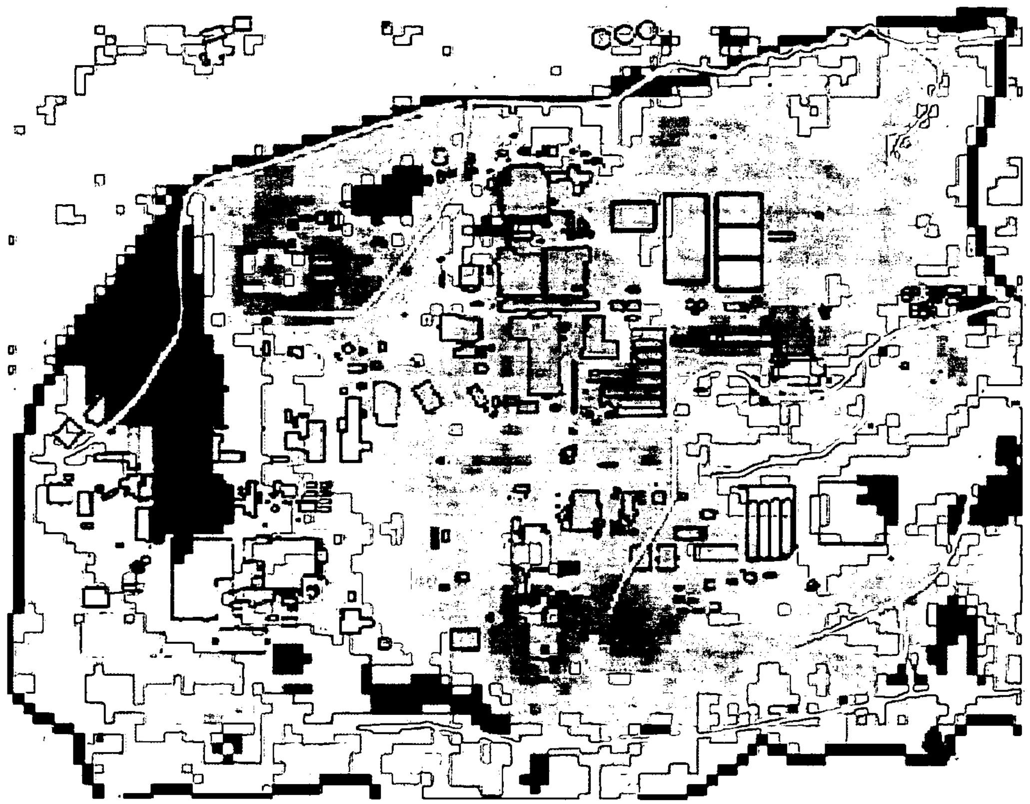


Figure 2.10b Change in simulated groundwater elevations(ft) –(2005 closure configuration – 2000 'current' configuration).

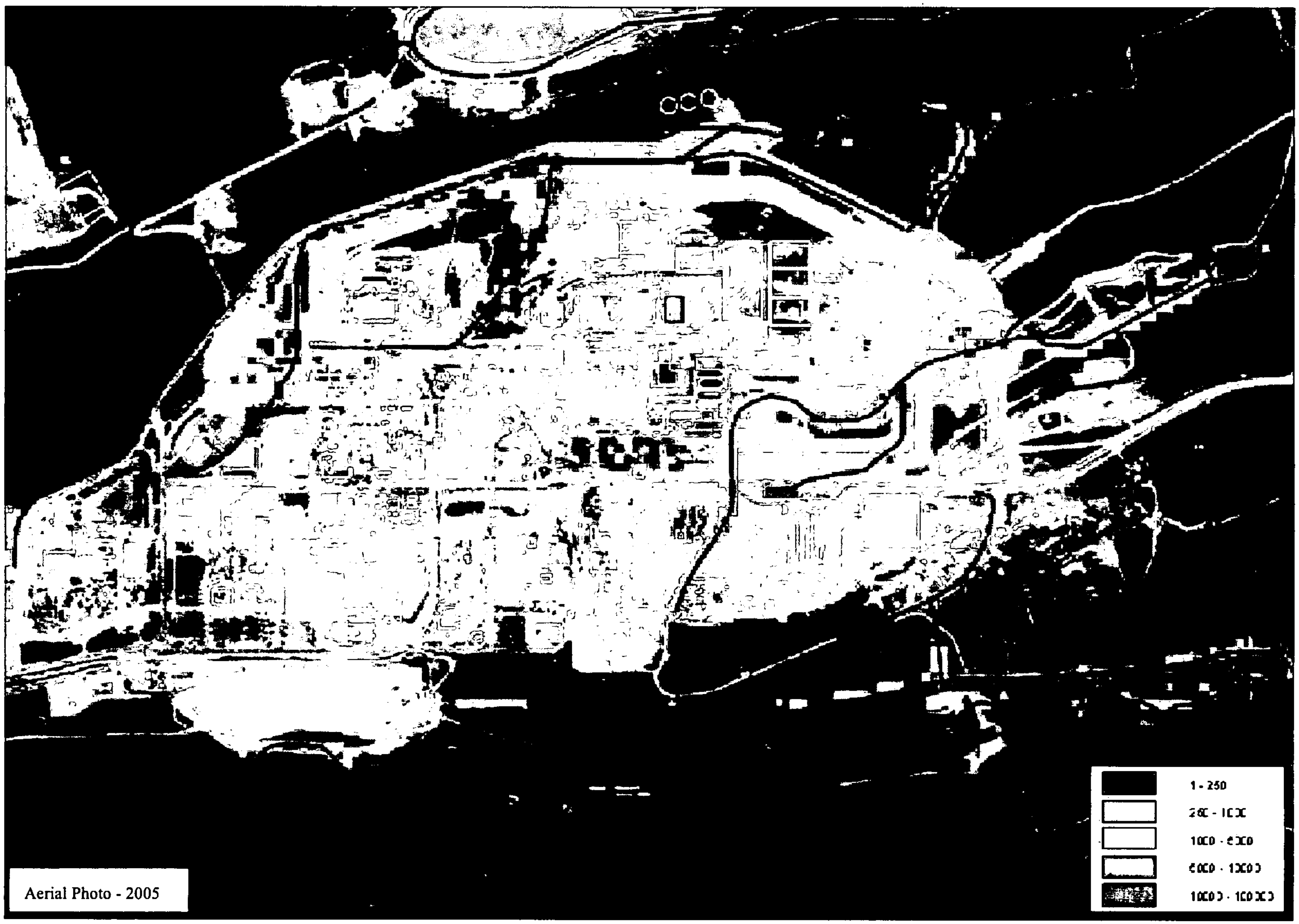


Figure 2.10c Simulated Annual Groundwater Discharge to the ground surface (seeps and baseflow) – units are gallons/year.

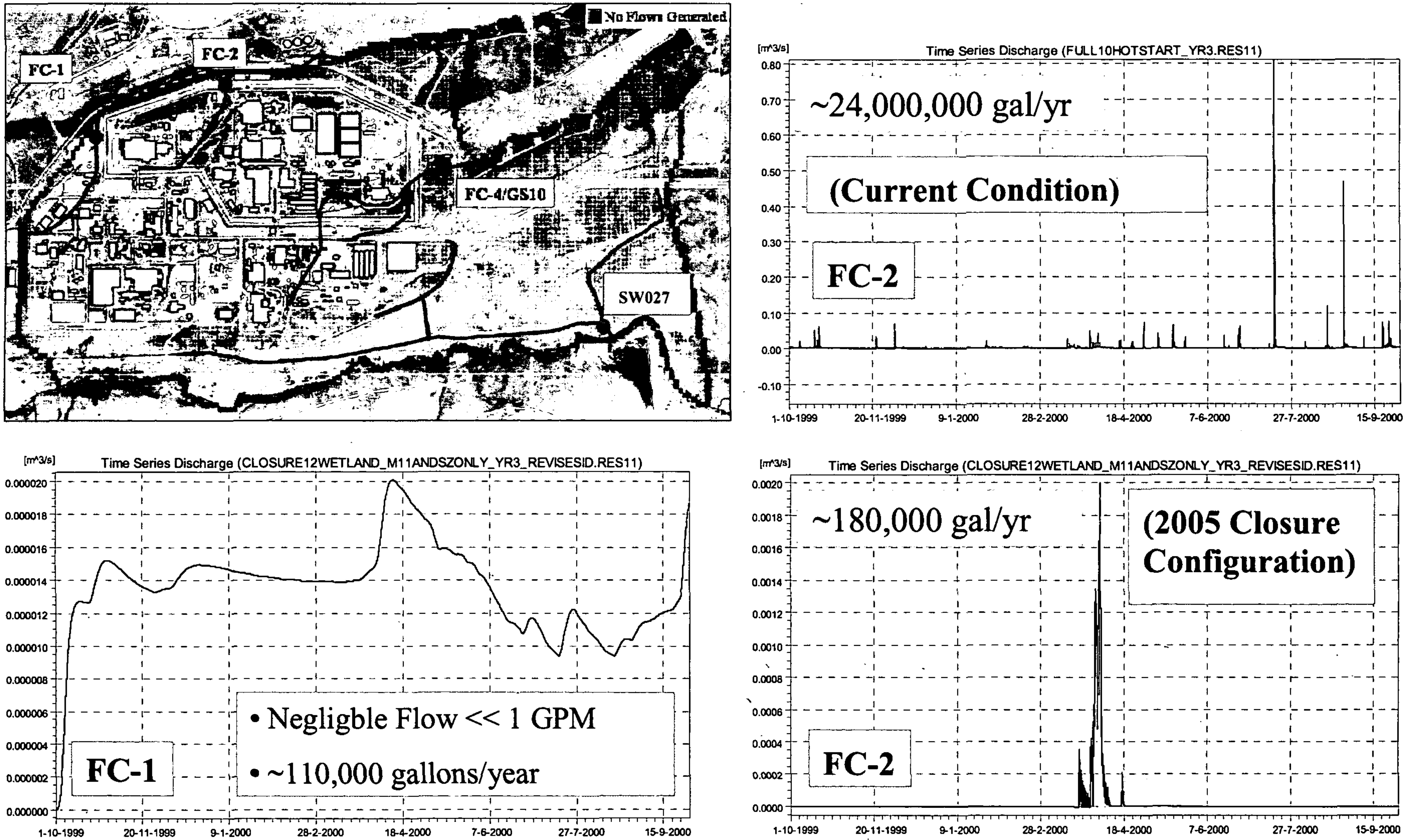


Figure 2.10d Simulated surface flows (m3/yr) at FC-1 and FC-2 – typical climate (WY2000) - 2005 closure configuration.

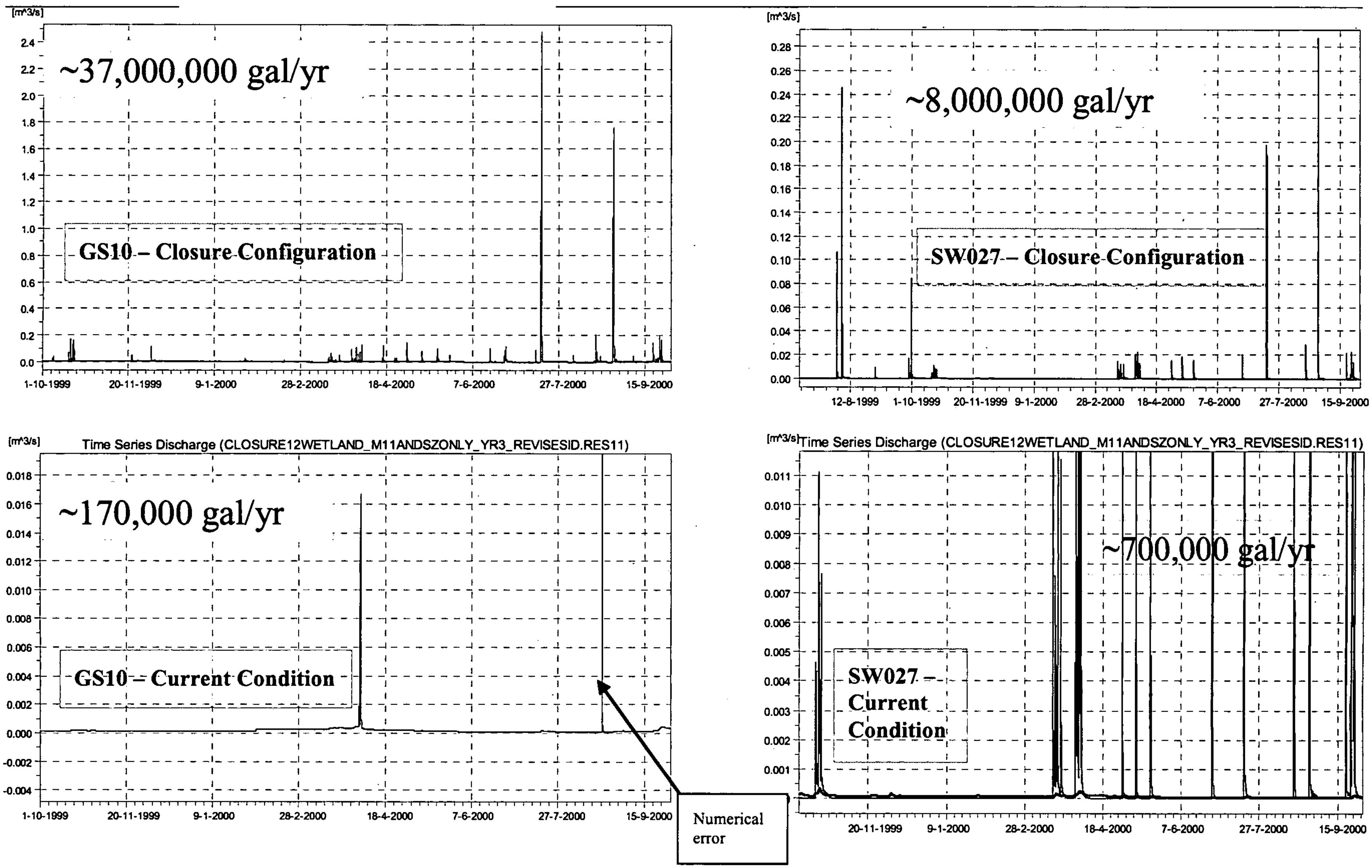


Figure 2.10e Simulated surface flows (m3/yr) at GS10 and SW027 – typical climate (WY2000) - 2005 closure configuration

configuration (~24 x 10e6 gal/year and ~5 gpm baseflow). This represents a decrease of about 99%. In addition, flows only occur during a larger spring rainfall event which tops the wetland berms. In reality, when wetland vegetation fully develops, it is not likely that any surface flow from Functional Channel 2 will contribute to the North Walnut Creek drainage.

Results of the simulated surface flow response at GS10 (i.e., Functional Channel 4) is shown on Figure 2.10d. As in the case of Functional Channel 2, flows in the South Walnut Creek drainage at GS10 are also greatly reduced (from ~37e10^6 gal/year to about 170,000 gal/year, or a ~96% decrease). Again, once vegetation becomes fully established in the drainage and along the berms, all flows upstream of the wetland are likely to cease contributing to flows downstream into the B ponds. These results are actually similar to the previous closure configuration simulations (2002 closure configuration in SWWB model), but are lower (i.e., annual flow is ~75% of previous estimates). Although not simulated in the flow model, it is possible that certain rain-on-snow events, where direct infiltration limited by frozen soils causes an increase in surface runoff, may produce a fast-runoff response that increases channel flows compared to these estimates.

Simulated surface flow results for the SID at SW027 are summarized on Figure 2.10e. Results indicate that flows decrease to less than 10% of pre-closure values (from ~8e10^6 gal/year to about 700,000 gal/year). No baseflow is simulated in the closure configuration, but this is similar to that observed for the pre-closure case, where flows only in response to larger precipitation events. In fact, the annual flows are similar to the previous closure configuration simulations in 2002 for the SWWB modeling report (K-H, 2002a).

2.5 Landfill Models

Fully integrated flow models were developed for both the Present and Original Landfills at RFETS. Model boundaries are shown on Figure 2.2.

The purpose of each model was similar:

- demonstrate an understanding of current flow conditions in the model area;
- evaluate closure configuration hydrologic response – mostly groundwater, but also affected by unsaturated zone and overland flow response; and
- form the basis for subsequent fate/transport modeling.

Much of the information from the original SWWB model was used in developing the landfill models, and many parameters did not require recalibration. Some model parameters, however, had to be adjusted during local-calibration to improve the ability of the model to capture more localized hydrologic response not previously captured in the more regional SWWB model.

2.5.1 Present Landfill Model

Information for the Present Landfill modeling project was derived principally from available reports in the Environmental Restoration (ER) library, site-wide well data, and the data collected for the SWWB (K-H, 2002a). A background on available landfill-related data and history is presented in Section 2.0, while available data and their interpretation used to develop an integrated conceptual flow model for the landfill are presented in Section 3.0. From the compiled information, a conceptual model of the hydrologic system at the Present Landfill was constructed and is presented in Section 4.0.

In 2003, a numerical model was constructed using the integrated flow code MIKE SHE using an approach similar to the SWWB model (Section 2.3.2). The numerical model area included the entire Present Landfill area, upgradient and downgradient areas (see Figure 2.2). Geologic surfaces for the top and bottom of the weathered bedrock zone were interpreted based on the most complete compilation of historical boring information to date. Extent and thickness of the waste material from previous work was incorporated into the model. In addition, key landfill control structures including the Groundwater Intercept System (GWIS), clay barrier, Landfill Drain (LD), and slurry walls were also incorporated into the model design. Published vegetation distributions for the 1993 to mid-1995 and 2000/2001 time periods were (K-H, 2002a) converted into hydrologically-significant categories and used in the model for calibration and model validation. The REF-ET Program (Allen, 2000) was used to calculate the PET using the FAO56 version of the standard Penman-Monteith equation for 1993 and 1994 Site climatic data.

The model was calibrated using data for the 1993 to mid 1995 period. This period was chosen as this was the latest historical period of water level measurements within the Present Landfill boundary and the Spring 1995 was an extremely wet period with substantial system response. Model calibration focused on matching average 1994 groundwater levels, timing and magnitude of system response at wells, and the seep flow at SW097.

Following model calibration, a sensitivity analysis was conducted to establish which model parameters dominate the hydrologic flow response for the Present Landfill system. Model sensitivity to hydraulic conductivity, leakage coefficients, landfill material properties, and pond water levels was evaluated for seep flow, modeled GWIS discharge, and groundwater levels.

The model was run for a validation period of WY2000 with the topography modified to the current land surface at the landfill and the vegetation coverage revised to reflect that the landfill area had been reseeded in 1998. The model was found to be sensitive to the WY2000 climate change and vegetation changes but simulates system response reasonably well.

In a fashion similar to the SWWB modeling (Section 2.3.8) a hypothetical scenario was run to evaluate the possible impacts of a potential closure scenario for the Present Landfill. This scenario modified the surface in the landfill area by adding 0.3 m of cover material and having the landfill area be fully vegetated with mesic vegetation. This simulation was compared to a simulation with the landfill not having the additional cover and less established vegetation. These simulations were run for the calibration model climate years of 1993 and 1994. An additional run was performed with the wet-year precipitation from the SWWB (K-H, 2002a) to evaluate impacts of a wetter climate on the landfill system.

2.5.1.1 Key Findings

The primary purpose of developing a flow model was to better understand the past, current, and possible future integrated hydrologic conditions to support a detailed water quality analysis in the Present Landfill area. The amount of modeling output generated through development and application of the integrated Present Landfill model is substantial and provides new insight into the integrated and dynamic hydrologic behavior within and surrounding the Present Landfill area. Key findings include the following:

- The calibrated integrated model reproduces observed annual landfill seep (SW097) flow location and discharge, and key spatial and temporal well water level response to annual recharge events and ET reasonably well;
- The model shows that observed seep flow and water level data are best simulated when the landfill trench system (i.e., GWIS, clay barrier, and LD) was assumed to be functional;
- Modeling showed that groundwater interior to the trench system flows outward to the landfill drain and is then routed toward the former west landfill pond area. Exterior groundwater was intercepted by the GWIS and directed away to either the landfill pond, or No-Name gulch. The clay barrier prevented exterior and interior flows from mixing;
- The model showed that water in the landfill waste material is derived mostly from direct recharge of precipitation over the waste material (greater than 90 percent), rather than lateral or vertical groundwater inflow;

- Seep flow at SW097 was most sensitive to the hydraulic conductivity of the waste material and the other unconsolidated material, the hydraulic conductivity of the LD drainage material, and the hydraulic conductivity of the weathered bedrock. Modeling results also showed subsurface water in the footprint of the landfill system, upgradient of the seep, discharging to the seep, or pond, regardless of whether the landfill trench system was functional;
- In a hypothetical scenario where additional cover material and fully developed vegetation were assumed, modeled seep flow was reduced by approximately 10 percent compared to the baseline scenario (i.e., current landfill configuration and WY2000 climate). In a comparably wet-year, seep flow increased by approximately 10 percent, while mean modeled groundwater elevations in the landfill increased by 0.1 m.; and
- In another hypothetical scenario where recharge within the landfill clay barrier and slurry walls was reduced by approximately 90 percent, modeled seep flow was reduced by approximately 25 percent over a 2.5-year period due to a reduction in saturated zone storage. Lateral subsurface flow into the landfill area was still small but increases as a result of increased gradients across the landfill trench. Mean modeled groundwater elevations in the landfill decreased by 0.5 m.

Additional details can be found in the Final Present Landfill Interim Measure/Interim Remedial Action Decision Document (K-H, 2004).

2.5.2 Original Landfill Model

Development and results of integrated flow and VOC fate and transport modeling to support the Original Landfill (OLF) IM/IRA document were described in the report entitled "Draft Interim Measure/Interim Remedial Action for the Original Landfill (including IHSS Group SW-2, IHSS 115, Original Landfill and IHSS 196, Filter Backwash Pond), December 6, 2004". The integrated hydrologic flow code MIKE SHE was used to simulate conditions that develop for closure configurations because system flows are complex, and realistic closure configuration model parameter values can be assigned in the physically-based code. Development of the integrated flow model follows an approach similar to that used in SWWB integrated flow modeling (K-H, 2002a), where saturated and unsaturated flows are dynamically coupled with overland and channel flows (see Section 2.3). Development of the reactive fate and transport modeling followed the approach used in more recent modeling to support the CRA (K-H, 2004b) where a reactive transport code is used to simulate attenuation processes such as degradation, sorption, dispersion and diffusion (see Section 3.5). Figure 2.11a shows the model boundary and features considered in the model development. Figure 2.2 shows the three-dimensional model boundary relative to other model boundaries.

The primary objective of the flow modeling involves simulating integrated flow conditions within the OLF for four closure configurations. In addition, the fate and transport of elevated levels of VOCs within the OLF are modeled to estimate a range of long-term groundwater concentrations at possible surface water discharge locations. The four OLF closure configurations considered include the following:

- Scenario 1 - IA reconfiguration, no OLF modifications;
- Scenario 2 - IA reconfiguration, OLF regrade (basecase);
- Scenario 3 - IA reconfiguration, OLF regrade, buttress fill, and drain;
- Scenario 4 - IA reconfiguration, OLF regrade, buttress fill, drain, and slurry wall.

These objectives were addressed in several steps. First, available geologic, hydrologic, and chemical data (including recent water levels and geotechnical information) were compiled into a GIS to conceptualize flow within the OLF. A localized, fully-integrated flow model was then developed for the OLF area based on these data for current conditions to demonstrate that parameter values were appropriate for simulating closure configurations. The integrated model was modified to simulate the hydrologic changes to the system for each of the four closure configurations. Finally, fate and transport of elevated levels of PCE and its daughter products were conservatively evaluated from inferred constant concentration source areas within the OLF using a reactive transport code (see Section 3.5).

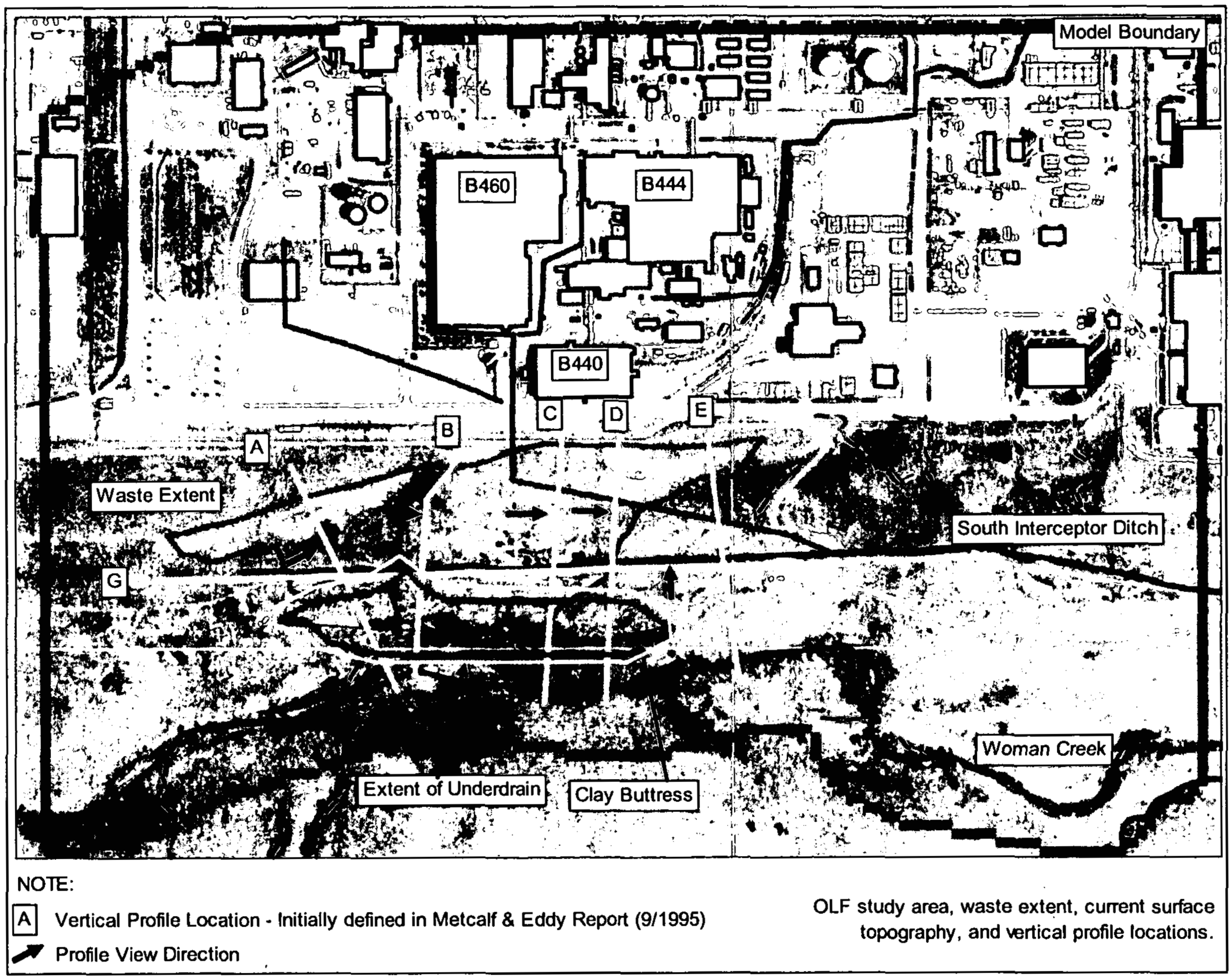


Figure 2.11a. Original Landfill model boundary and key features.

Current Configuration Data Evaluation

Several observations were made from evaluation of available hydrologic data that are relevant to the geotechnical stability analysis:

- Evaluation of historical groundwater level data in the OLF area indicated groundwater levels above the weathered bedrock ranged from 0 to 10 feet over about two thirds of the waste extent, while the levels were actually below the bedrock over the remaining one third;
- For current conditions, average annual observed groundwater depths throughout the OLF area varied from over 20 feet depth at the top of the hillslope to less than 3 feet near Woman Creek and in shallow bedrock areas within the OLF; and
- Seasonal levels varied from 5 to 10 feet within the OLF.

2.5.2.1 Integrated Flow Model Development and Performance

A much finer numerical grid resolution (25- x 25-ft) was specified for the OLF model compared to the former SWWB model. This was to more accurately simulate the spatial variability of factors that affect flows in the OLF such as permeability distributions, surface topography and the weathered bedrock surface. The model only considered the UHSU material, but this unit was subdivided into four distinct layers that differentiated between the OLF waste, fill material, native soils, and the underlying weathered bedrock. Flow through the unsaturated zone was simulated using United States Geological Survey (USGS)-mapped soils distributions and the current waste extent. Overland flow simulated in paved areas, or in unpaved areas when precipitation rates exceed the infiltration rate of the soils, was routed into surface channels where it dynamically interacted with subsurface flows, or exits the model. The model also included spatially distributed and time-varying inflow to channels from subsurface drains in the IA.

Results of model simulations for the 2000 configuration showed that input parameter values reproduce average flow conditions well over the OLF. The model simulated average annual water levels within the OLF to within a foot of observed levels, and over the entire model area to within just over a foot with a standard deviation of less than 4 feet.

2.5.2.2 Closure Configuration Model Development and Simulation Results

Several model parameters were adjusted in the integrated flow model to simulate hydrologic effects of the OLF closure configurations. In Scenario 1, adjustments are made to model input only in the IA. In the remaining scenarios adjustments were made to both the IA and OLF area. Closure modifications in the IA were similar to those assumed in the SWWB modeling (K-H, 2002a), where pavement and buildings are removed, subsurface drains are deactivated, and the surface of the IA is regraded and revegetated. For Scenarios 2 through 4, the surface topography in the OLF was regraded using a preliminary surface that was later modified based on this modeling and geotechnical analyses. In Scenario 3, a structural buttress fill extending to the weathered bedrock surface and an upgradient drain were assumed along the southern extent of the OLF. In Scenario 4, a slurry wall extending to the weathered bedrock surface was placed upgradient of the OLF to simulate the hydrologic effects of reducing lateral inflow from the IA into the OLF.

A typical climate sequence, based on year 2000 data developed in the SWWB modeling (K-H, 2002a), was considered reasonable for simulating flow conditions within the model because this sequence reproduced time-averaged (10 years) water levels well in the current configuration model. To support geotechnical stability analyses, a wet-year climate sequence (based on 100 years) was simulated for Scenario 2 to approximate conservatively high groundwater levels that develop within the OLF area.

Modeling results are summarized as follows:

- Model results showed that reconfiguring the IA (Scenario 1) caused groundwater levels to increase less than one foot over the OLF. However locally, levels decreased less than 3 feet and increased up to 4 feet. Simulated depths were similar to current conditions and ranged from less than 5 feet to over 20 feet within the OLF;
- Simulated effects of regrading the OLF and reconfiguring the IA (Scenario 2) for a typical climate sequence (WY2000) caused levels to increase an average of about 2 feet. Locally they decreased up to 3.5 feet and increased up to nearly 7 feet. This was due in part to the adjustments in ET caused by changes in the depth to groundwater below the new regrade. Simulated groundwater depths varied throughout the OLF, mostly in response to 'fill' and 'cut' adjustments. At the western and eastern waste extents depths increased to near 40 feet due to increased fill thickness. Saturated heights above the bedrock increased from 3 to 7 feet over most of the OLF compared to Scenario 1;

- Simulating a wet-year climate (100-year basis) sequence for Scenario 2 caused average annual groundwater levels within the OLF to increase about 2 feet (ranging from 0 to 4 feet over the OLF) compared to those for a typical climate sequence. Results also indicated that groundwater reached ground surface in shallow bedrock areas, though this could be controlled by increasing the regrade surface height above bedrock. These simulated groundwater levels represented conservatively high levels that might be sustained for up to a month during a wet-year climate sequence;
- Simulated effects of adding a buttress fill and upgradient buttress drain (Scenario 3) caused average annual groundwater levels to decrease less than 1 foot over the OLF. However locally, the drain caused levels to decrease up to 3 feet over the southern half of the OLF. Levels near the drain decreased about 11 feet. Simulated annual discharge rates from the drain were less than 1 gpm;
- Simulated effects of adding a slurry wall to Scenario 3 (Scenario 4) caused average annual groundwater levels over the OLF to change less than 1 foot. However levels downgradient (south) of the slurry wall decreased less than 3 feet, while those upgradient of the slurry wall (north) increased up to 3 feet within about 300 feet;
- Results of the current and closure simulations indicated that surface regrading resulted in the largest impact on OLF groundwater levels. Modeling also showed that seeps may occur under wetter climate though this could be controlled by adjusting the surface regrade topography; and
- A sensitivity analysis to determine the most sensitive parameters controlling water levels in the OLF was not conducted in this study, though modeling results suggested that the regraded surface, bedrock depth and waste area hydraulic properties are the most sensitive. An uncertainty analysis to assess the range of hydrologic response to input parameter value uncertainty was also not conducted in this study. As such, simulated responses could change depending on the specific parameter values used, though reasonable values were assumed.

2.5.2.3 Recent Original Landfill Model Updates

More recent updates to the Original Landfill modeling was conducted subsequent to the modeling summarized in the report "Integrated Flow and VOC Fate and Transport Modeling for the Original Landfill (K-H, 2004a) summarized in Table A.1. More recent modeling was conducted up until March 2005 and included updates to the location, and configuration of the OLF clay buttress, underlying drain, and to the surface regrade topography. Results were provided to Earthtech and included in their final draft IM/IRA report. Simulated groundwater depths in plan and profile for the recent updates (March 2005) are summarized on Figures 2.11b and 2.11c.

2.6 Local Building Closure Configuration Modeling

In the anticipated physical condition at contract completion, portions of subsurface building structures at several building areas within the IA will remain. These subsurface structures have the potential for impacting the local surface and groundwater hydrology because they extend below the groundwater table. Concerns raised about potential impacts to the local hydrology are graphically illustrated on Figure 2.12. The primary concern is whether groundwater levels increase behind basement walls (1 on figure), or above basement slabs (2 on figure), causing surface seeps to develop, and subsequent ground surface slumping that exposes the basement structures. A second concern is how the fate and concentration distribution of VOCs in groundwater is impacted by the subsurface structures.

The hydrologic response due to the anticipated physical completion, including leaving subsurface structures below grade for the IA, is complex. Many factors in areas where deep building basement

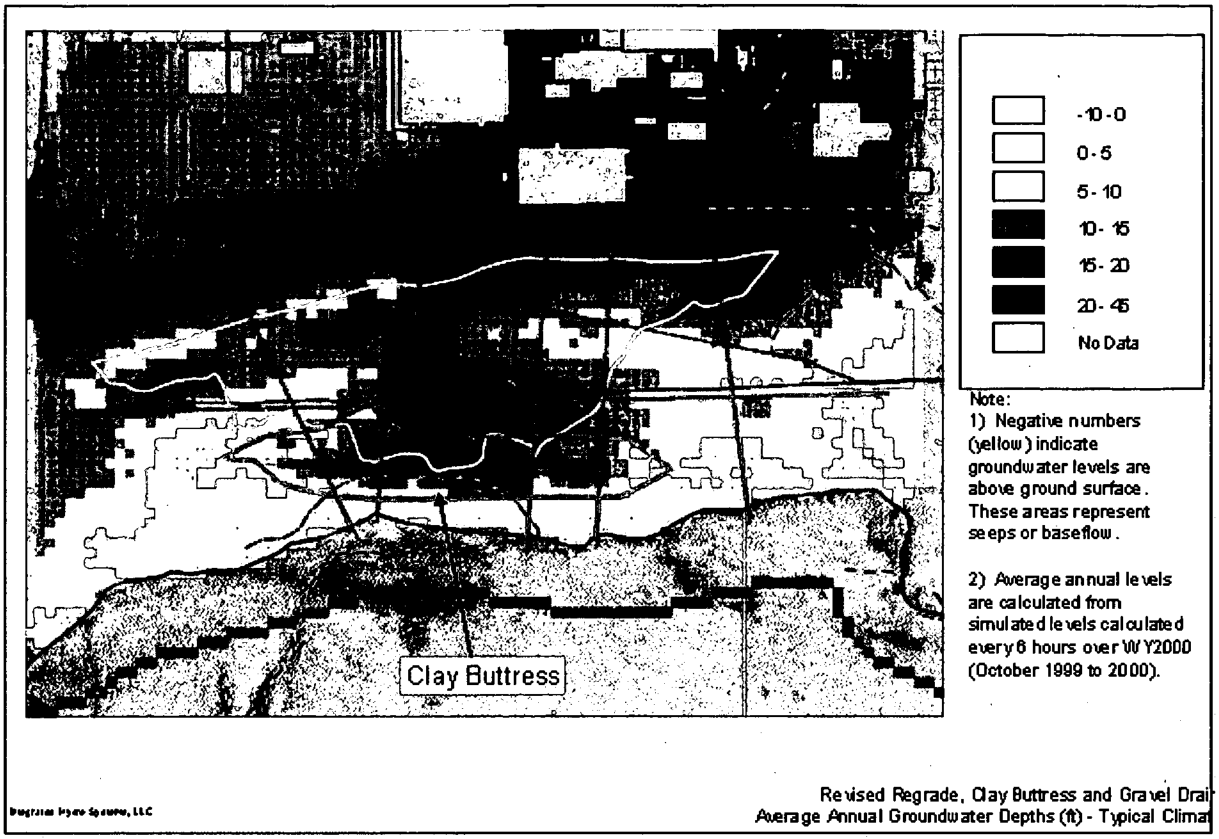


Figure 2.11b. Average Annual Simulated Groundwater Depths (ft) – Typical Climate.

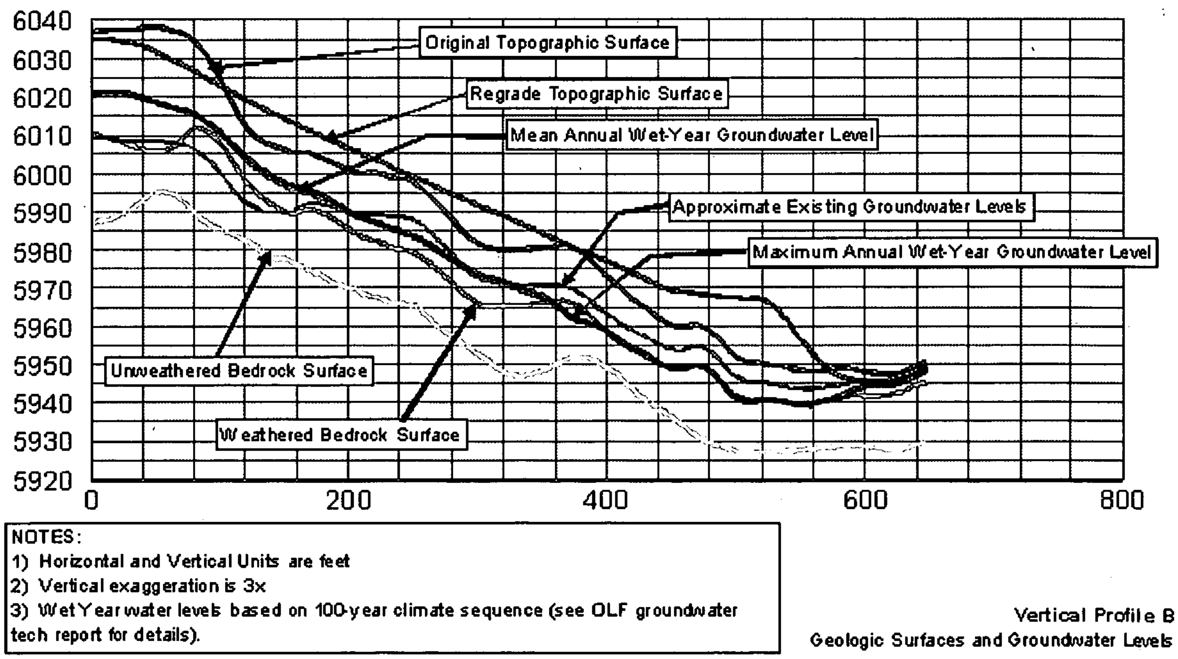


Figure 2.11c. Existing and Simulated Mean and Maximum Groundwater Levels – Profile B

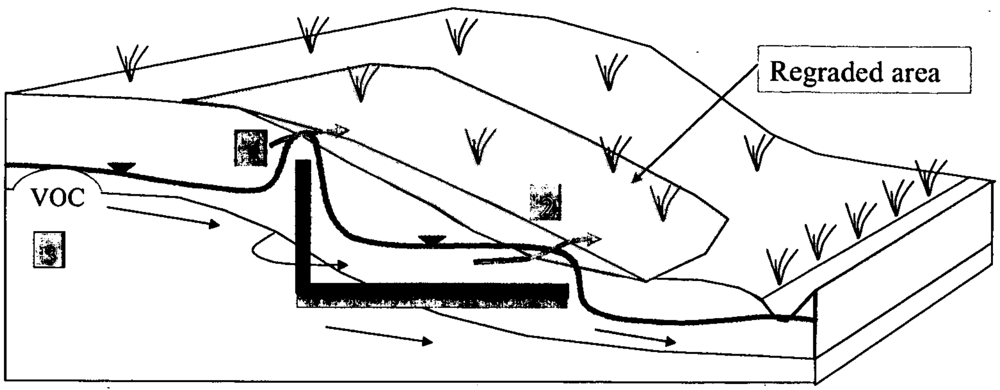


Figure 2.12 Areas of Concern.

structures are left in place influence groundwater levels and surface runoff. Previous integrated hydrologic analyses conducted as part of the SWWB modeling (K-H, 2002a) demonstrated that the dynamic interaction between the surface flows, and unsaturated and saturated zone flows, combined with climate dynamics are essential for predicting the spatial and temporal hydrologic system responses over time, like groundwater levels. In addition, several IA features, such as subsurface utilities, drains, pavement, and buildings further complicate the natural integrated system response which is dominated by features such as the depth to weathered bedrock, and the spatial distribution of unconsolidated material and vegetation.

To evaluate the potential surface and groundwater impacts from remaining subsurface structures, an integrated hydrologic flow model was developed with the MIKE SHE code, which was also used in the SWWB modeling (K-H, 2002a). A much higher numerical model grid resolution (i.e., smaller grid cell size) was required to better simulate the hydrologic effects of localized features not captured in the SWWB model. Specific integrated models developed included the following:

- Former B771 model (includes 774 area);
- Former B371 model (includes 374 area);
- Former B881 model (includes 883 area);
- Former B991 model (including B991, the 996, 997 and 998 Vaults, and the 991 and 998 tunnels);
- Former B460 model (includes 444 area); and
- Former B777/776 model.

Figure 2.2 shows the three-dimensional locations and extents for each of these models overlying the existing (2000) surface topography. Despite differences in hydrologic conditions within each model area, a general modeling approach was developed to evaluate the anticipated physical condition at contract completion. Details of this approach are described first in Section 2.6.1, followed by a brief summary the anticipated physical completion influencing the system hydrologic response in Section 2.6.2. A discussion of building-specific model simulations and results are presented in Section 2.6.3.

2.6.1 General Modeling Approach

Several steps were required to develop the higher-resolution models to assess the more localized hydrology (compared to the SWWB model resolution) of the anticipated physical completion at each of the building areas. Although much of the model input and basic information used to develop the SWWB model was used to construct the local-scale integrated flow models for each building area, individual GIS databases had to be prepared due to the refinement in grid resolution. Moreover, local-scale spreadsheet

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algorithms, linked to the model-specific GIS databases were prepared to organize and automate input to each integrated model.

The resolution of the numerical grid forming the basis for saturated zone, unsaturated zone, and overland flow processes is 25-ft by 25-ft. This represents a significant increase in the model grid resolution compared to the original SWWB modeling (i.e., 200-ft by 200-ft). The reason for increasing this resolution was to improve the ability and accuracy of the models to simulate the subsurface structures left in place. The local-scale building models also required increased vertical numerical resolution to account for the anticipated physical completion as well as building structures, underlying gravel material, the weathered bedrock surface, and the three-dimensional distribution of Arapahoe sandstone. Because of the increase in horizontal overland flow resolution, explicit definition of surface channel flow using the MIKE11 module was not considered essential. Instead, overland flow is simulated based on the topographic surface and two-dimensional diffusive wave approximation in MIKE SHE.

Hydraulic properties for each integrated building area model were obtained principally from the former SWWB model. However, several features required re-scaling from the original GIS coverages. For example, all of the subsurface utility trenches and the associated invert elevations originally obtained from engineering drawings and available information were re-scaled to the refined 25-ft grid. Other model input information also had to be refined, such as weathered and unweathered bedrock depths, observed head distributions, vegetation and soil distributions, and impervious/pervious areas. Finally, engineering drawings were referenced to obtain both internal and external three-dimensional building structures so that groundwater flows within and external to the remaining building basements could be simulated as accurately as possible with the integrated model.

To simulate more extreme hydrologic flow conditions (i.e., higher water levels, increased seepage rates and areas), a 100-year wet-year continuous-climate sequence was specified in each model. Initially three consecutive wet-year sequences, described in the SWWB modeling report (K-H, 2002a), were used to stabilize initial conditions and to obtain representative wet-year flow conditions and water levels. For final building models, two typical-climate years (based on WY2000 climate data) were used to stabilize initial conditions, and a single wet-year, 100-year basis, was used to simulate conservatively high groundwater levels and flows. In addition, preliminary simulations and discussions with CDPHE indicated that existing building footing drains would be simulated as disrupted so that conservatively high groundwater levels would develop surrounding remaining building structures. This assumption simulated effects of possible future footing drain failure (i.e., collapse, plugging).

Several simulated system responses were assessed for each model. For example, both the mean and minimum annual simulated groundwater depths were used to assess areas where groundwater levels were predicted to be near, or above ground surface. Groundwater discharge rates, flow rates, and three-dimensional flow directions were also estimated for each model area. Lastly, an advection-dispersion transport module as part of the MIKE SHE code was used to assess impacts to the distribution of VOCs in groundwater in each model area. Because attenuation processes such as sorption, degradation, diffusion and volatilization were not simulated, the transport modeling results were conservative. Specific details on assumptions made for the anticipated physical completion are described in Section 2.6.2 below.

2.6.2 Anticipated Physical Condition at contract completion

Prior to developing the integrated flow models for each building area, detailed information on the proposed closure configuration was discussed with ER personnel. This section therefore, describes details associated with each assumption. It should be noted, that although, similar to closure configuration simulated in the SWWB modeling, there are several notable changes.

Each model area was defined large enough to avoid effects of boundary conditions on internal, near-structure hydrologic conditions. The areas were also selected so that appropriate surface and subsurface boundary conditions could be assigned to prevent unreasonable effects. Lastly, the model boundaries were selected so that transport of VOCs to nearby surface discharge areas could be assessed. In other words, model boundaries were generally associated with streams, so that the fate of VOCs in groundwater could be assessed more realistically.

Three-dimensional structural details of all building basement slabs, walls, vaults, and tunnels were obtained from available land reconfiguration engineering drawings (provided by Site Subject Mater Experts [SMEs]). Where subsurface structures remain, a minimum of 3 feet of soil will remain below the regraded topography. Where basement structures, such as walls, extend above the regraded topography, they were removed to be 3 feet below the final grade. Within the building basements, rubblized concrete and/or fill material will be placed above the concrete slab and has hydraulic properties similar to Rocky Flats Alluvium (RFA). Although difficult to estimate, the saturated hydraulic conductivity of the remaining subsurface concrete slab and walls was assumed to be low (i.e., $1x10^{-10}$ meters per second [m/s]). This permits the walls and slab to leak, but only at a slow rate to simulate effects of leakage through cracks and joints in the structure.

Subsurface pipelines, including sanitary, storm, and building footing drains and process waste lines and water supply lines were all assumed to be removed, or disrupted. All subsurface utility trenches are simulated as remaining in place. These include the above drains as well as trenches associated with alarms, communications, natural gas, and electric. Therefore, the assumed higher conductive backfill trench material is simulated as a preferential pathway, where higher than surrounding natural material conductivity.

A regrade topographic surface was provided by Site SMEs in a high resolution file format. This surface includes both cut and fill areas. In areas where soil fill is added, the fill material was assumed to have similar hydraulic properties as the RFA. A fully established, mesic-type, vegetation was assumed over the entire regrade areas and in areas where pavement or buildings were removed. In areas where the topography remains unmodified, existing vegetation was assumed. Vegetation growth model input parameter values were obtained from the SWWB model vegetation database.

2.6.3 Model-Specific Details

Specific details of simulations run for each model and subsequent results are described in this section. The former B771 area model is described first because this model was developed first and initial simulations of current conditions were conducted to demonstrate that the rescaled model input reproduced observed groundwater levels and discharge rates adequately.

2.6.3.1 Former B991 Model

Model Details

A localized, high-resolution integrated flow model was developed for the area associated with the former 991 Corridor C Tunnel and Vaults 996, 997, and 999 (Figures 2.2 and 2.13). The integrated B991 area flow model also includes the B991, 998 Vault, and Buildings 984 (B984) and 985 (B985). The purpose of the refined model was to better simulate localized hydraulic conditions surrounding the B991 structures proposed to be left in place under conservative wet-climate conditions. The need to model the local conditions accurately was in response to concerns about groundwater levels building up behind structures left in place, which then might cause surface erosion and possible slumping, particularly along the southern hillslope to South Walnut Creek.

A grid resolution of 25 feet was developed for the saturated, unsaturated, and overland flow processes in the integrated model. Surface channel flow was not explicitly simulated in the model because it does not impact the hydrologic conditions within the former B991 area, and the hydrologic response in South Walnut Creek was not of concern. An appropriate set of overland flow (non-channelized) and saturated

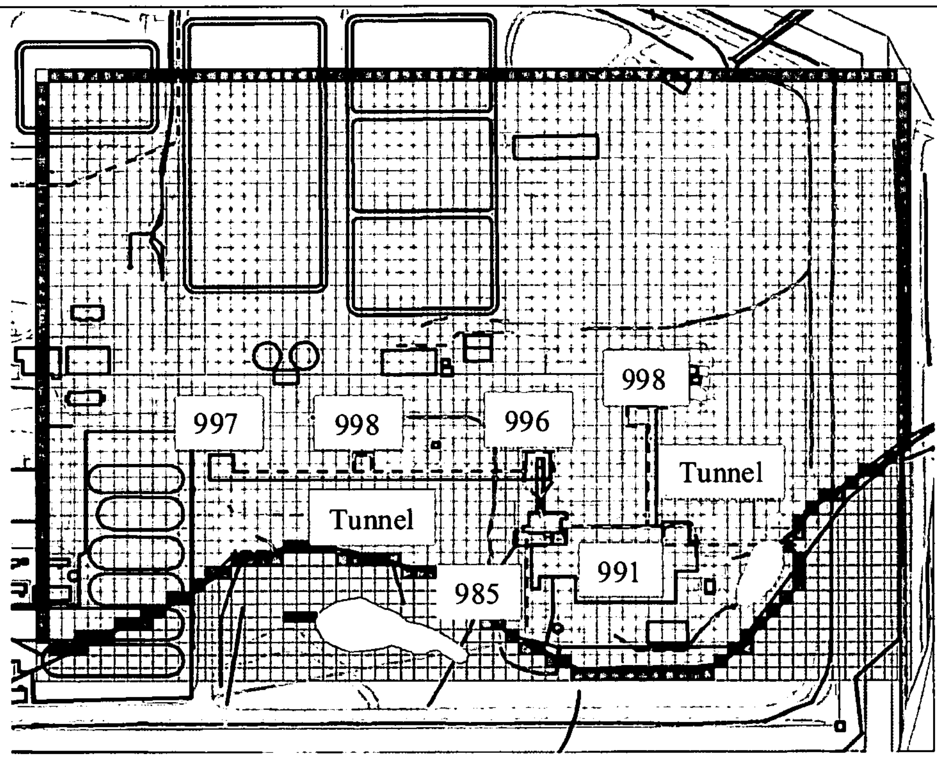


Figure 2.13 Model Boundary and Buildings of Interest – former B991 Area Model.

zone boundary conditions were specified along the southern model boundary that coincides with South Walnut Creek.

Specific closure conditions for the B991 structures combined with other land configuration modifications were provided by ER. For example, the entire subsurface structure associated with B984 was assumed removed for closure, while the 991 Tunnel, Vaults 996, 997, and 999, and the 998 Vault were to be left in place. Based on the regrade surface topography, only portions of B991, the 998 Tunnel structures were removed to remain at least 3 feet below the regrade surface.

Conservative conditions were assumed in modeling the local hydrology of the tunnel system. Any conditions causing higher groundwater levels were considered conservative. Two primary conservative assumptions included a 100-year, wet-year climate sequence, and disruption of current drains (upgradient of the 991 Corridor C Tunnel, B991 and the 998 Tunnel). Low hydraulic conductivities were assumed for the tunnel structures (i.e., 1e-10 m/s) to simulate leakage through slab joints, or cracks. Although it was impossible to simulate flow within tunnel/vault voids given the grid resolution, flows were controlled by the assumed effective concrete hydraulic conductivities. Fill material placed inside former B991 and to meet the regrade fill areas was assumed to have hydraulic properties similar to the RFA material.

Closure Configuration Simulation Results

Simulated mean and minimum annual groundwater depths in the B991 model area for a wet-year are shown on Figures 2.14 and 2.15, respectively. Results indicated that average annual groundwater depths during the wet-year remained below 1 meter for the entire eastern portion of the B991 area structures. However, depths were within 1 meter along south Walnut Creek and at the western end of the 991 Corridor C Tunnel and near the former Solar Ponds where bedrock was shallow. This was further confirmed by simulating conditions without the 991 Tunnel. Virtually no difference occurred in simulated groundwater depths for larger precipitation events. Minimum annual groundwater depths (see Figure 2.15) showed that groundwater levels reach the regrade surface topography in these areas.

Figure 2.14 Simulated Mean Annual Groundwater Depths (m). Wet-year, no footing drains.

Figure 2.15 Simulated Minimum Annual Groundwater Depths (m). Wet-year, no footing drains.

Minimum depths near the eastern B991 structures remained deeper, ranging from 3 to 5 meters. Greater depths occurred to the east because of increased bedrock depths and Arapahoe Sandstone that immediately subcrops the unconsolidated material and extends northeast.

Simulated groundwater flow directions within the unconsolidated material are shown on Figure 2.16. Results showed that groundwater flows were affected by the remaining subsurface structures, but the effects remained localized. Although groundwater flowed southward over the former 991 tunnel, this was because the tunnel structure occurred entirely within the weathered bedrock, except for the 997, 999, and 996 vaults that span a greater vertical extent. At the former B991 wall and 998 Tunnel areas groundwater flows were directed eastward and downward, and enhanced by the gravel layer simulated below the remaining slab. Groundwater south and east, downgradient of the B991 structures, flowed directly towards the regraded Woman Creek channel.

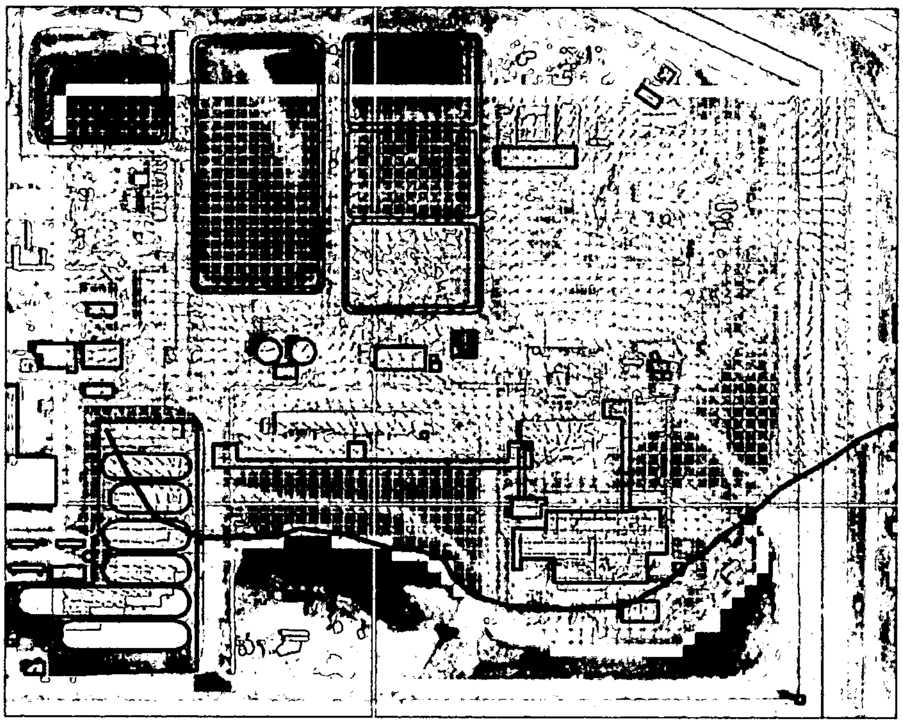


Figure 2.16 Simulated Groundwater Flow Directions – Unconsolidated Material.

Transport simulations showed that VOC plume movement from the north into the B991 area did not occur due to the local northerly flow direction in the plume area (Figure 2.17). Other detectable concentrations in some wells north and northeast of the former B991 area were low and showed no clear association with known sources, or historical releases in the area. Moreover, groundwater flow paths shown on Figure B-14 confirmed a more easterly flow direction in this area.

2.6.3.2 Former B771 Model

Model Details

The model area and 25-ft square grid are also shown on Figures 2.2 and 2.18. Specific buildings of interest in the B771 model area include B771 and Building 774 (B774) shown on Figure 2.18. The majority of the basement slabs and walls for these buildings remain based on the new regrade topographic surface. B771C, located between B771 and B774 will be removed entirely. Remaining subsurface support pilings associated with former B776 and B777 structures located along the southern model boundary will not likely impact groundwater flows significantly and therefore were not considered explicitly in the model.

The integrated hydrology in the B771 model area is complex and groundwater flow is three-dimensional and affected by several factors. Some of the factors evaluated in the model were: 1) the B771 and B774

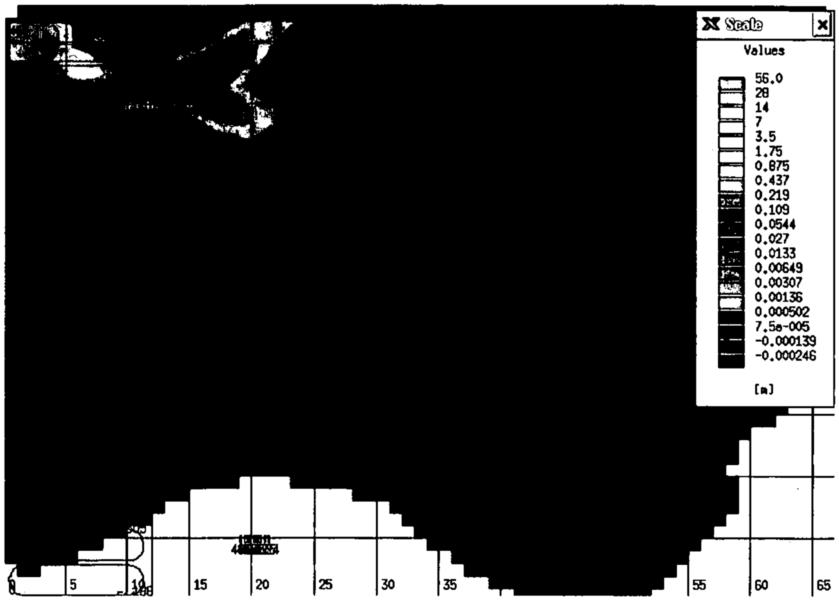


Figure 2.17. Simulated Advective-Dispersive transport of VOCs – after 200 years.

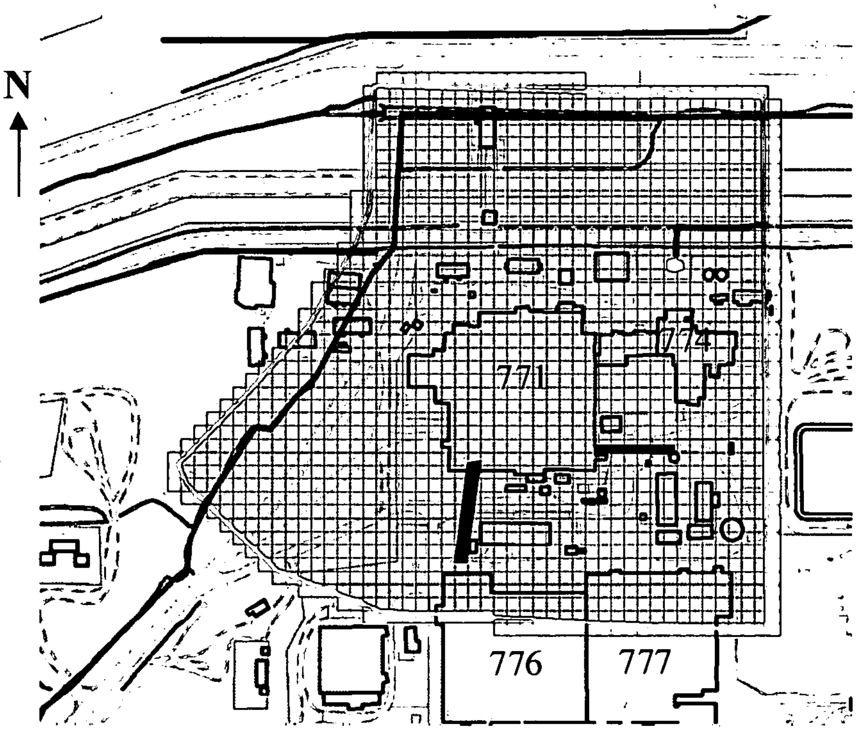


Figure 2.18. Model Boundary and Buildings of Interest – Former B771 Model Area.

basement slabs and walls; 2) Arapahoe Sandstone in the area; 3) subsurface tunnels between B771 and B776 and between B771; 4) disruption of footing drains; and 5) the stack to the east, and the hillslope morphology west and north of B771 and B774.

The hydrologic impact of closure was of interest in several areas of the former B771 model. For example, areas upgradient of the B771 basement walls (southern and southwestern edges), and upgradient of the

B774 walls (southern) were of concern for groundwater level buildup. In addition, the potential for groundwater buildup immediately upgradient (east) of the 771-776 tunnel and upgradient (south) of the 771-stack tunnel was also of interest.

Lateral boundary conditions were selected at sufficient distances to prevent impacts in the areas of interest. Channelized surface flow was simulated in the unnamed tributary to the west of B371 and in North Walnut Creek using MIKE 11 (surface water flow module in MIKE SHE). Simulated overland flow generated by groundwater discharge to the surface flows into these channels.

The long-term (100-year) movement of the CCl_4 (IHSS 118.1) south of former B771 was simulated using a conservative advection-dispersion module (a DHI computer code) that based on integrated MIKE SHE flow model results. Effects of degradation, diffusion, or sorption were not considered. Therefore, transport model simulations produced conservatively high concentrations and larger plume extent (due to dispersion), considered reasonable for evaluating impacts of different scenarios on the CCl_4 plume as this is conservative. Effectively, the advection-dispersion module was used as a particle tracking tool to assess flow paths, but not concentrations.

Closure Configuration Simulation Results

An integrated model of the current system configuration (WY 2000) was first developed to demonstrate model performance with the grid refinement and rescaled model input data. Only minor adjustments to the current system configuration model input obtained from the former SWWB model (K-H, 2002a) were required to obtain a reasonable comparison between simulated and observed hydraulic response. Average annual groundwater levels from available wells in the area were compared against simulated average annual groundwater levels. Average annual simulated groundwater levels compared well (within 3 feet) with observed values. The model also reproduced the observed average annual foundation drain discharge rates well, ranging from between 10 to 20 percent of reported values.

For a typical annual climate sequence (i.e., WY2000), the closure configuration model showed that average annual water levels remained well below 3 feet below grade within and surrounding most of former B771 and B774. Along the northern slab boundary, average annual groundwater levels rose to within 1 meter of ground surface because of lateral drainage off of the slab and the shallow bedrock in the area. Several simulations were conducted to assess the sensitivity of the groundwater levels along the northern boundary to assumed model input parameter assumptions. For example, adjustments in hydraulic conductivity, the annual climate sequence, subsurface drain conductance, and holes in the slab and wall were evaluated.

Results from the sensitivity simulations showed that a 100-year wet-year climate sequence (K-H, 2002a) combined with deactivated drains (conservative model) caused significant increases in average annual groundwater levels around the former B771 compared to average conditions for the case described above. Drilling holes in the slab floor caused groundwater levels to increase only about 0.5 meters above the slab. Assuming the Arapahoe Sandstone was not present in the model only caused a slight increase in groundwater levels upgradient of B771 and B774.

Simulated mean and minimum annual groundwater depths for the conservative model assumptions (i.e., wet-year climate and no foundation drains) are shown on Figures 2.19 and 2.20, respectively. Results showed that average annual groundwater levels upgradient of the remaining B771 walls remained more than 1 meter below ground surface. Simulated closure configuration water levels did not build up upgradient of either of the two tunnels (former B771 to B776 tunnel, B771 to east stack tunnel). However, for larger precipitation events during the wet-year, groundwater reached the ground surface along the upgradient, or southern and eastern B771 basement walls. This was caused by the remaining basement wall, but also by shallow bedrock and deactivated foundation drains in these areas. Results also

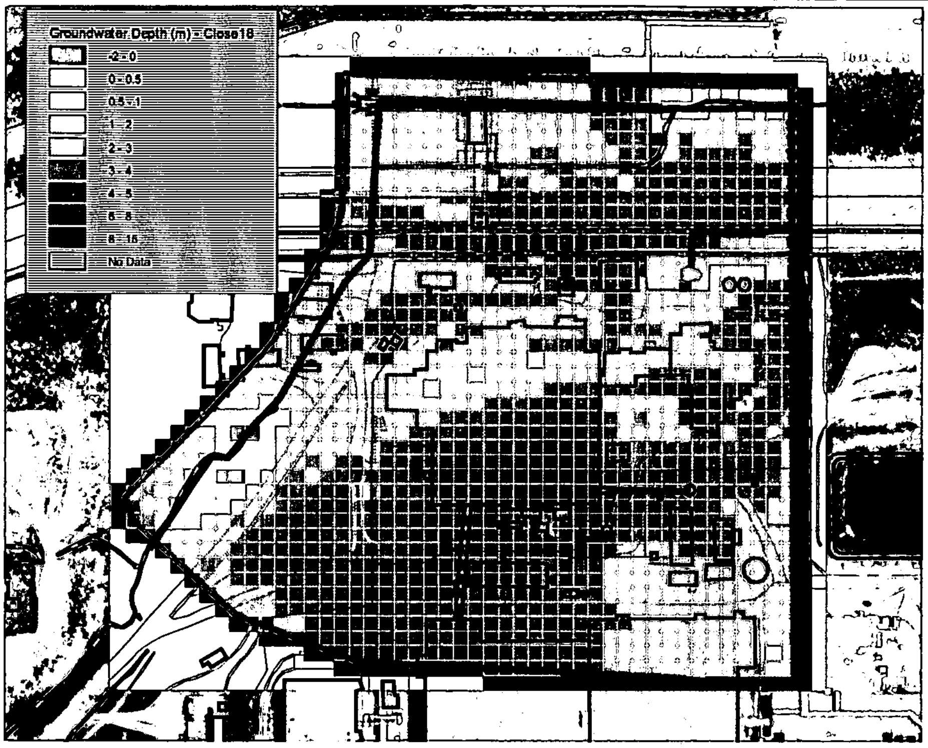


Figure2.19 Simulated Mean Annual Groundwater Depths (m). Wet-year, no footing drains.

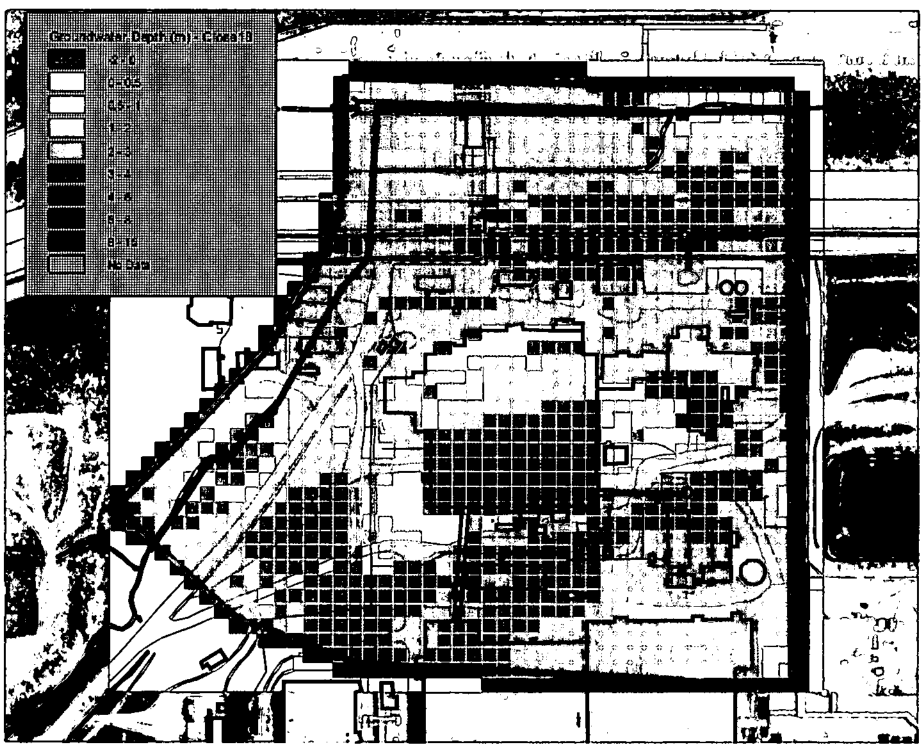


Figure 2.20 Simulated Minimum Annual Groundwater Depths (m). Wet-year, no footing drains.

indicated that average annual groundwater levels rose above ground surface along the northern edge of the slab for B771, where depths below the regrade surface topography were approximately 1 meter.

Average annual groundwater flow directions are shown for unconsolidated materials and the weathered bedrock model layers on Figure 2.21. Simulated flow directions for the two layers were similar, though flows immediately upgradient of subsurface structures were locally forced to flow around, or beneath them. Groundwater levels above the building slabs in both B771 and B774 flowed directly north because of the remaining the east and west basement walls. Groundwater discharge from the building slabs flowed north-northeast and eventually discharges to North Walnut Creek, while a portion discharged to FC-2 (between B371 and B771)

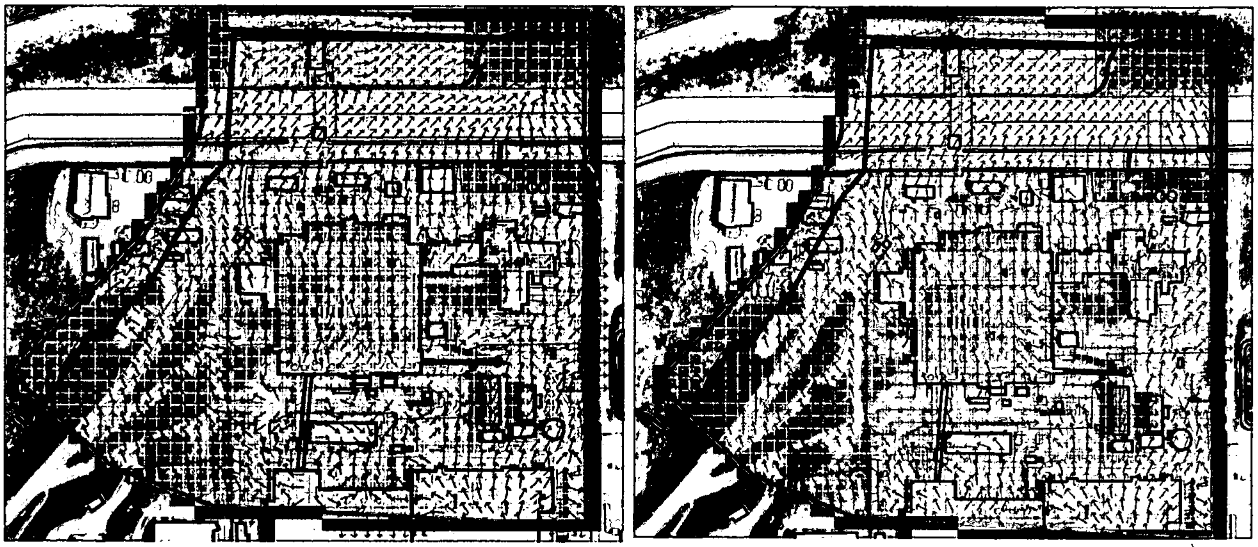


Figure 2-21 Simulated Average Annual Groundwater Flow Directions – Unconsolidated Material and Bedrock, respectively.

The conservative advective-dispersive transport simulation results are illustrated on Figure 2.22 for unconsolidated material and the weathered bedrock model layers (concentrations are in parts per billion [ppb]). From the 118.1 CCl_4 source south of B771, contaminants flowed downward and into the weathered bedrock and gravel layer underlying the B771 slab. As contaminants flowed north-northeast north of B771, upward groundwater gradients forced the contaminants back up into the unconsolidated material, where they then flowed preferentially towards North Walnut Creek. It should be recognized that this simulation only demonstrated where contaminants would flow after 200 years, but natural attenuation processes like degradation and sorption reduced actual concentrations notably.

2.6.3.3 Former B881/883 Model

Model Details

Basement slabs and walls associated with the former B881 and B883 were included in the B881 area model. Figure 2.23 shows the integrated flow model area, numerical grid, profile, and boundary cells aligned with Woman Creek to the south. Boundary cells were defined far enough away from B881 and B883 to prevent impacts to these areas. This was reasonable given that groundwater levels within the IA typically responded mostly to direct recharge and ET (K-H, 2002a) than lateral inflow conditions (i.e., constant head cells along boundary). Initial simulations assumed a 1-ft thick gravel layer underlying both B881 and B883 slabs. Later this assumption was modified based on more recent field information suggesting the gravel layer beneath B883 was approximately 20 feet thick (Figure 2.23). A subsequent simulation was conducted to assess implications of the increased 20-ft thick gravel layer compared to the initial simulations and discussed at the end of this section.

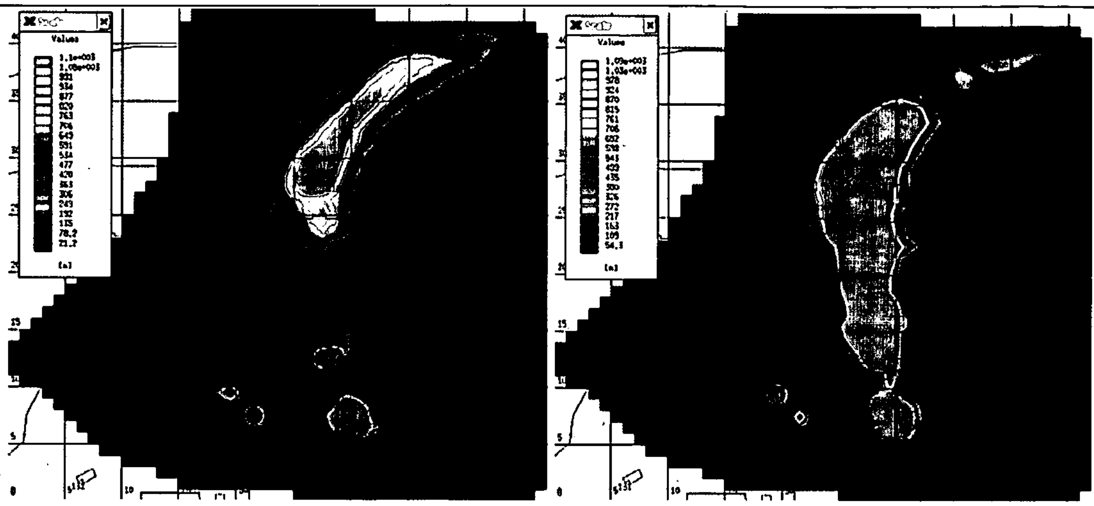
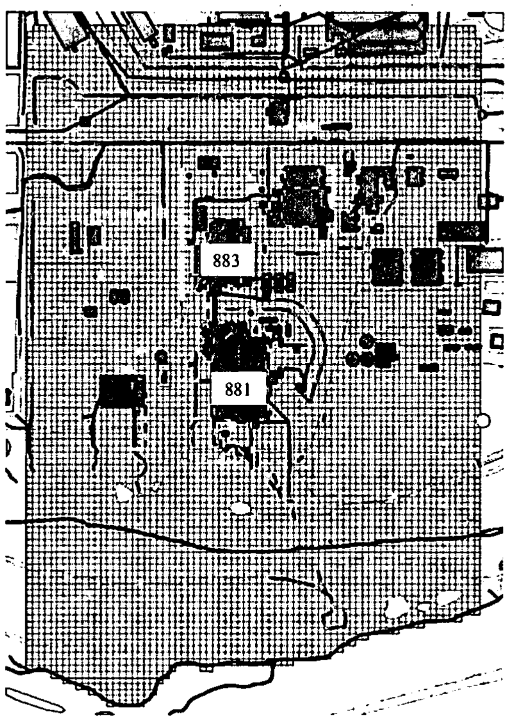
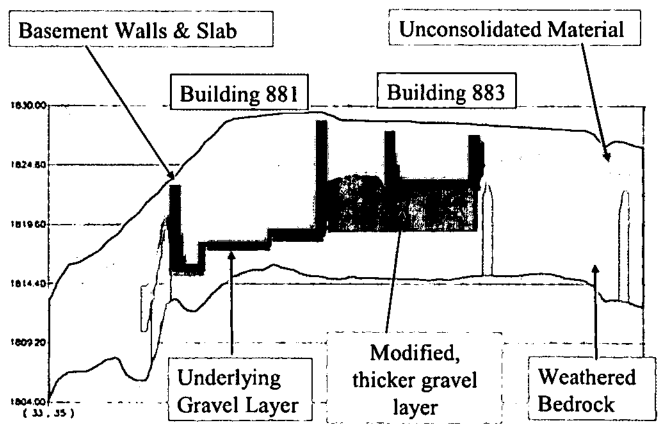


Figure 2.22 Simulated conservative PCE groundwater distribution after 200 years (only advection-dispersion considered).





Note: Original B883/B881 model considered only 1-ft thick gravel layer

Figure 2.23 Model Boundary, Profile and Buildings – Former B881/883 Model Area.

Review of engineering drawings of subsurface basement walls and slabs for the former B881 and B883 combined with discussions with Site SMEs were used as the basis for developing two closure scenarios of interest. Based on the regrade topography provided, the entire B881 slab was assumed to remain intact, while portions of the basement walls to the south were removed to within 3 feet below the new topographic surface. Although B883 doesn't extend as deep below grade as B881, most of its subsurface basement slab and portions of its walls remained.

Subsurface slab elevations for both former B881 and B883 were spatially variable within each building footprint. All subsurface drains (footing, storm, and sanitary) were assumed to be completely disrupted, while the permeable backfill associated with all other subsurface utility conduits were assumed to remain undisturbed (i.e., permeable) to assess the potential for seep development.

Little Arapahoe Sandstone is present within this model area, though the weathered bedrock surface and surface regrade topography dominated groundwater flow paths. As a result, under current conditions, groundwater south of the former B881 flowed southward toward Woman Creek because the hillslope south starts here, while north of B881 groundwater flowed in a more easterly direction, consistent with the topographic and bedrock surface gradient directions.

Hydrologic conditions for two closure scenarios were evaluated using the integrated flow model for the former B881 area. The first scenario assumed that all vertical walls for B881 were impermeable, while the second scenario assumed that the north and south walls were permeable. There were two reasons for simulating these scenarios. The first was to evaluate whether groundwater levels within and surrounding the former B881 would be reduced significantly by using permeable walls. The other reason was to evaluate whether impermeable walls reduced potential southern migration of a VOC plume immediately to the west of the former B883.

Closure Configuration Simulation Results

Simulated mean and minimum annual groundwater depths below the proposed closure regrade topography for the wet-year climate sequence for the impermeable wall scenario are shown on Figure 2.24. Selected grid cells denote areas predicted by the model where groundwater depths were less than 1 m below grade. The simulated depths were calculated for a single 100-year basis annual wet-year climate sequence following two typical-climate years (WY2000) to stabilize initial saturated and unsaturated zone flow conditions.

Results indicated that simulated closure groundwater depths surrounding the former B881 were well below 1 meter for both cases, but more so for the case using permeable walls. Minimum annual depths for the revised B883 gravel thickness simulation (Figure 2.25) showed groundwater levels reach the ground surface behind the impermeable B881 walls and to the north. Groundwater to the north of the former B883 reached ground surface mostly in response to shallow bedrock. High levels are possible at the southern end of B881 caused by transmission of the high levels north of B881. In both cases, groundwater depths decreased towards the north and eastern model areas because of thinning unconsolidated material thicknesses. Simulated groundwater depths also decreased less than 1 m towards Woman Creek in response to the hillslope structure and thinning unconsolidated materials near the creek. Depths did not buildup within and above the B881 slab because its depth below the regrade topography is more than several meters.

Although groundwater depths decreased upgradient and within the former B881 compared to the scenario where the walls were permeable, they remained well below a depth of 1 m below the proposed grade. Groundwater depths immediately north of the remaining B883 basement structure were also less than 1 meter, but are in an area where the surface topography is relatively flat. Simulated groundwater flow directions above and below basement slabs for B881 and B883 are illustrated on Figure 2.26. Results showed that groundwater flows around the B881 structure.

Results of a conservative advective-dispersive transport simulation (using DHI's module in MIKE SHE) of a PCE PSA located west of B883 are shown on Figure 2.27. Results are shown for the impermeable wall scenario. Permeable north and south B881 walls showed conservative PCE migration would be southward with permeable walls, rather than eastward and northward on Figure 2.27. Maximum PCE concentrations were less than currently proposed surface water PRG, but greater than surface water standards. As such, the long-term fate and transport of VOCs in this model area were further assessed and discussed in Section 3.3 (PSA East model).

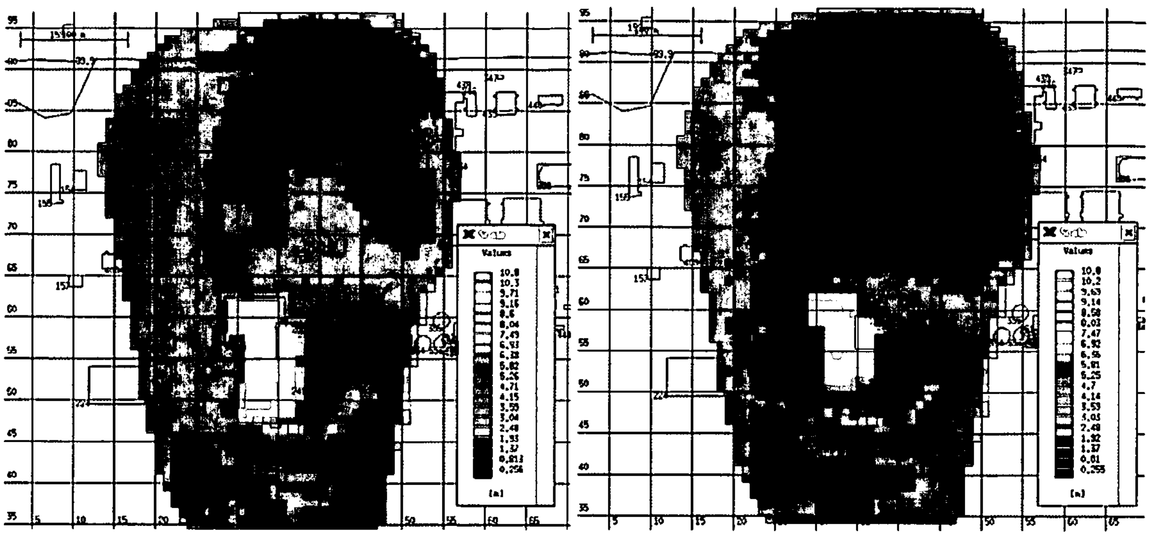


Figure 2.24 Mean and Minimum Annual Groundwater Depths (m) - Impermeable Wall Scenario.

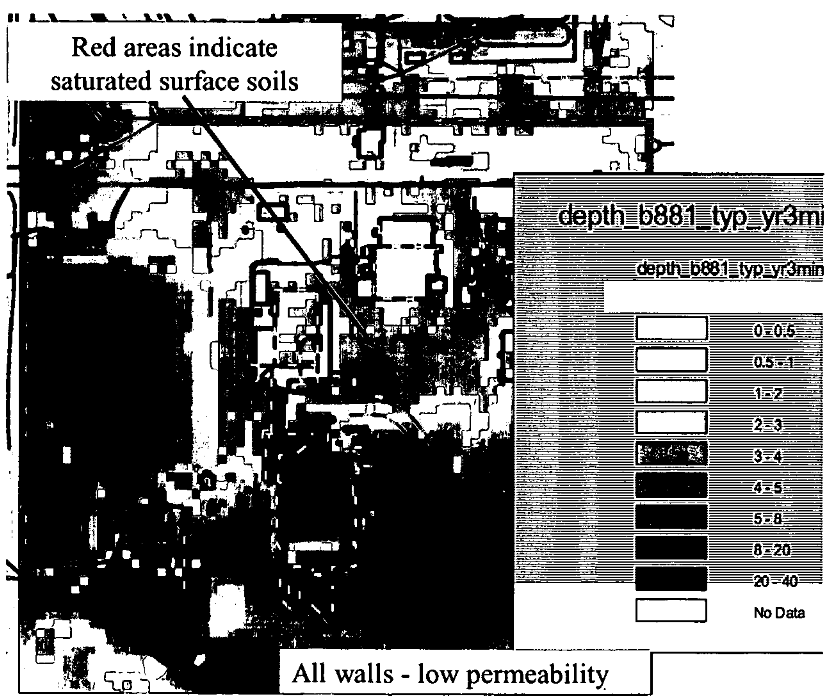


Figure 2.25 Minimum Annual Groundwater Depths (ft). Wet-Year Climate, Updated Gravel Thickness below B883.

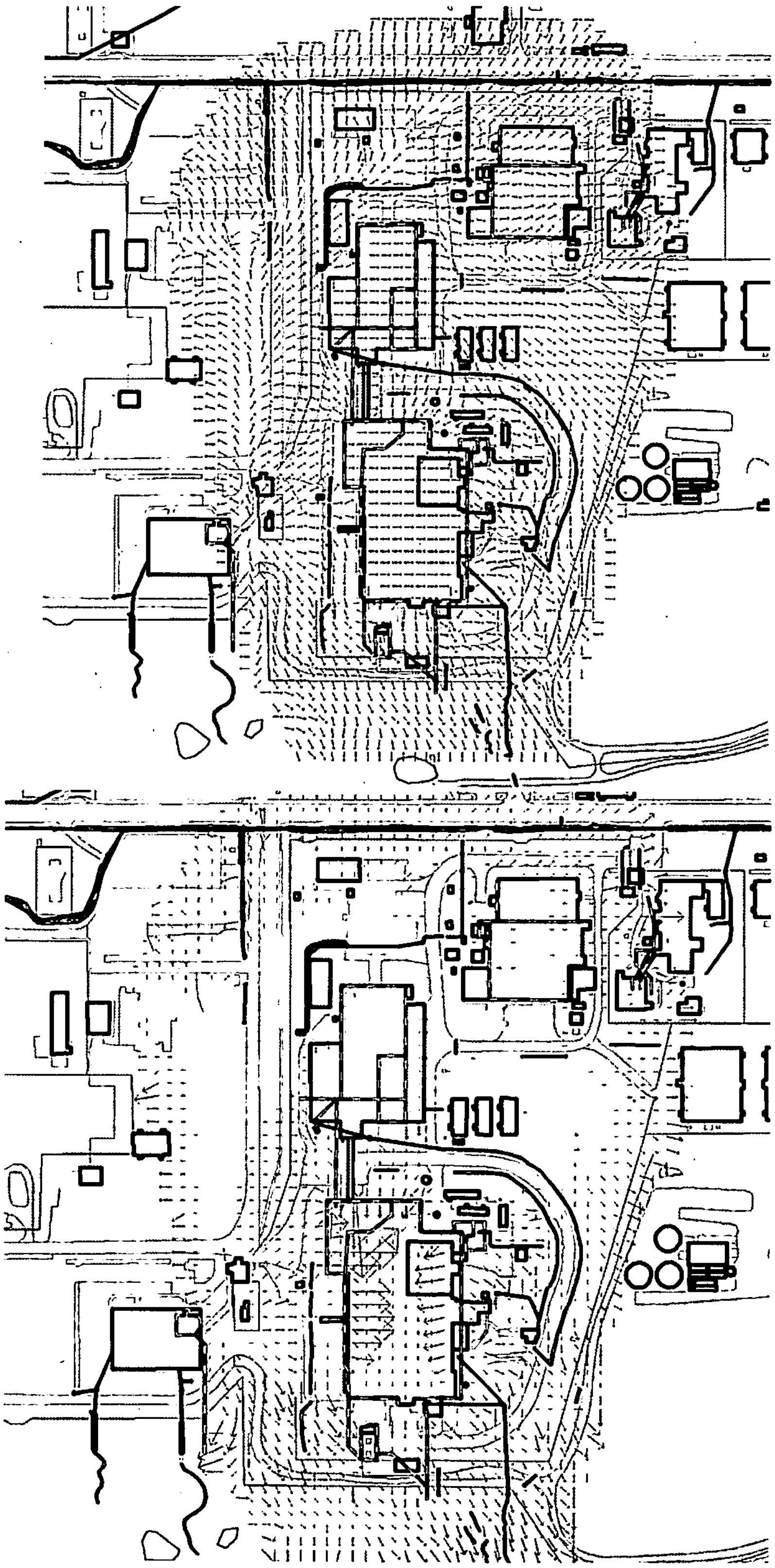


Figure 2.26 Simulated Groundwater Flow Directions, Above and Below Slab, respectively.

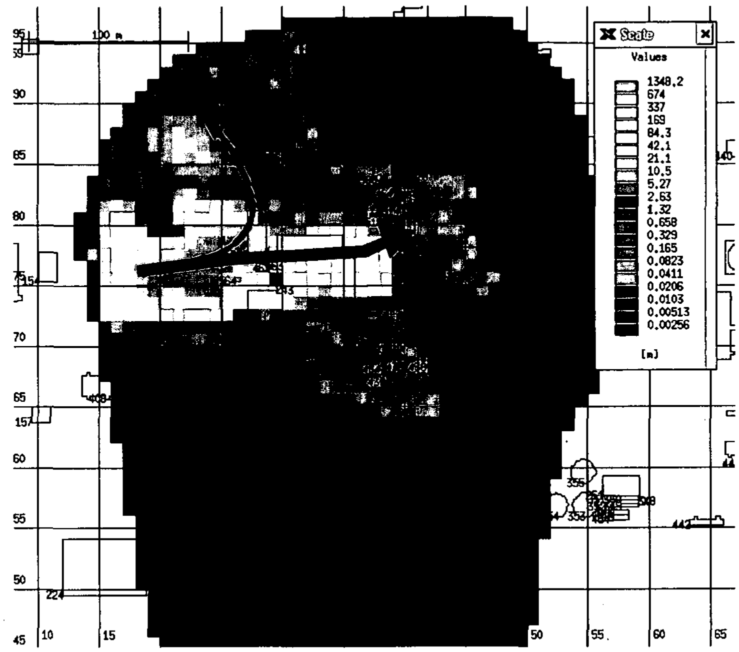


Figure 2.27 Simulated conservative PCE groundwater distribution after 200 years (only dispersion considered).

As a result of the former B881 area flow and conservative transport modeling, it was recommended that B881 walls and slab should remain impermeable to prevent increased migration of VOCs west of B883 southward through B881. The subsurface structure associated with the former B883 had a limited effect on groundwater levels, or transport though. Modeling results suggested that footing drains between former B883 and B881 be disrupted to prevent possible pathways for southward migration of PCE intercepted near B883.

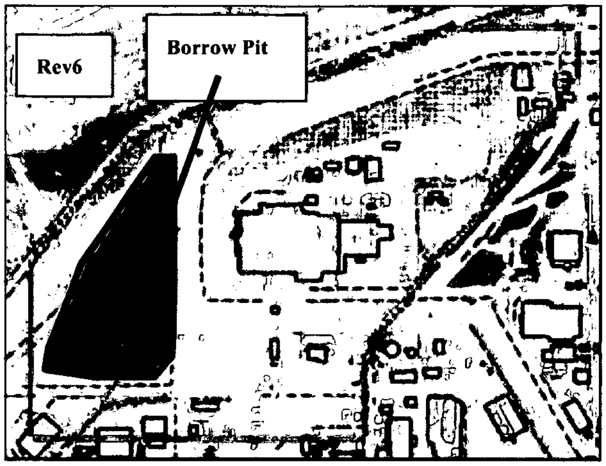
2.6.3.4 B371 Model

Model Details

The model boundary for the former B371 area is shown on Figures 2.2 and 2.28. The model boundary includes the entire former B371 structure. Boundaries to the north and east were selected to coincide with North Walnut Creek and the unnamed tributary between former B371 and B771, respectively. Boundaries to the south and west were selected far enough upgradient of the former B371 area to prevent influence on internal calculations.

Arapahoe Sandstone is present only in the southern portion of the model and does not influence the local hydrologic conditions around B371. Instead, as in other models, the weathered bedrock and topographic surfaces dominate the flow directions and potential buildup of groundwater levels in the model area. In the closure configuration, the regrade topography (Figure 2.28) included a borrow pit area west of B371 which intercepted the weathered bedrock surface in the northern part of the pit. The regrade topography resulted in shallow bedrock depths in the area north of B371 that modeling showed caused groundwater seeps and fast runoff from the area.

The integrated hydrologic system responses for several scenarios were evaluated in the B371 area model. First, two surface water routing configurations were evaluated in the B371 area model (Rev 6 and 6b on Figure 2.28). Simulated groundwater levels were slightly lower for the case where a channel is routed west of the B371 area (Rev 6). As such, only simulated closure configuration response with this surface channel routing was considered further. In the second two scenarios, simulated hydrologic conditions



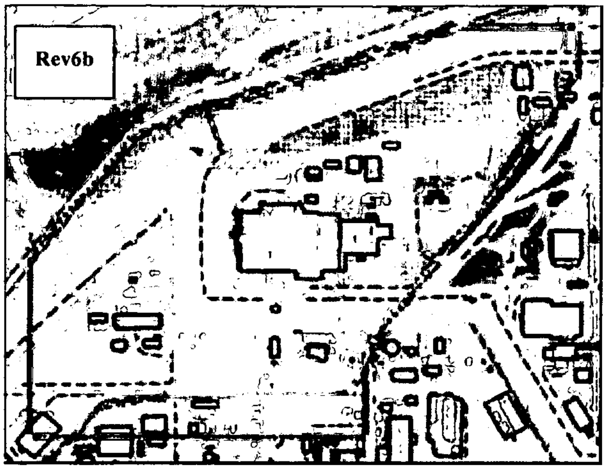


Figure 2.28 Model Boundary and Buildings of Interest – B371 Model Area.

were assessed for permeable and impermeable basement walls. Finally, a model was prepared to evaluate the hydrologic response to creating truck access holes in the impermeable wall scenario along the north, west and east walls (i.e., 25 feet wide). Advective-dispersive transport model simulations were run for both the permeable and impermeable wall scenarios to assess conservative migration pathways for a VOC source located south of former B371 (Oil Burn Pit #1). In these simulations, only dispersion was simulated (no sorption, degradation, etc.). Footing drains and subsurface utilities were specified in these models as described in the general modeling approach (Section 2.6.1).

Recent updates to the B371 model (i.e., see Table A.1, Appendix A) in 2005 involved updates to the Rev 6 model surface topography and drainage configuration. Figure 2.29 shows updates to the Functional Channel-2, located between B371 and B771. Specifically, a wetland was added at the confluence with North Walnut Creek, and the upstream end was re-routed along the southern portion of B371. The upstream part of FC-2 was modified to run along the southern part of former B371 compared to earlier (Rev 6 and 6b) scenarios (shown on Figure 2.28).

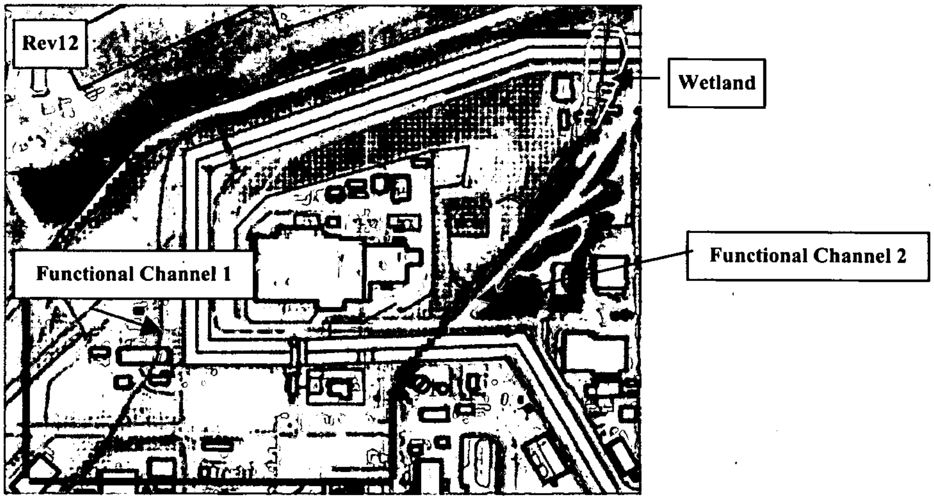


Figure 2.29 Current (June 2005) Closure Configuration Surface Drainage Network.

Closure Configuration Simulation Results

Simulated minimum annual groundwater depths for the permeable and impermeable basement wall scenarios for a wet-year, with inactive building footing drains are shown on Figures 2.30 and 2.31, respectively. The simulated groundwater depths effectively reflected conditions associated with the wettest part of a 100-year wet year. Results indicated that groundwater depths are notably shallower (0 to 1 m below grade) within and immediately upgradient of the former B371 area for the impermeable wall scenario. Despite shallow depths in this area, the potential for slumping was limited due to the relatively flat topography upgradient of B371.

In both scenarios, groundwater depths range from 1 to 2 m below grade immediately north of B371, where the hillslope grade begins. Along the hillside to the north and within the borrow pit, where bedrock is shallow, groundwater levels reached the ground surface during a wetter period of a wet-year. Model results of constructing truck access holes in the north, east and west side indicated that groundwater levels actually decreased slightly within the building foot print as they equilibrated with external water levels.

Simulated average annual groundwater flow directions are shown for the impermeable wall scenario on Figure 2.32 for unconsolidated materials. Groundwater flow vectors denote only flow directions, and do not define flow magnitude. Generally, groundwater flowed towards the nearest surface channel, including to the diversion west of former B371, to the channel between B371 and B771, and to Walnut Creek to the north. As groundwater neared the impermeable basement walls of B371 from the south, it diverged west and east around the building and to the north within the sub-slab gravel layer.

Results of the conservative advective-dispersive transport simulation of VC south of former B371 after 200 years, for the permeable and impermeable wall scenarios suggested that it was possible for contaminants to reach Walnut Creek and the unnamed tributary to the west of B371. However, reactive transport modeling showed that attenuation processes (i.e., biodegradation, sorption, diffusion, etc.) significantly attenuate VOCs close to the Oil Burn Pit #1 area to levels well below surface water standards (see Section 3.2 for more details).

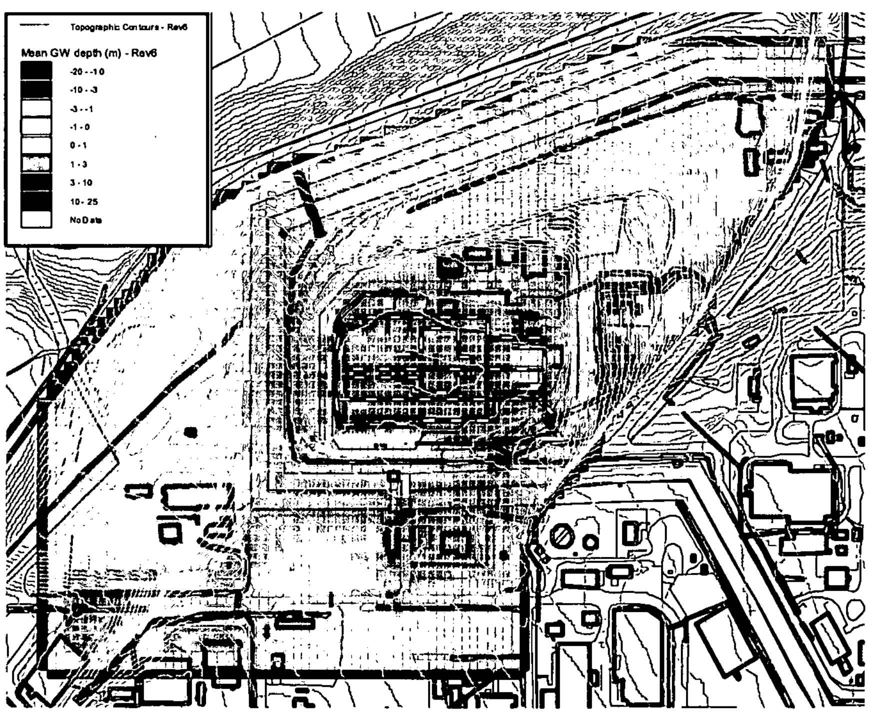


Figure 2.30 Average Annual Simulated Groundwater Depth (m) - Permeable Walls.

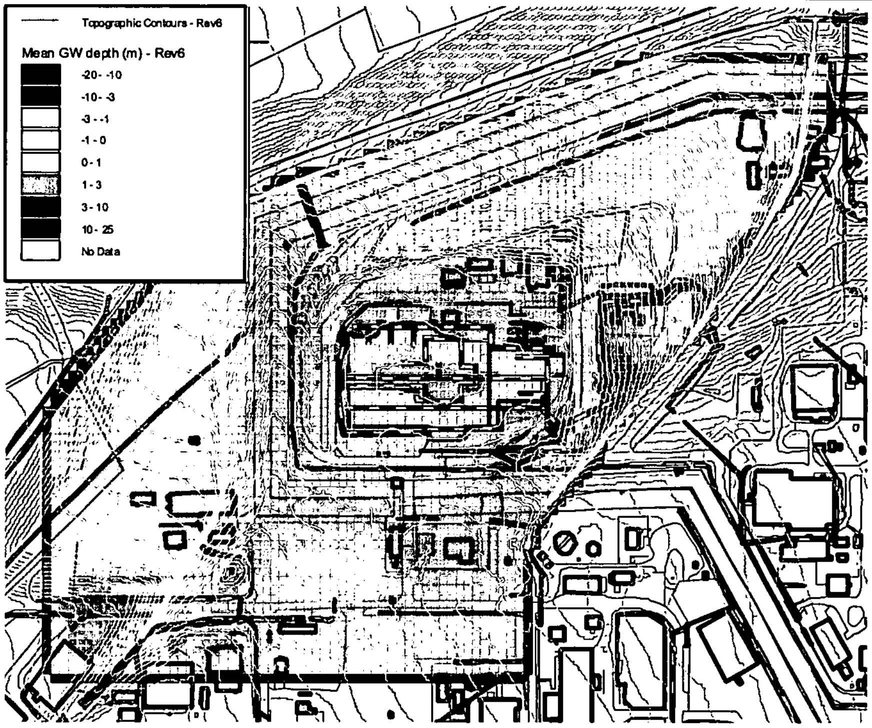


Figure 2.31 Average Annual Simulated Depth to Groundwater (m) - Impermeable Walls.

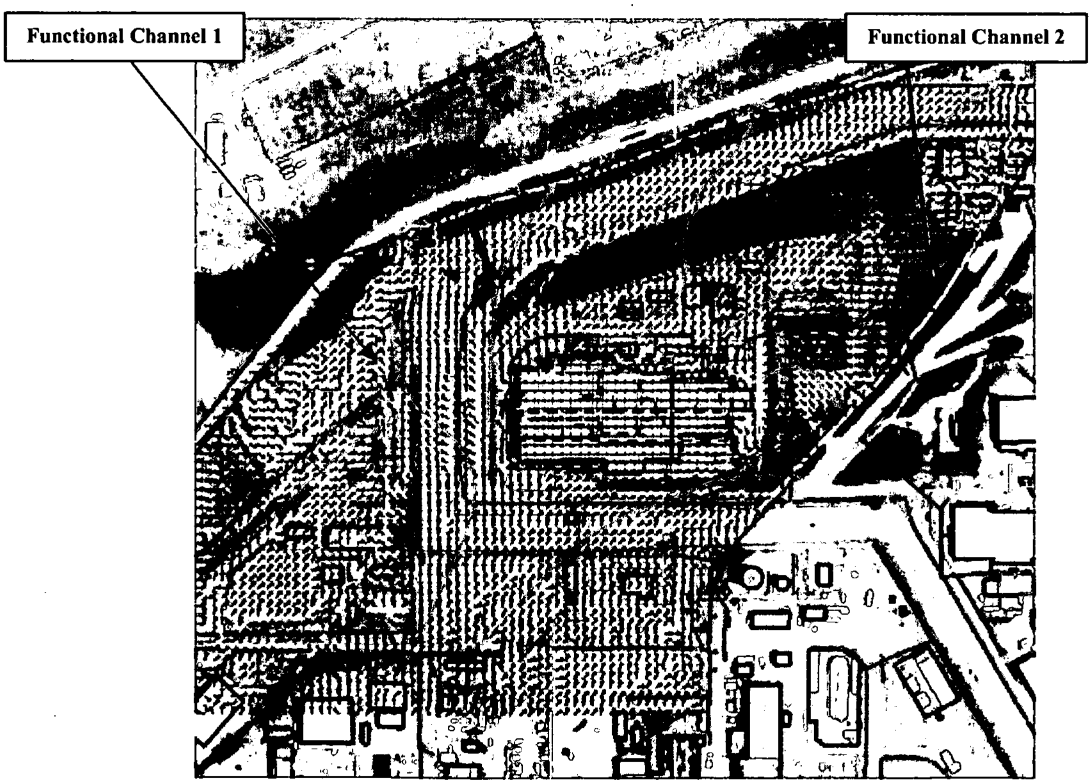


Figure 2.32 Simulated Groundwater Flow Directions – Unconsolidated Material.

Recent updates to B371 model

Recent updated closure topographic and drainage information (Revision 12 - 2005) were used to revise the previous integrated flow model closure configuration (Section 2.6.3.4) shown on Figure 2.28. Figure 2.28 shows in the vicinity of former B371, the surface drainage between former B371 and B771 was modified so that the revised surface water channel is located just south of B371, along its southern wall instead of continuing south into the IA along its existing drainage. This change also resulted in a change to the surface topography.

Figure 2.33 shows simulated groundwater elevations, flow paths, and discharge areas for the current configuration in PSA13 area south of former B371. Results indicate that groundwater flow discharged primarily to the B371 footing drains and the drainage channel between former B371 and B771. The general gradient direction from the Oil Burn Pit #1 source area was northeast toward the surface drainage.

Figure 2.34 shows the change in groundwater levels between the current and closure configuration. Positive values (in ft) reflect an increase in levels, while negative values indicate a decrease. The groundwater levels around B371 increased significantly by deactivating footing drains, while levels west of B371 decreased in response to the decreased surface elevations (i.e., borrow pit).

Simulated closure configuration groundwater levels and flow directions are shown on Figure 2.35. Results showed that groundwater flow directions changed significantly in the area immediately around former B371 by eliminating footing drain discharge. The new closure configuration caused groundwater to flow around impermeable basement walls (i.e., south), and then into FC-2. From the Oil Burn Pit #1 area, groundwater still flowed towards the northeast and then into FC-2 (but not into the new section south of B371). Flows from the source area were not influenced by the new drainage and borrow pit area to the northwest.

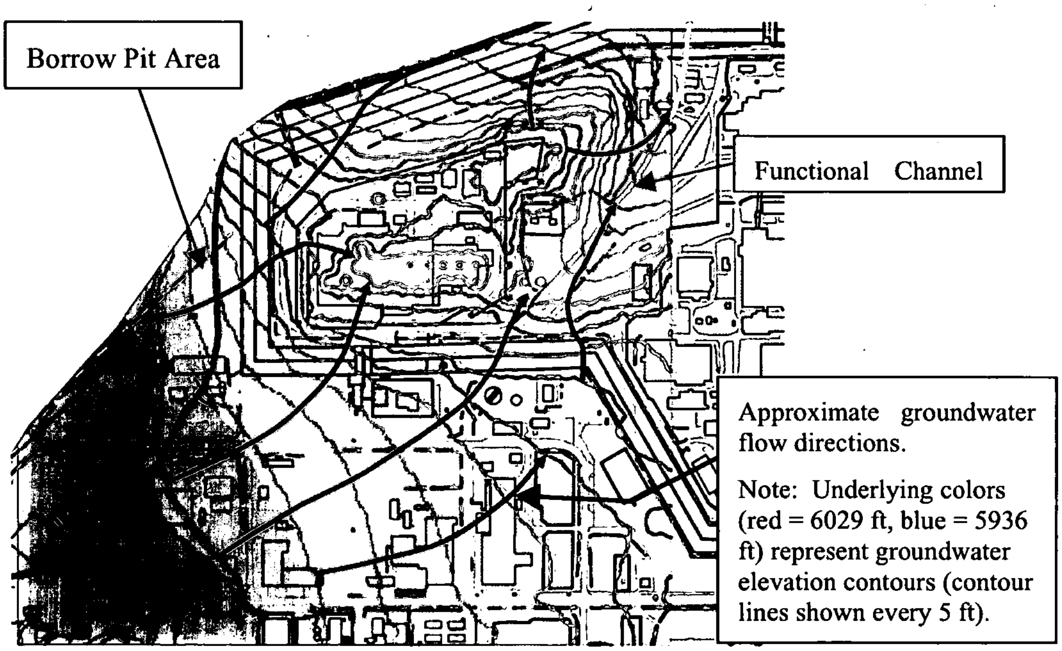


Figure 2.33 Simulated Groundwater Levels and Flow Directions – Current Conditions.

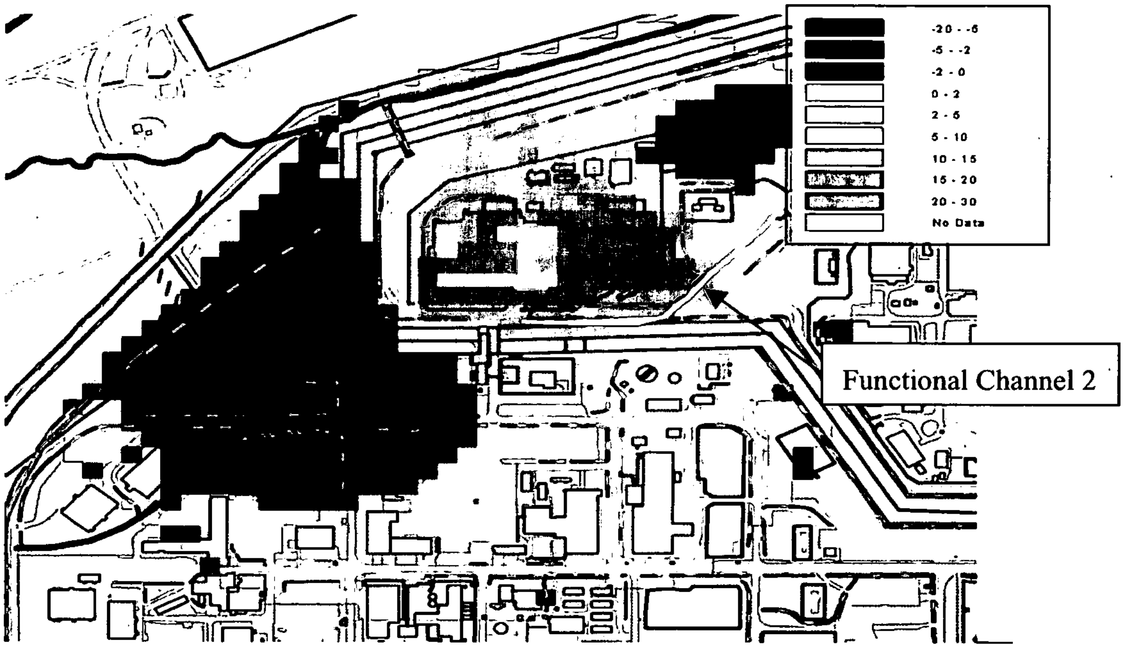


Figure 2.34 Change in Simulated Groundwater Levels (ft) From Current to Closure Configuration. Positive indicates increase in levels, negative indicates a decrease.

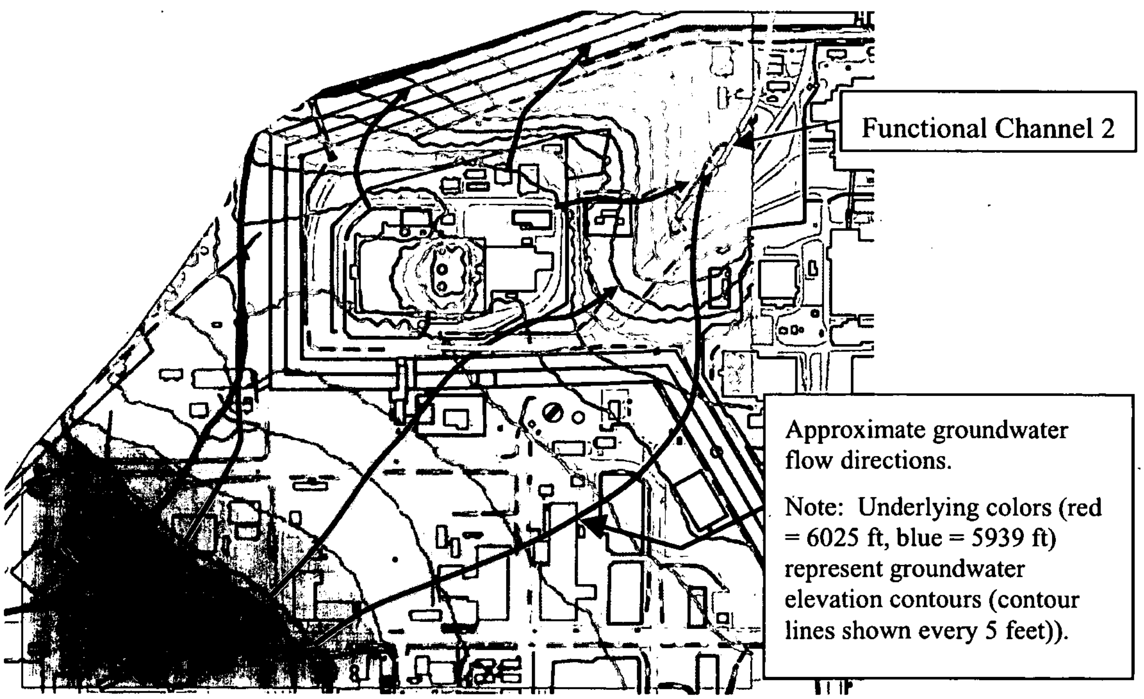


Figure 2.35 Simulated Groundwater Levels and Flow Directions – Closure Conditions.

2.6.3.5 B776/777 - Dust Suppression Model

Continuous and extended periods of the application of dust suppression water can cause groundwater levels surrounding former B777 and B776 to saturate the ground surface and affect both surface and groundwater. Once saturated, runoff can increase dramatically over the surface, either from individual precipitation events, or continued dust suppression water spraying. Higher groundwater levels surrounding the former B777 and B776 building footprints will cause increased gradients away from the building in all directions. Which may in turn, affect existing VOC plume configurations north and west of B777 and B776. Changes to the groundwater gradient and water levels may also affect currently planned source remediation of the IHSS118.1 CCl_4 plume source area immediately north of the former B777/776 area (shown on Figure 2.36).

A local-area integrated flow model was developed to evaluate the possible hydrologic effects of both short- and long-term dust-suppression applications over the footprint of the former B776 and B777 area (Figure 2.2). The model was based on the existing, calibrated IA VOC flow model (Section 2.4). Figure 2.36 shows the model boundary, and boundary conditions imposed on the flow model.

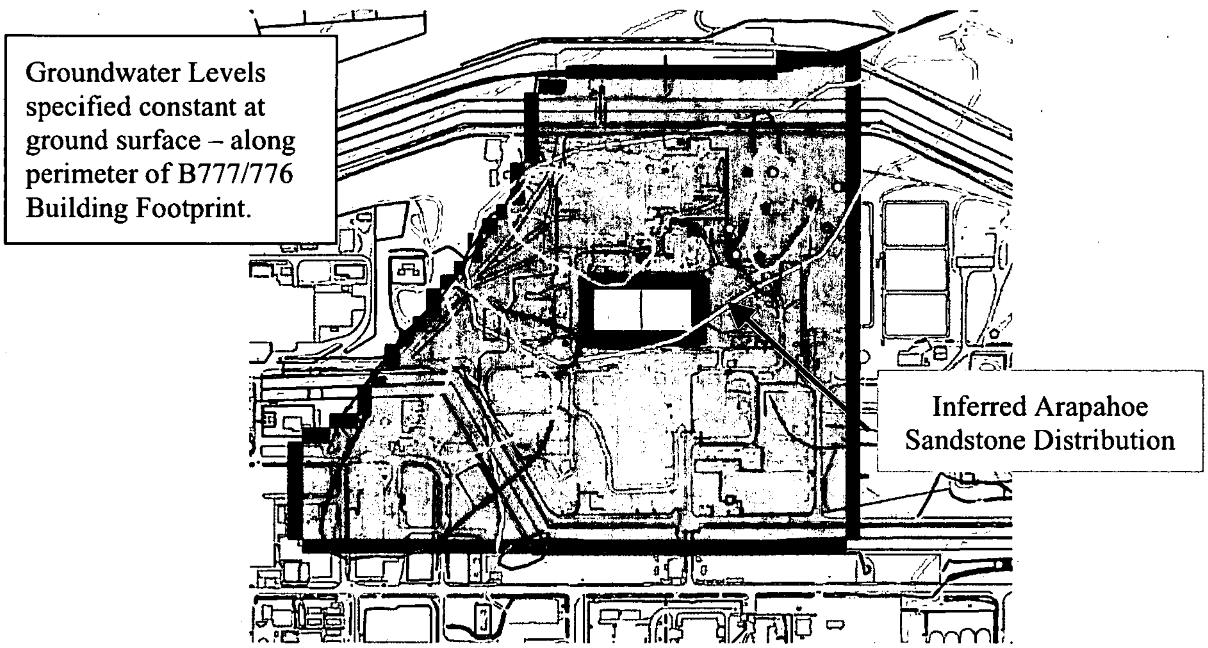


Figure 2.36 B777/776 Integrated Surface-Goundwater Flow Model Boundary.

In this model, the ground surface within the former B776/777 footprint was assumed to be continuously saturated for three months. This assumption was conservative. Although the model considered preferential flow in utility conduit backfill material, it assumed that sanitary, footing, storm, and process waste lines were plugged. It was also assumed that the tunnel and any permeable backfill material between B776 and B771 were fully disrupted.

Approach and Assumptions

Several factors were believed to affect the response of the groundwater levels in the vicinity of B777/776 area due to dust suppression water application. These are summarized below:

- Spray flow rates;
- Locations and rates of possible infiltration (i.e., localized, unlined ditches to detention pond);

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- Depth to bedrock;
- Arapahoe Sandstone occurrence and distribution in bedrock;
- Climate sequence characteristics (i.e., frequency, durations, intensity and type – snow/rain, temperature);
- Snow removal and placement; and
- Effects of the B771/774 closure, deactivation of surrounding footing drains, and other nearby land configuration modifications (i.e., pavement removal, subsurface utility deactivation, etc.)

Not all factors that affect the integrated flow response near B777 and B776 could be defined accurately in the integrated model due to uncertainty. As a result, the approach used to evaluate possible response due to dust suppression spraying was based on a relatively conservative assumption. To simulate the effect of the dust suppression activities, it was assumed that groundwater levels remain at ground surface along the perimeter of the B777 and B776 building slabs for a three month duration. A localized integrated, surface-groundwater flow model was prepared using the IA 60-ft MIKE SHE model used as the basis for fate and transport analysis of VOCs within the IA (see Figure 2.1).

Although the integrated flow model is capable of simulating the dynamic response of the surface flow system to the dynamic response of groundwater levels caused by infiltration of dust suppression spray water, the focus here is only on groundwater response. It is assumed that surface runoff is contained under all conditions.

Dust Suppression Model Results

Results showed that groundwater levels increased surrounding the former B777/B776 buildings due to maintaining constant groundwater levels at ground surface around the buildings for three months, though the magnitude was limited. Figure 2.37 shows the change in groundwater levels after 3 months. Results indicated water levels increased between 1 and 2.4 m only within approximately 200 feet from the building perimeter. The propagation of the increase in groundwater levels was most significant on the northern side, but part of this was also caused by B771 decommissioning effects.

Changes in groundwater levels one month after spraying ceased (after 3 month duration) are illustrated on Figure 2.38. Simulated levels decreased from 0 to 1 m within the building footprint. Results at 2 months after spraying ceases indicated continued decrease of groundwater levels between 0.3 and 1.4 meters within and surrounding the footprint to within 100 feet. This suggested it takes longer for the groundwater levels to decline than increase.

While groundwater levels in the immediate vicinity of former B777/776 declined after spraying ceased, levels north of B771 might increase as a result of delayed groundwater flow response (see Figure 2.38) and release of confining pressure within the Arapahoe Sandstone. Although, the

exact configuration of the Arapahoe sandstone in the B771 area is uncertain, it possibly subcrops the unconsolidated material as simulated in the model. In this case, the Arapahoe sandstone may preferentially channel flow to the hillside north of former B771, though this depends on the exact configuration of the sandstone.

Recommendations

Several recommendations were made based on the integrated flow modeling described above. The following recommendations were made:

- The area subject to surface runoff from dust suppression activities associated with the B777/776 demolition should be minimized to the extent possible;

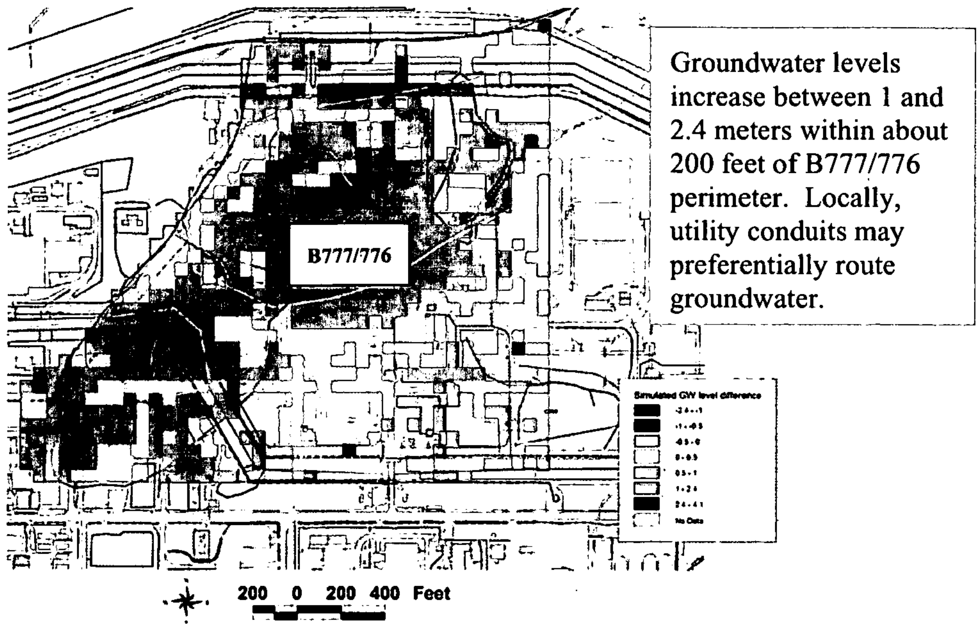


Figure 2.37 Change in Groundwater Levels (m) – After three months Positive (red) denotes increase, negative (blue) denotes decrease.

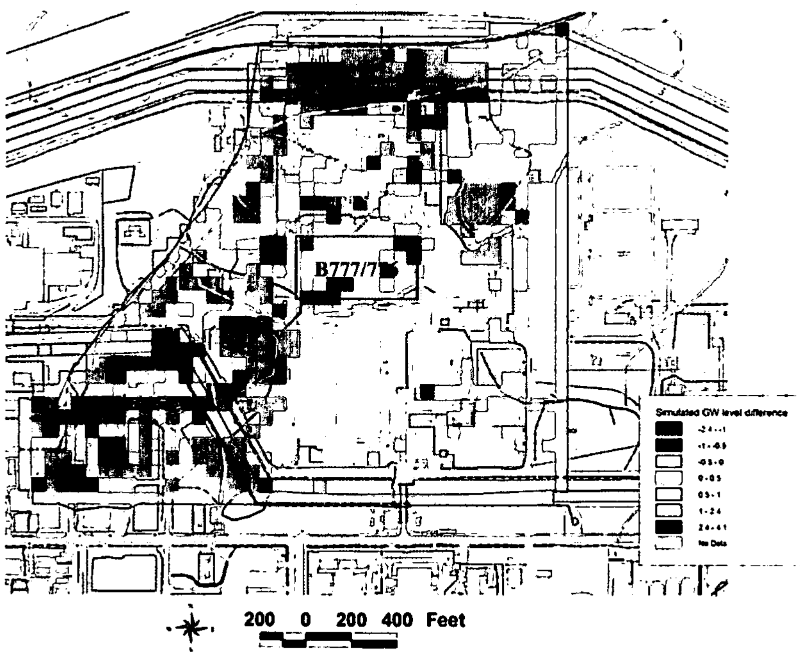


Figure 2.38 Change in Groundwater Levels (m) – (One month after spraying stops). Positive denotes increase, negative denotes decrease.

- Increased surface saturation may cause increased surface runoff outside of the controlled area. This should be monitored; and
- Particular care should be used in preventing increased heads in the 118.1 area. Model results show increased heads are possible in this location. IHSS118.1 Hydrogen Release Compound

(HRC) accelerated action immediately north of former B777 and B776 may be impacted. Increased VOC concentrations may be observed downgradient of the source area, possibly exacerbated by preferential flow through the Arapahoe sandstone. One recommendation is to maintain dewatering of the DNAPL source area for the duration of the former B777 and B776 demolition.

2.6.3.6 B444 Model

The model boundary for the B444 area is shown on Figure 2.39. The model boundary includes the entire B444 structure and the associated basement in the south eastern corner. The model boundary to the south coincides with Woman Creek. The remaining east, north, and west boundaries were placed far enough away to limit effects on internal model cell calculations.

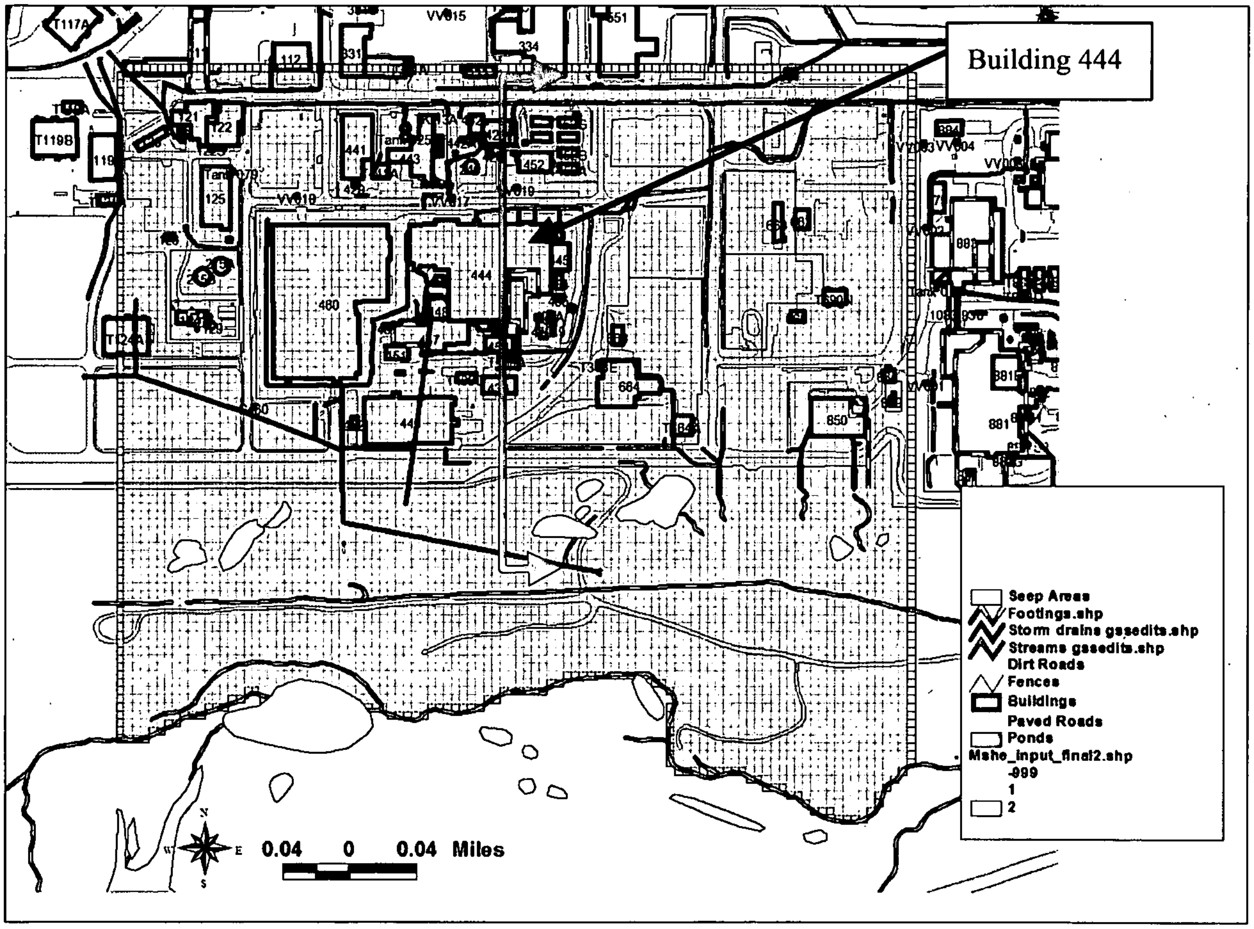


Figure 2.39 Model Boundary and Buildings of Interest – B444 Model Area.

Arapahoe Sandstone is present in the northern portion of the model area. The sandstone subcrops only the northernmost part of its northeast trending extent. Current groundwater depths in the former B444 area are relatively deep compared to other areas within the IA, ranging from about 2 to 6 m. Part of the reason for this is due to the effect of the deep building foundations around B444. It is also due to the relatively thick unconsolidated material in the area as well, which ranges from about 4 to 9 m as shown on a vertical profile through the building (Figure 2.40).

Only a single closure configuration was simulated for the former B444 model area. A wet-year climate was specified for the closure configuration with building footing drains deactivated. For the closure configuration, the surface topography over the Original Landfill (south of former B460 and B444) is re-graded and the SID surface drainage feature removed.

A conservative fate and transport model was developed to address concerns about the potential for uranium detected on the internal basement walls and floor to enter the UHSU groundwater flow system. Because estimating the fate and transport of uranium in groundwater is complex, depends on many geochemical factors, and is uncertain, a conservative modeling approach was adopted. Long-term concentration distributions and migration pathways were estimated using the USGS fate and transport code, RT3D (Clement, 1997) and the conservative Advective-Dispersive Transport module coupled with the integrated flow model, MIKE SHE (DHI, 2000).

Two conservative scenarios were simulated to assess the fate and transport of uranium in groundwater from the B444 basement. In the first scenario, very conservative assumptions for transport process parameter values and uranium source concentrations are used. The second, more likely scenario, though still conservative (i.e., over-estimates uranium concentrations in groundwater) considers the effects of sorption alone on the fate and transport of the uranium. These scenarios, and the assumptions made for source concentrations and transport processes, are described further below.

In both model simulations, it was assumed that the entire estimated inventory of uranium (~2.6 Kg) was instantaneously introduced into the groundwater (into a single 25-ft by 25-ft model grid cell) in the southernmost corner of the former B444 basement. In reality, it is highly unlikely that the entire uranium inventory would instantaneously dissolve immediately upon contact with groundwater. In addition, it is equally unlikely that the entire inventory would concentrate into a single model cell because leakage would probably occur throughout the basement footprint.

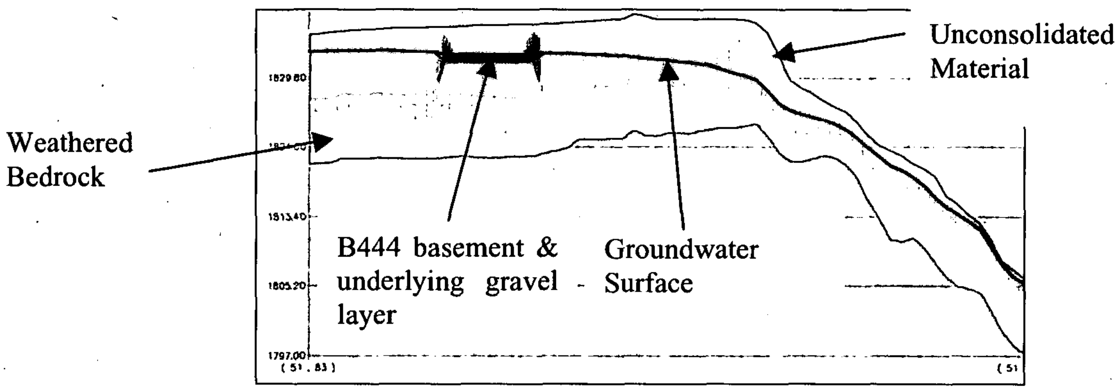


Figure 2.40 North-South Hillslope Profile (viewed to east) through B444 Building and Basement.

Closure Configuration Simulation Results

Simulated mean and minimum annual groundwater depths for the former B444 model closure configuration (for a wet-year climate) are shown on Figure 2.41 and Figure 2.42, respectively. The mean annual groundwater depths represent an average value resulting from a 100-year wet-climate sequence. The minimum annual simulated groundwater depths reflect the response after the wettest part of the year.

Simulated depths surrounding the B444 basement remained well below the ground surface. Mean annual simulated ranged from about 1.5 to 5.5 m below grade, while minimum annual depths increased about half a meter. Simulated groundwater depths remained greater than 8 meters immediately south of B460 and B444, but north of the SID. Simulated mean annual groundwater depths were less than 1 meter in the central model area extending from Woman Creek to north of the SID, where former seep areas have been identified by the USGS (Figure 2.41). Figure 2.42 showed that minimum annual groundwater depths

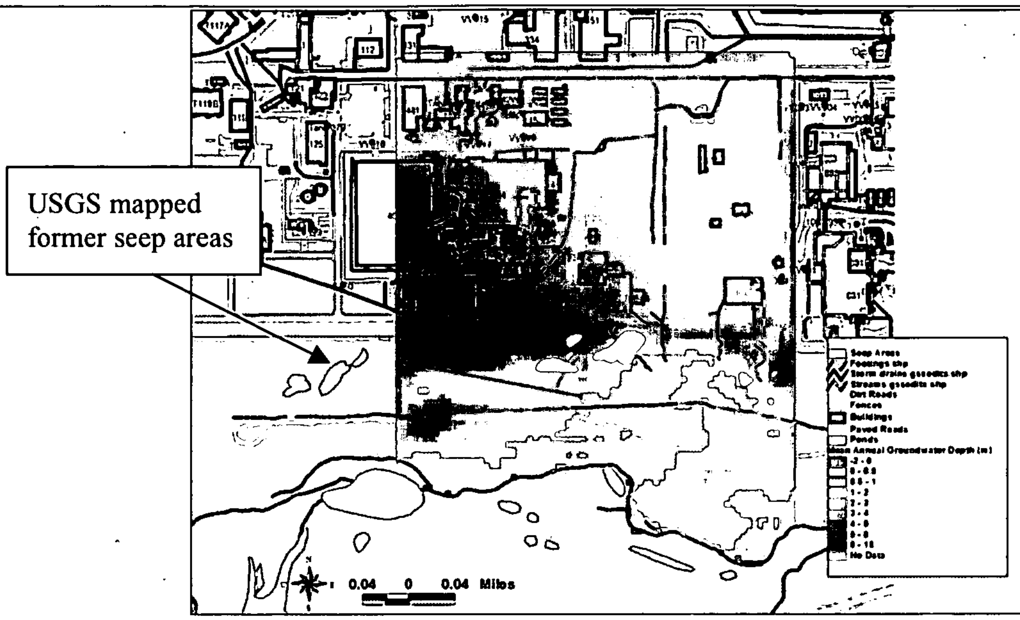


Figure 2.41 Simulated Mean Annual Groundwater Depth (m)

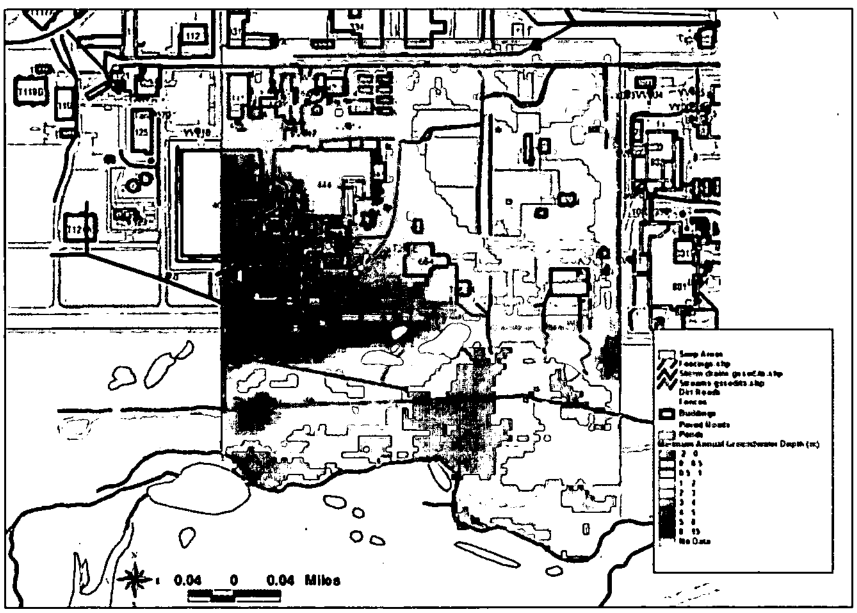


Figure 2.42 Simulated Minimum Annual Depth to Groundwater (m).

were less than one meter in the same area. Minimum depths were also simulated to be less than 1 meter for most of the area east of the former B444 area.

Simulated annual groundwater elevations with time surrounding the B444 basement are illustrated on Figure 2.43 for a wet-year climate sequence. The horizontal line on Figure 2.43 represents the internal surface elevation of the basement slab. Model results indicated that simulated groundwater elevations surrounding the basement were above the slab elevation most of the year at all surrounding cells. Model results also indicated that groundwater elevations within the basement footprint could be even higher. However, this depends on the assumed effective permeability of the basement walls/slab. In this simulation, the effective wall permeability was assumed similar to unweathered bedrock values. Simulated groundwater levels would be higher if the wall/slab permeabilities were assumed lower, and levels would be lower if permeabilities were assumed higher. It is likely that groundwater levels would be higher within the basement footprint, than outside. Because this would cause a continuous outward flow gradient, it implies that any uranium on the internal basement walls/slab would migrate outward and its flux would depend on the effective permeability of the basement concrete.

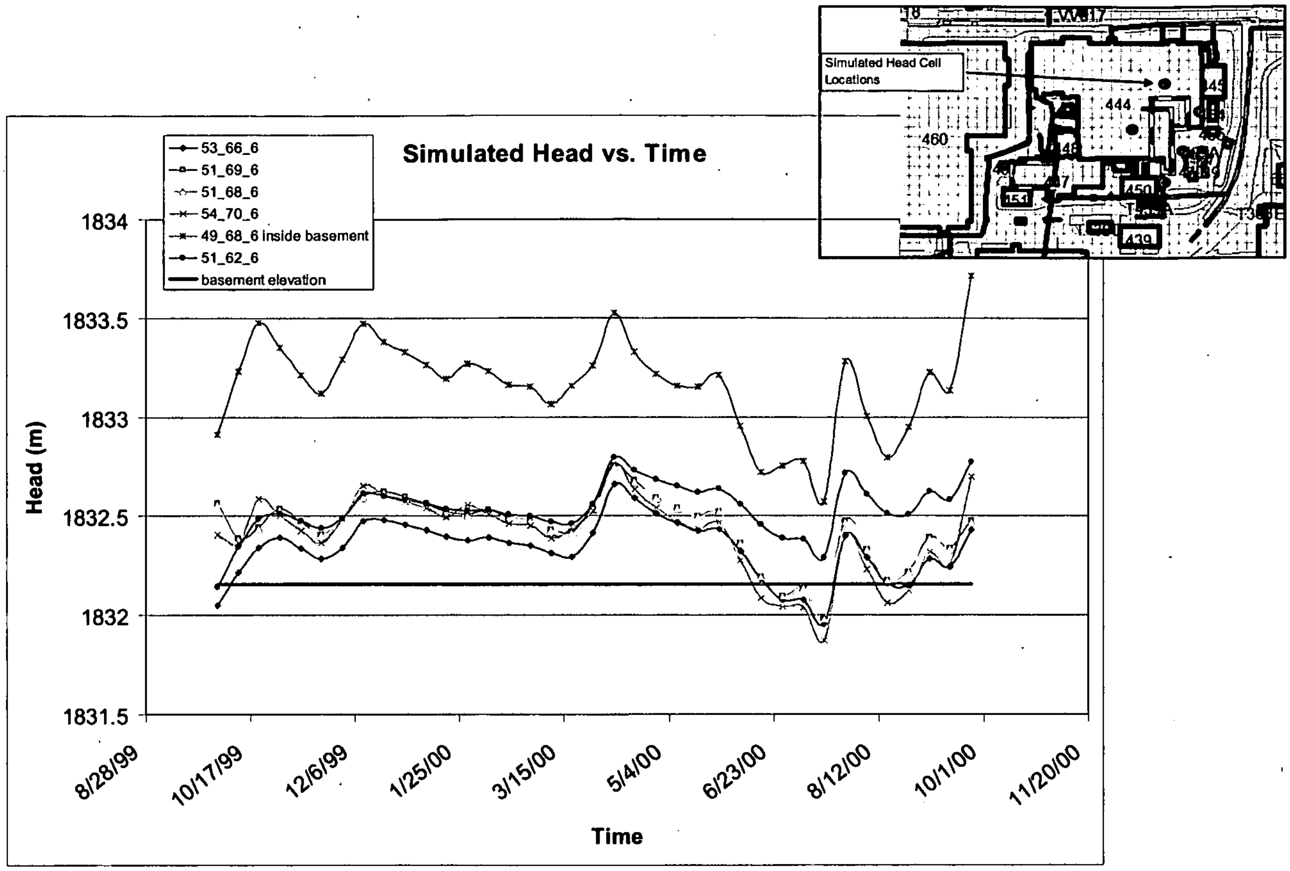


Figure 2.43 Simulated Groundwater Levels With Time in B444 Area.

Simulated average annual groundwater flow paths for the unconsolidated material for the wet-year climate are shown on Figure 2.44. Simulated average annual groundwater flow paths for a typical climate sequence (i.e., WY2000) deviated little from the wet-year paths shown on Figure 2.44. Groundwater flow near the former B444 basement was routed around to the north and south due to the lower assumed concrete permeability (walls and slab). From the former B444 basement, simulated groundwater flowed predominantly towards the east to northeast. Groundwater south of the B444 basement area flowed east, and then southeast towards Woman Creek. Flow directions were more variable in the former B444 and B460 area compared to other areas within the model because of the high density of utility corridors in the area and the basement structures left in place. The effect of higher permeable backfill material associated with the subsurface utility corridor was included in the closure configuration model.

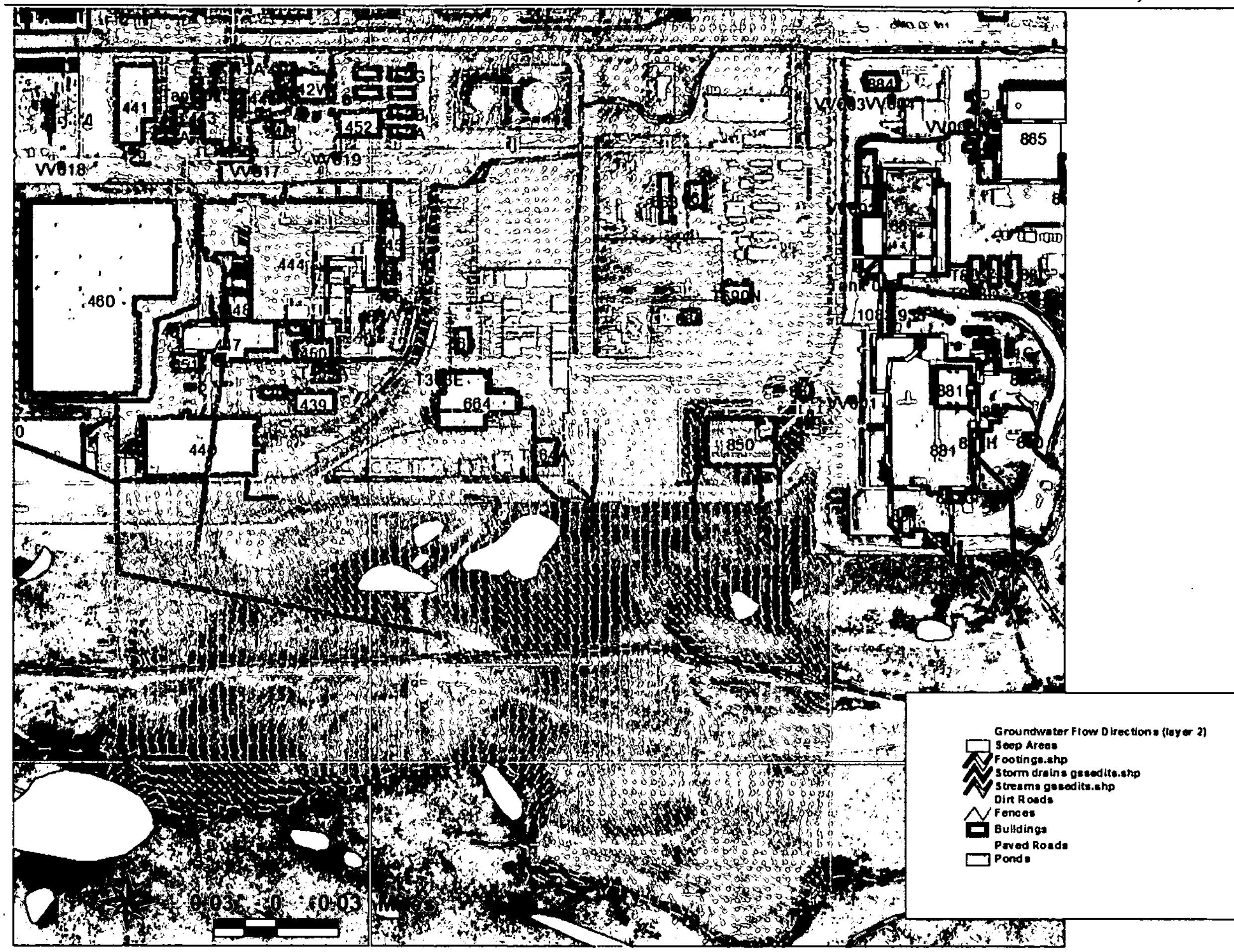


Figure 2.44 Simulated Groundwater Flow Directions – Unconsolidated Material.

Based on the modeling conducted for the former B444 area, several conclusions were drawn. These included the following:

- The basement slab associated with B444 would likely be saturated most of the year. Only lower portions of the external wall would likely be saturated, while a greater portion of the internal wall might be saturated throughout the year. This would depend on the effective basement wall/slab permeability;

- Model-simulated groundwater depths around the B444 basement slab/wall remained well below the ground surface for a wet-year climate sequence; and

- Flow would likely be outward from the basement footprint due to higher internal water levels (within the basement) relative to external levels (outside the basement). The rate of flow would depend on the effective permeability of the basement walls and slab.

2.6.3.7 Former B460 Model

The purpose of the former B460 model was to assess the hydrologic effects of leaving the B460 slab in place, rather than removing it as in the original proposed SWWB closure configuration. The latest version of the OLF integrated flow model (see 2.5.2) was used to perform this assessment. The B460 model boundary, relative to other model boundaries, is shown on Figure 2.2

Results shown on Figure 2.45 indicated that localized mounding occurred at the perimeter of the B460 floor slab left in place, even for a typical year. In addition, simulated average annual flow paths in the area immediately south and east of the B460 slab were redirected in a more southeast direction compared to the case without the slab. Recent information on the actual closure configuration for the B460 slab indicated that holes were created frequently throughout the slab. This will reduce the buildup of perched levels above the slab and localized mounding at the perimeter.

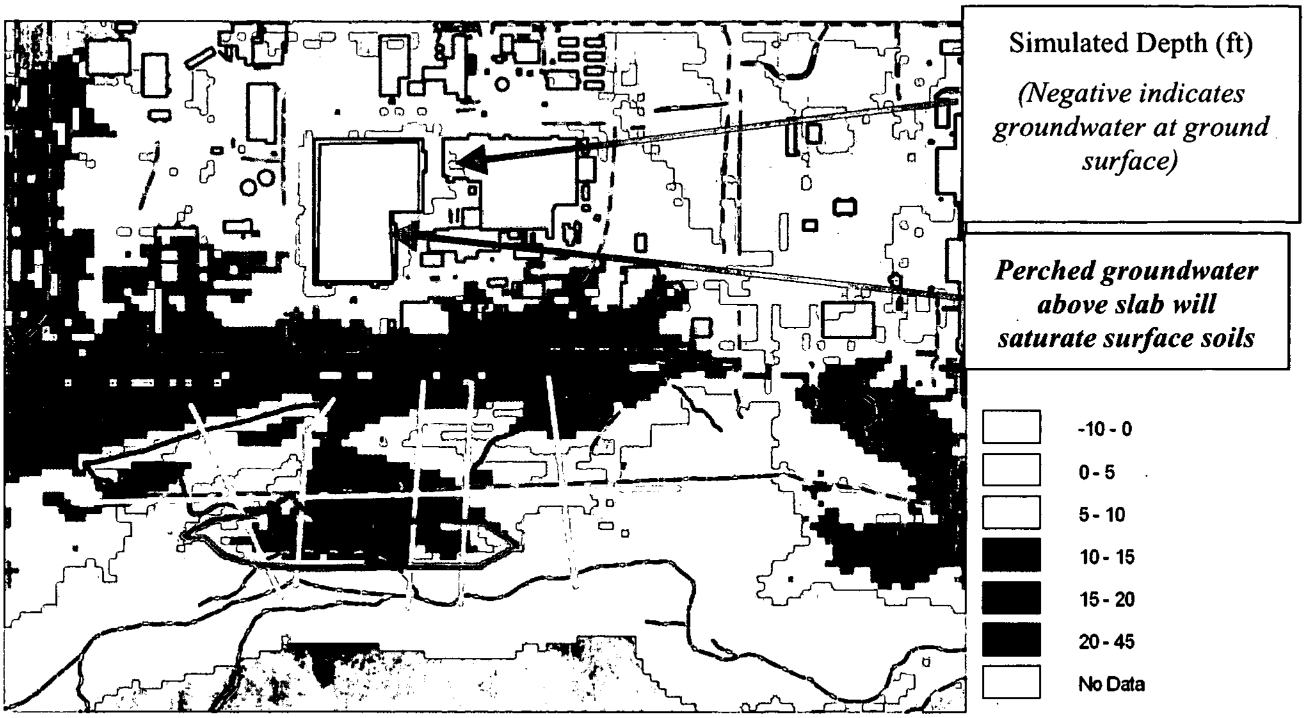


Figure 2.45 Minimum Annual Simulated Groundwater Depth (ft) – Typical Climate Year (WY2000).

2.7 Accelerated Action Modeling

2.7.1 Mound Plume Treatment System Model

To more accurately represent the local-scale groundwater capture zones associated with the Mound Plume Treatment System collection trench and associated French drain, a fully integrated hydrologic flow model was developed using a 10-ft by 10-ft grid. The increased grid resolution also allowed for improved simulation of the local hydraulic effects around the 72-inch storm drain pipe. Figure 2.46 shows the locations and features included in the integrated model domain of the Mound Plume Treatment System.

The model extent was defined so that inferred VOC sources (i.e., Mound Site and Oil Burn Pit #2), current observations, and estimated contaminant distributions (plumes) could be modeled. Lateral boundary conditions are located far enough away from plume areas and don't influence flow or fate/transport calculations in these areas.

Development of the integrated flow model for the most recent closure configuration involved two steps. First, because the model grid resolution is high, the hydraulic conductivity and drain conductance values had to be modified to improve model performance. Model performance was iteratively improved by adjusting key model parameter values so that the difference between simulated and observed average

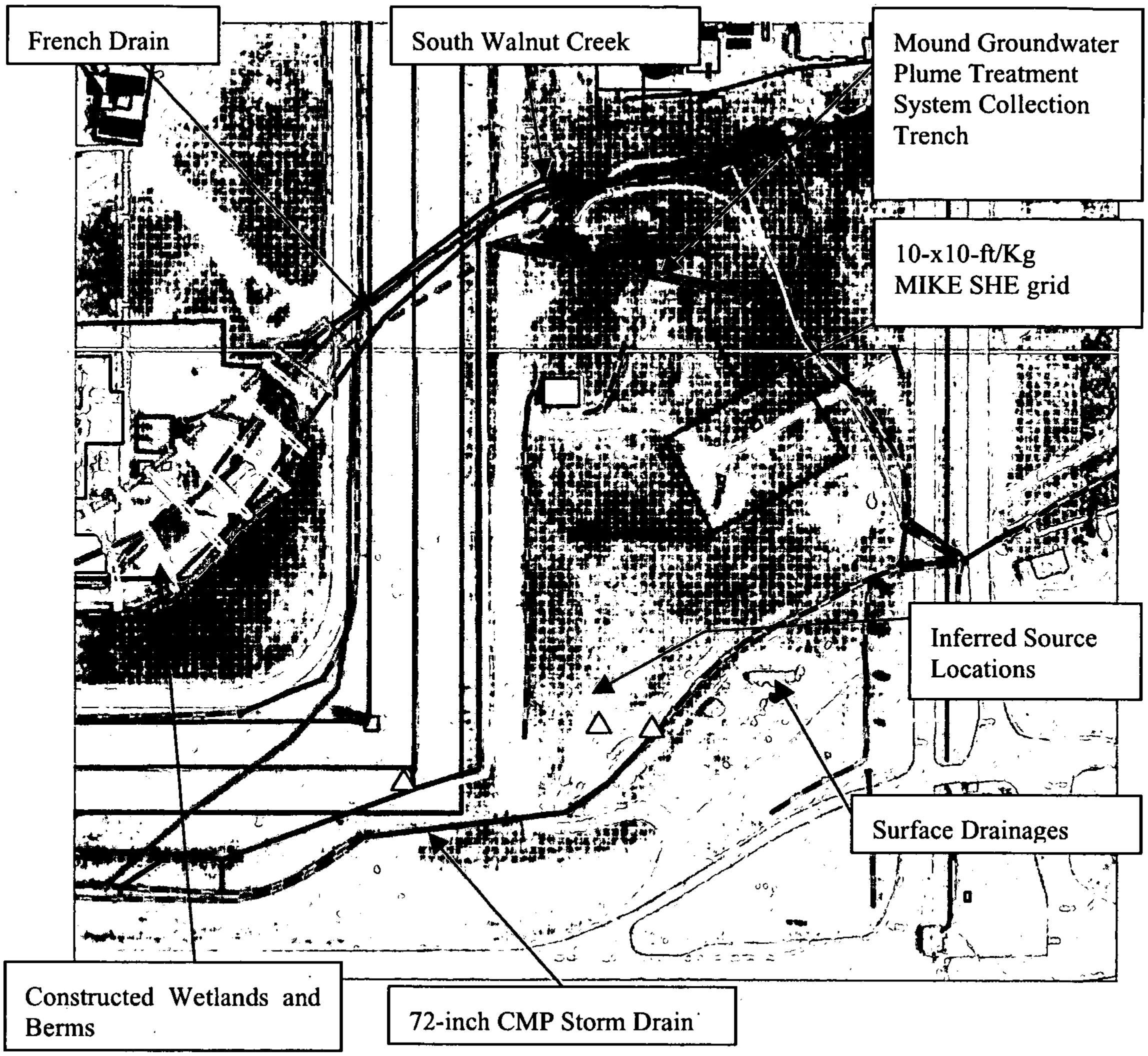


Figure 2.46 Integrated Flow Model Grid and Key Model Features.

annual water levels and trench discharge was minimized. Information on observed water levels and collection trench discharge were obtained from the Soil and Water Database (SWD) and automated flume gauging information from 2000 to 2004, respectively. Although available field information on the 300-ft long French drain is limited, it was assumed that the 300-ft long French drain intercepting the western part of the trench collection system was emplaced at the weathered bedrock surface within the unconsolidated material. Secondly, recent updates to the RFETS land configuration including surface regrading, drainage realignment and a constructed wetland area along South Walnut Creek, immediately north of the Mound Plume Treatment System were applied to the current flow conditions. This step is referred to as the closure scenario.

Previous integrated flow modeling of the groundwater system in the Mound and Oil Burn Pit #2 areas (K-H, 2004b) was based upon an interpolated bedrock surface constructed using data available at the time. Since then, a significant amount of additional data on bedrock depths became available (i.e., geoprobe information in the Oil Burn Pit #2 area and test trench information in the South Walnut Creek drainage immediately south of B991). A new bedrock surface was constructed and is shown in Figure 2.47.

Results of the re-interpolated bedrock surface show that the area immediately north of the Oil Burn Pit #2 and to the northwest is much shallower than previously estimated (greater than 10 feet change in some areas). Preliminary modeling showed this change causes groundwater to flow in a more northward direction rather than northwest as previously simulated.

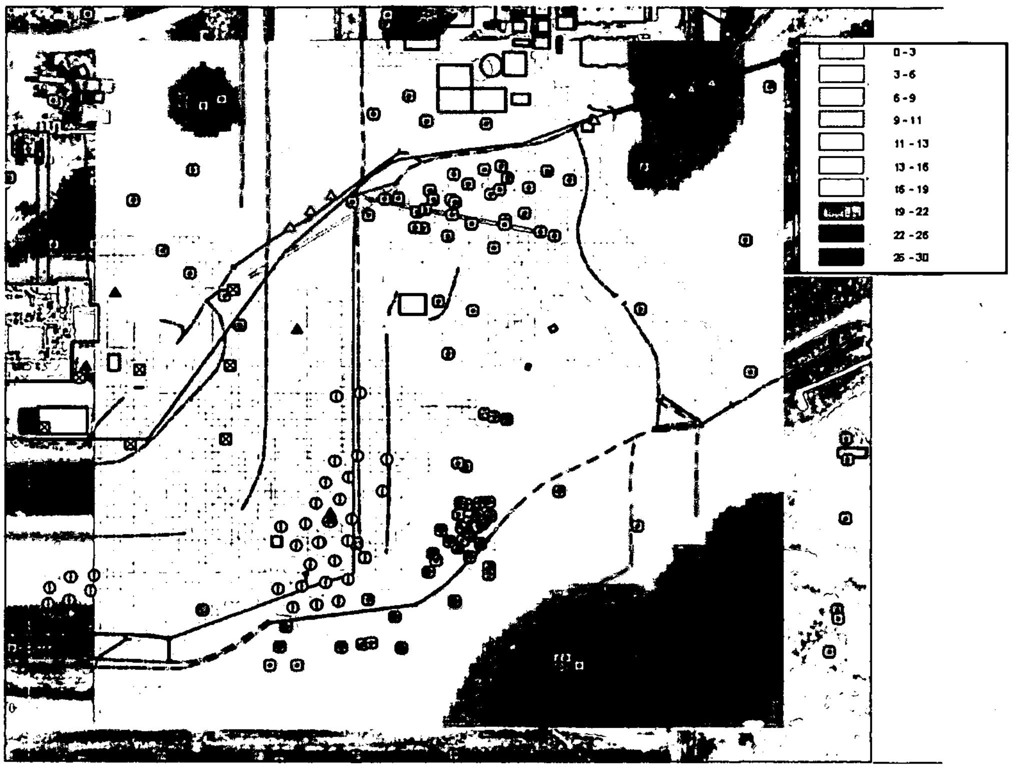


Figure 2.47 Revised Depth to Weathered Bedrock (ft) (Control Points Shown).

Results of simulating current conditions showed that the refined integrated flow model reproduced both groundwater levels and trench discharge rates well. Average annual simulated water levels are within 2 feet of time-averaged observed water levels throughout the model area. The model simulated discharge rates slightly higher than observed (as shown in Figure 2.48) probably because of local variability in hydraulic properties that were not accounted for in the model. Observed discharge from 2000 to 2004 shows higher initial discharges, suggesting it took several years for discharge rates to stabilize. The model reflects only the first three years of operation.

2.7.2 IHSS118.1 – Dewatering Model

Subsurface Tanks 9 and 10 are located immediately east and within the same excavation pit associated with the former 5,000-gallon subsurface tank that leaked and created the former CCl_4 DNAPL (IHSS118.1) between the former B771 and B776/B777. Tanks 9 and 10 consisted of two 22,500 gallon and two 4,500 gallon tanks, respectively. These tanks were removed and attempts were made to remove existing DNAPL. Prior to removal surrounding groundwater levels were reduced below a sandstone lens, immediately subcropping the unconsolidated material in the area. This step was taken to reduce the potential for increasing local concentrations of CCl_4 in the shallow aquifer. To predict the quantity and time necessary for dewatering the former excavation pit used to construct the subsurface tanks, a localized saturated zone model was produced and summarized here.

Approach

The USGS MODFLOW2000 code was used to simulate saturated zone flow conditions surrounding the former pit excavation area associated with the tanks. The MODFLOW model was prepared within the

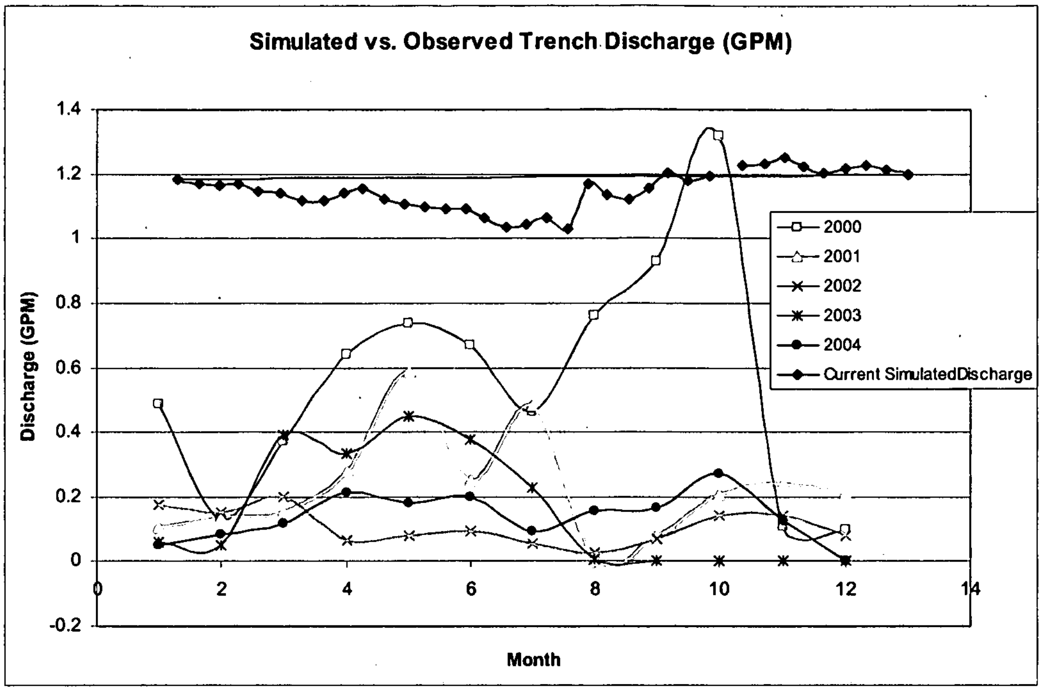


Figure 2.48 Simulated Trench Discharge (Gallons/Minute – GPM).

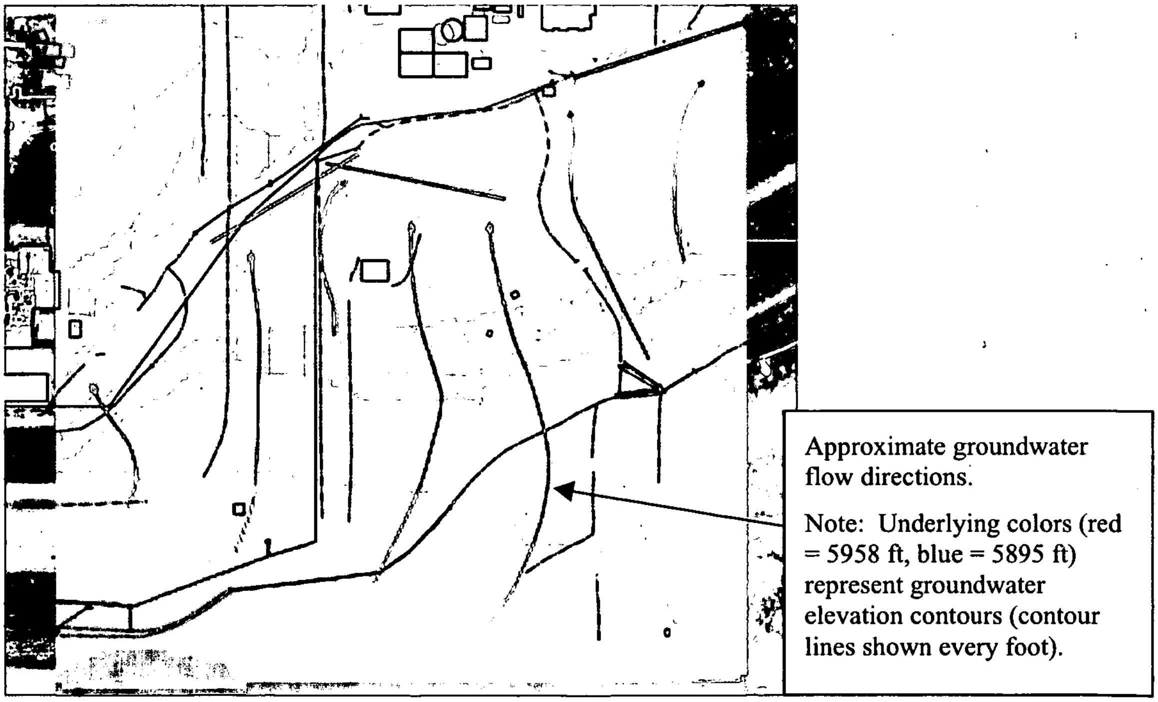


Figure 2.49 Simulated Current Condition Groundwater Levels (ft) and Flow Directions.

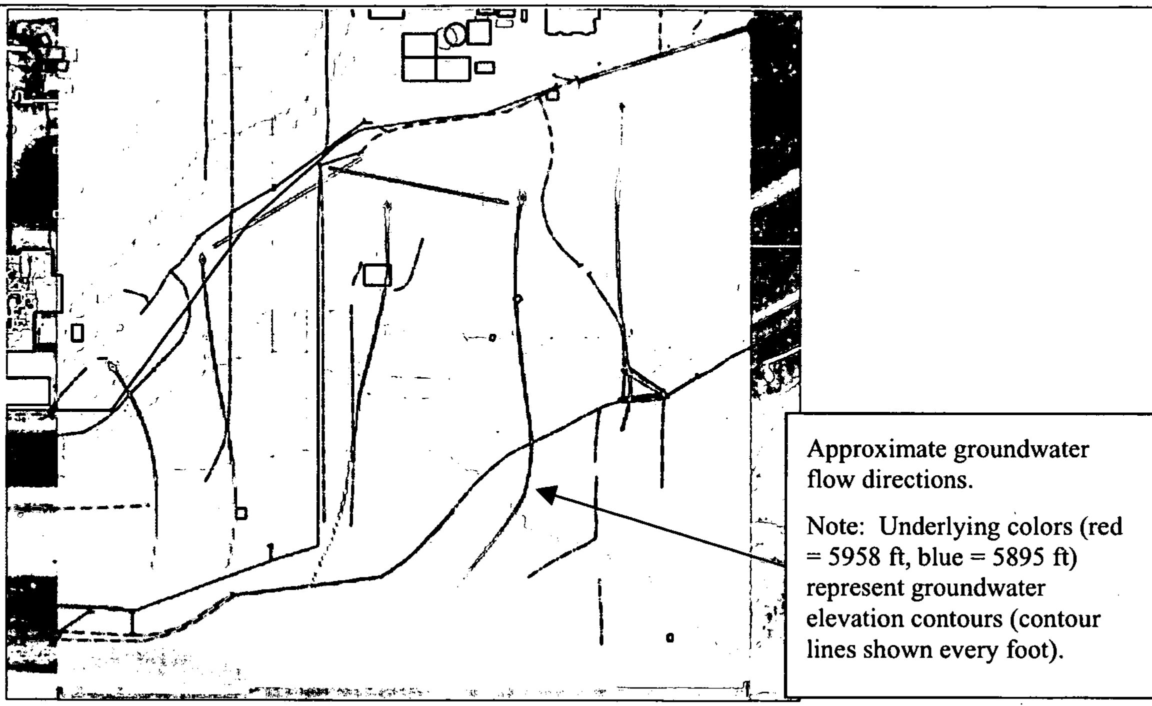


Figure 2.50 Simulated Closure Configuration Groundwater Levels (ft) and Flow Directions.

Graphical User Interface (GUI) included with the Groundwater Modeling Systems (GMS) software developed by the Department of Defense (DOD). This software enabled rapid development of a fully three-dimensional groundwater flow system for the tank area. Figure 2.51 shows the extent of the

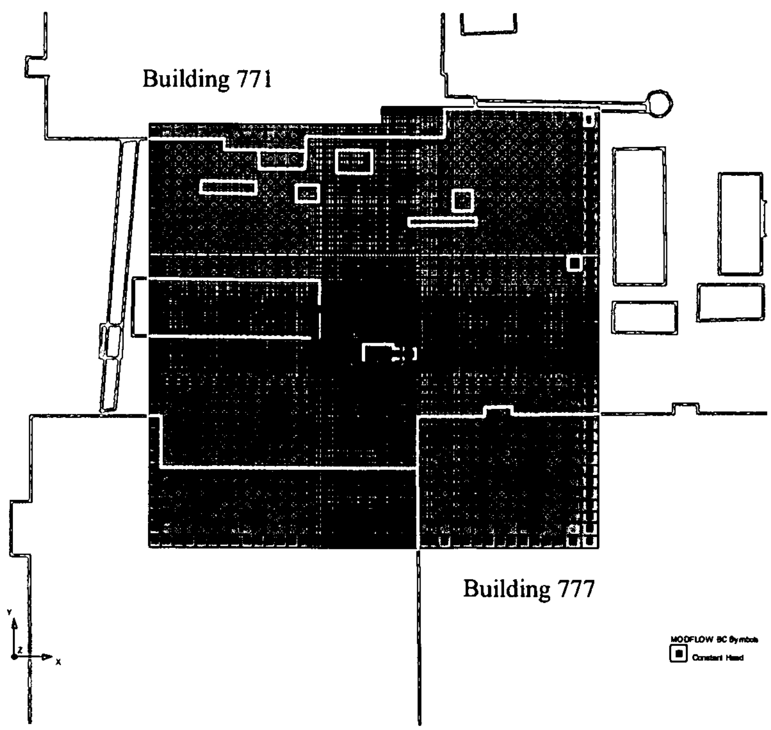


Figure 2.51 Groundwater Model Boundary.

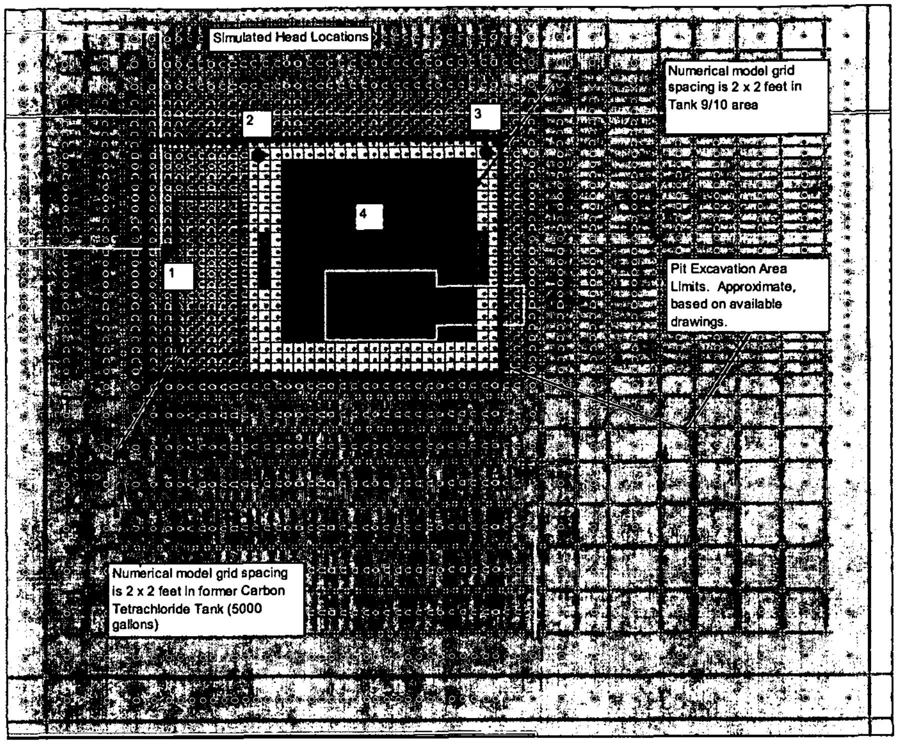


Figure 2.52 Local Grid Resolution and Model Features.

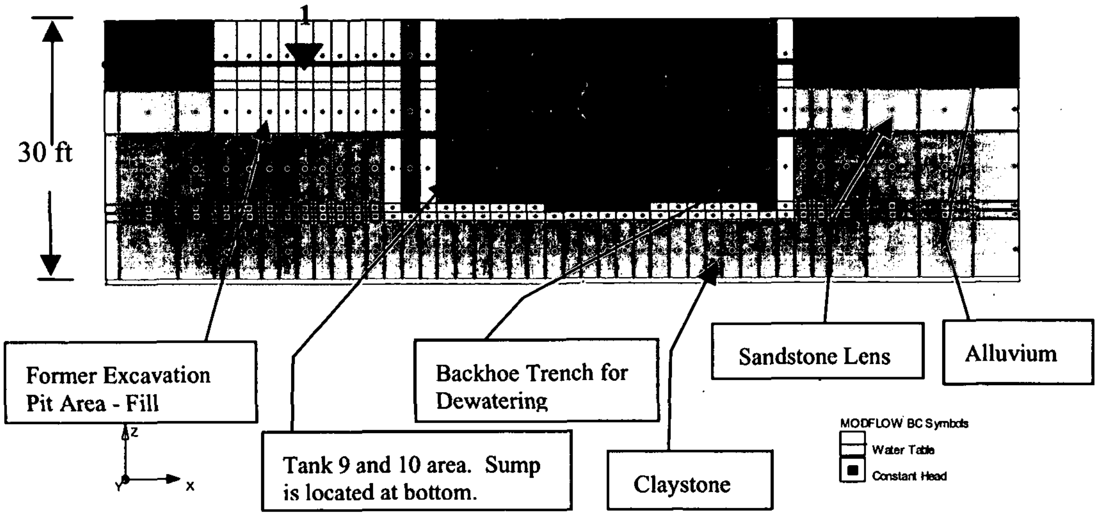


Figure 2.53 Vertical Model Layers and Key Features.

groundwater model area and former buildings (i.e., B771, B776/B777, and Building 730 (B730)). Local features affecting flows and grid resolution are shown on Figures 2.52 and 2.53.

Initial water levels were assumed to be at 7 feet below ground surface to be conservative, though levels vary between 6 and 9 feet, below ground surface annually. This depth, relative to hydrostratigraphic information, is shown on Figure 2.53 with a label 'one'. Label 'two' on Figure 2.53 refers to the depth to which the former excavation area is dewatered in the model to prevent loss of dissolved phase CCl_4 to the more regional groundwater flow system. The total depth of the model was assumed to be 30 feet. Tanks 9 and 10 are shown on the figure, extending to 23 feet below ground surface, including the underlying sump.

Dewatered hydraulic head response and discharge due to the dewatering in the two backhoe pit areas (Figures 2.54 and 2.55) were simulated with the flow model for 92 days. The model assumed that water levels in the two pits could be maintained at 15 feet below ground surface for the entire time period. Therefore, constant head boundary conditions were imposed on the model in these cells. Conservative estimates of storage were used (i.e., 0.0001 1/ft specific storage and 0.03 for specific yield). Mean values for hydraulic conductivity were assigned to each hydrostratigraphic unit, and the tank 9 and 10 area was assumed impermeable. The fill material in the former excavation area was assumed to have a hydraulic conductivity value of 15 ft/day, slightly higher than the surrounding alluvium (10 ft/day) as this material was disturbed. Results of simulations are described below.

Results

A single backhoe trench may not be capable of dewatering the entire excavation sufficiently to the levels within the pit. Results of simulating two pits suggested as shown above showed it takes about 1-2 days to dewater most of the excavation area to 15 feet below ground surface (see Figure 2.54). This did not appear to change significantly for different storage values. Only two pits were necessary to dewater the former excavation area.

Simulated discharge showed approximately 35,000 gallons would be needed to dewater the excavation after 92 days. At later times during this period, about 200 gallons/day might be generated to maintain the lowered water levels at 15 feet, below ground surface (bgs). A greater flow would occur if dewatering was lower. This estimate was also subject to assumptions about hydraulic properties (i.e., uniform, mean values) as well as an assumption that other features (i.e., subsurface utilities, leaky water supply lines, building footing drains, or other barriers) did not affect the dewatering. The model also estimated that two thirds of the water removed from the excavation would occur within the first two days. Figure 2.55 showed how the groundwater removal rate decreases as a function of time.

Other simulations were conducted to evaluate discharge volumes and dewatering times for the former excavation area. For example, dewatering the backhoe pits to about 21 feet, below ground surface produced about 20 to 30 percent more water after 92 days than dewatering to 15 feet below ground surface.

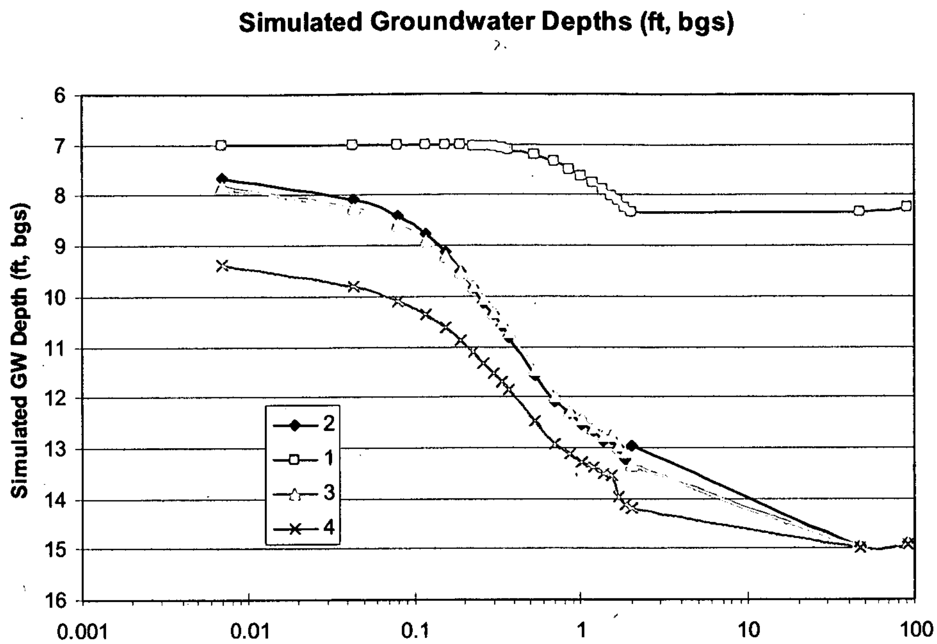


Figure 2.54 Simulated Groundwater Depths (ft) at Select Points within the Excavation.

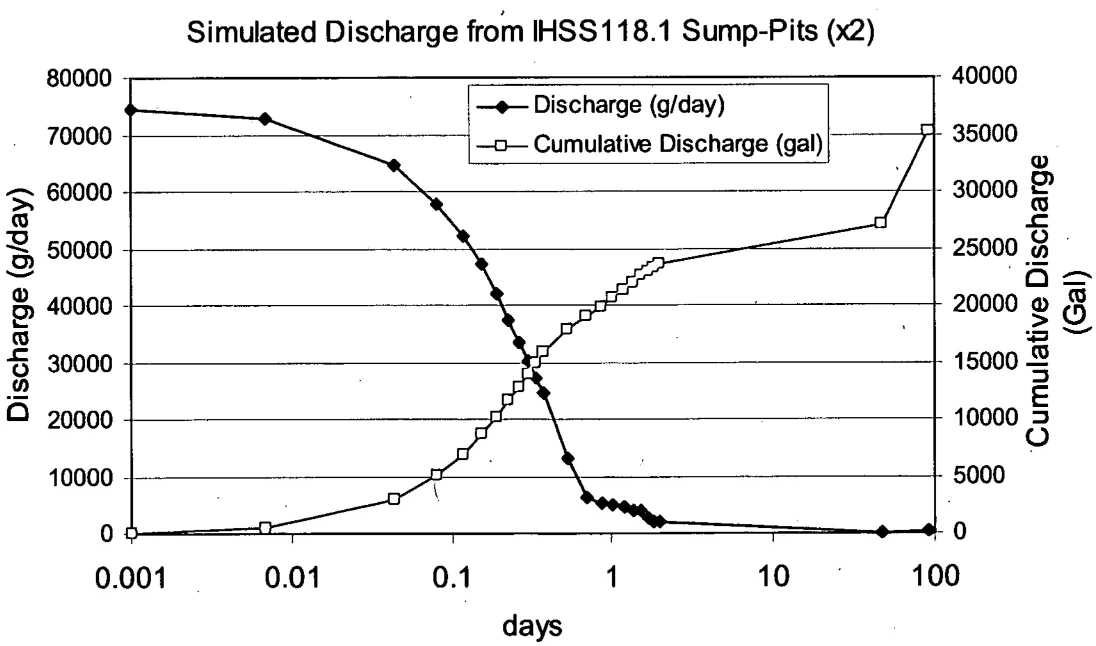


Figure 2.55 Simulated Excavation Discharge (Two backhoe trenches to 15 ft, bgs).

3.0 FATE AND TRANSPORT MODELING OF VOLATILE ORGANIC COMPOUNDS IN GROUNDWATER

The long-term, closure-configuration, fate and transport of VOCs in RFETS groundwater above draft PRGs was originally evaluated (K-H, 2004b) in Modeling Studies 14 through 22 summarized in Table A.1 (Appendix A). Several VOC-impacted areas were delineated based on a detailed evaluation of available groundwater VOC data, groundwater flow directions, and historical release information. The data review indicated it was not possible to define unique sources for each well in which VOCs were detected because of the uncertainty in locations, release times, and volumes. Despite this uncertainty, 19 distinct areas were originally defined in which VOC-impacted groundwater appears correlated with unique source locations. These areas were subsequently defined as PSAs to emphasize that the distinct VOC impacted areas can be defined, but source characteristics for each PSA remained uncertain.

By inferring locations, depths, release times, and source area release rates, it was possible to numerically simulate the long-term fate and transport associated with each PSA. A reactive fate and transport model, RT3D (Clement, 1997), was then used to evaluate the fate and transport of VOCs in groundwater because it includes the primary attenuation processes believed to be significant at RFETS (biodegradation, sorption, dispersion, and loss via ET). Figure 3.1 shows each of the reactive transport model boundaries.

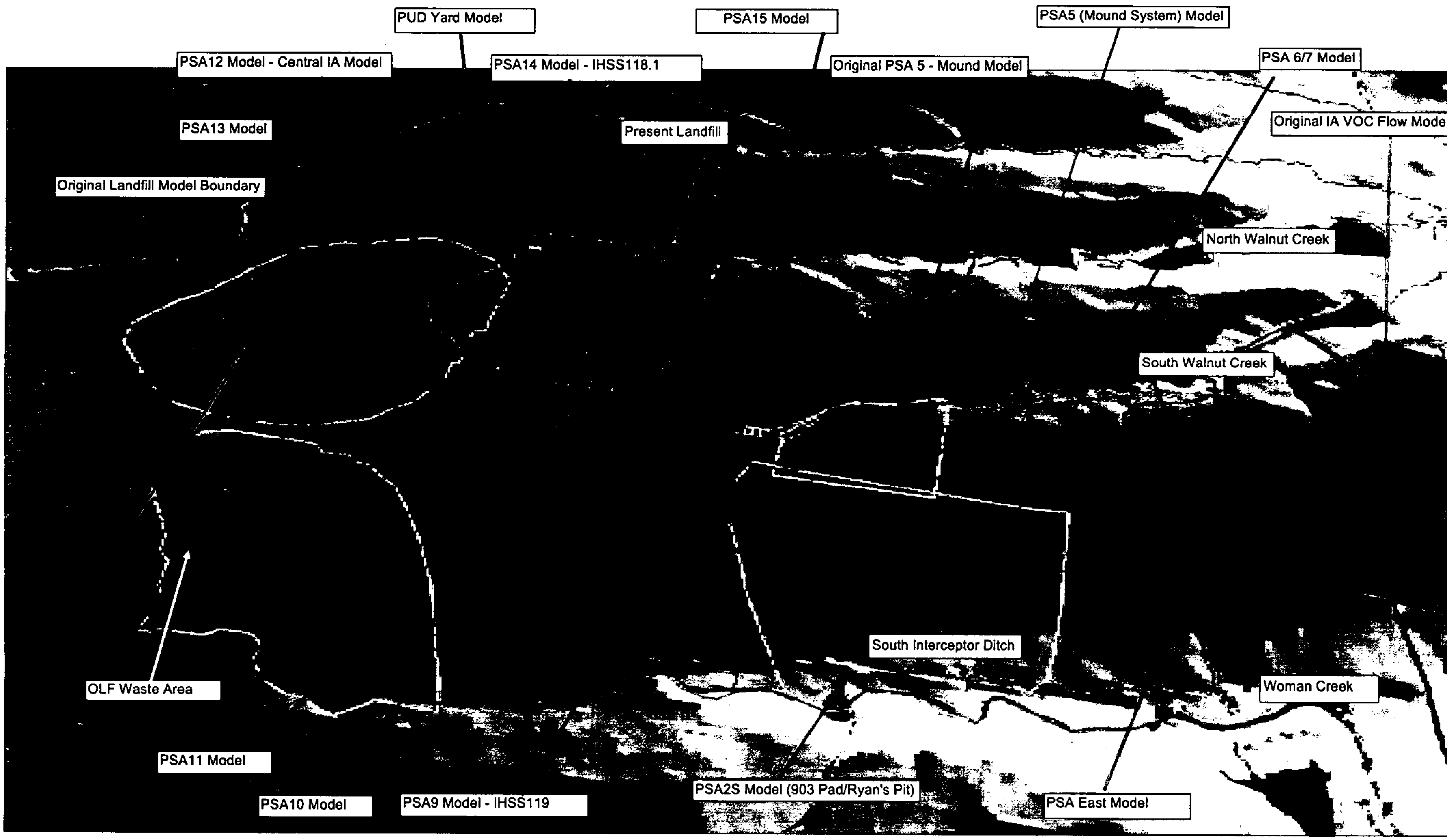
Since the original VOC Fate and Transport Modeling (K-H, 2004b), two factors that affect the original fate and transport have changed. One factor relates to assumptions originally made about the land configuration. The most current site configuration was used in the original modeling study (i.e., Fall 2003), but has been continually modified for subsequent modeling. As such, some areas had to be refined and then remodeled. In addition, instead of evaluating fate and transport based on PRGs, assessing surface water impacts has been changed to consider surface water action levels. All fate and transport modeling conducted subsequent to the original VOC fate and transport modeling study (K-H, 2004b) is summarized herein. Specific model areas shown on Figure 3.1 and summarized in Table A.1 in Appendix A include the following:

Modeled Area	Model/PSA	Contaminants
CCl_4 Plume (IHSS 118.1)	14	CT
	14	PCE
	14	TCE
B771 North-Side	14	VC
East Trenches	2N/6/7	CT
	2N/6/7	PCE
	2N	TCE
700 Area Northeast Plume	15	CT
	15	CF
	15	PCE
	15	TCE
Mound (IHSS 113)	5	PCE

Modeled Area	Model/PSA	Contaminants
	5	TCE
Oil Burn Pit #2	5	PCE
	5	TCE
903 Pad (IHSS 112)	2S	CT
	2S	PCE
	2S	TCE
Ryan's Pit (IHSS 109)	2S	CT
	2S	PCE
	2S	TCE
IHSS 119.1 (OU1)	9	TCE
	9	CT
Central IA (IA Plume Sources)	12	CT
	12	PCE
	12	TCE
East Area	EAST	CT
	EAST	PCE
Central IA (IA Plume Sources)	11	PCE
(B441/B883 areas)	11	TCE
PU&D Yard	PUD	PCE
	PUD	TCE
Oil Burn Pit #1	13	VC
B444/443	10	PCE
	10	TCE
AD module in MIKESHE B444 model	10	Uranium
Original Landfill	OLF	PCE

Several significant assumptions had to be made in the modeling the fate and transport of VOCs in groundwater. Although these clearly affect the conclusions regarding possible impacts to groundwater quality near surface discharge areas, attempts were made to be conservative. Some of the more significant assumptions included:

- Groundwater flow conditions are assumed to be constant in time (i.e., steady-state). In reality, the groundwater flow conditions vary seasonally and in response to annual variations in climate;



Note: Underlying colored grid represents current surface topography.
Colors are constant topographic elevation bands.

Figure 3.1 Fate and Transport Model Boundaries

- Although assuming steady conditions is reasonable, the model's ability to accurately reproduce observed concentration distributions is simply not possible at each well location;
- VOC source locations, concentrations, depths were all assumed, or inferred from available data. Although assumptions about VOC sources were considered reasonably justified through model calibration against available time-averaged concentration data, this probably represents the largest uncertainty in estimating long-term, closure-configuration groundwater concentrations at surface discharge locations; and
- In the original VOC modeling (K-H, 2004b), effects of the groundwater treatment systems on the long-term fate and transport of VOCs were not considered for three reasons. First, the RI/FS CRA required estimation of maximum groundwater VOC concentrations at surface discharge areas. Maximum discharge area concentrations were estimated by excluding effects of existing groundwater collection systems. Second, the model grid resolution of the original IA VOC flow model was not considered sufficient to effectively model the localized effects of the groundwater treatment systems. Effects of the Mound Plume Treatment System and french drain were considered using a much higher resolution model (see Section 2.5.1) to assess system performance in capturing VOCs in groundwater given new bedrock and french drain information.

Several sensitivity simulations were conducted in the modeling to determine those parameters which most affect fate and transport of VOCs in groundwater (K-H, 2004b). The sensitivity analysis was also conducted to determine approximate ranges over which the most sensitive model parameters reasonably reproduce observed distributions of VOCs in groundwater at RFETS. The sensitivity simulations later supported uncertainty simulations to assess uncertainty in closure configuration estimates of VOC concentrations in groundwater at surface discharge areas. The most sensitive model parameters were typically VOC degradation rates, porosity, hydraulic conductivity, source area concentrations, source depths, and sorption. The relative sensitivity of each of these parameters was found to change for each PSA.

Approximate fate and transport parameter values for each PSA model were determined through calibration against available concentration data to the extent possible. Uncertainty in model input parameter values, particularly related to source information (i.e., timing, volumes, locations, etc.), limit the ability of the fate and transport models to accurately predict future concentration distributions. In an attempt to estimate a range of possible future closure configuration concentration distributions, several model simulations were run in which values for the most sensitive parameters controlling fate and transport were adjusted over a range previously determined through parameter sensitivity simulations (K-H, 2004b). In addition, conservative sensitive model parameter values were selected which over-estimate downgradient plume concentrations based on current information. As a result, some of the uncertainty simulations over-simulate steady, or long-term concentrations downgradient of inferred source areas. Only 10 sensitivity simulations were considered, instead of the 16 simulated in the original IA VOC modeling (K-H, 2004b), because they represent a more realistic range of uncertainty in sensitive model parameters.

Although the actual number of uncertainty simulations varies for each PSA, an attempt was made to adjust only the most sensitive model parameters controlling fate and transport over a range that conservatively accounts for the range of uncertainty in simulated long-term, steady VOC concentrations for the closure configurations. In most cases, conservative fate and transport parameter values were determined for each PSA during calibration against all available time-averaged VOC concentration data. In this context, conservative refers to parameter values that result in greater VOC concentrations or distributions downgradient of inferred source areas.

3.1 CCl_4 Plume (IHSS 118.1) (PSA14 Model)

Three different models were prepared to assess fate and transport of VOCs in the former B771 area. The original IA VOC flow modeling addressed only the CCL4 associated with the IHSS118.1 source area. Model development, calibration and long-term fate and transport were described well within the IA VOC Modeling Report (K-H, 2004b) referenced in Table 2.1.

The CCl_4 degradation chain compounds were previously modeled for the PSA 14 area in the VOC Modeling Report (K-H, 2004b). The PCE degradation chain compounds were not modeled because of their relatively low concentrations in the area. However, when considering PCE concentrations in the area with respect to its surface water standard and the reduced surface water standard, modeling was warranted. As part of this newer modeling, revised closure configuration information was also used to simulate more realistic long-term groundwater concentrations at surface discharge areas. These results are described in Section 3.1.1 below.

A third model was also constructed using the same B771 reactive transport model (see Figure 3.1) as the two previous models to assess long-term fate and transport of VC concentrations immediately north of B771 that are higher than surface water standards. The results are summarized in Section 3.1.2 below.

3.1.1 PSA 14 - Simulated Groundwater PCE Sources

The PSA boundary for PCE was estimated at its surface water standard (0.69 ug/L). Though no specific PCE releases have been reported in the area, the release locations from the CCl_4 modeling (K-H, 2004b) were used as the inferred simulated PCE source locations. It is likely that some PCE (present in much lower concentrations) was used and probably released in the same locations as CCl_4. One known release is found in the area and is located north of the B776/777 area and south of former B771. This source is well known (IHSS 118.1) and NAPL has been observed (based on information from SMEs) at the interface between the unconsolidated material and weathered bedrock during field characterization. Historical release information indicates this is a Priority 1 release, identified as "Multiple Solvent Spills west of Bldg. 730", and "South End of Building 776 Solvent Spill" (HRR Reference No. 18 through 20 in Appendix A of the Fate and Transport Modeling report). The HRR describes the priority area as a CCl_4 tank discovered leaking prior to 1970. Several occurrences of leaking CCl_4 (with vague or unknown dates and volumes) were noted in the HRR both before and after this time. The source area for this release is represented by three model cells.

Another CCl_4 source was inferred west of the known release to reproduce the comparatively high time-averaged concentrations in wells located on the hillslope above the tributary between former B771 and B371. Time-averaged concentrations in these wells are above the surface water standard values. No known HRR release, or likely source area, could be clearly identified in the area to account for these higher concentrations. Though, model simulations indicated that an inferred source in this area could reproduce time-averaged parent and daughter concentrations in downgradient wells, the location, depth, and source concentration remain unknown.

PSA 14 - Transport Model Results

Under current conditions groundwater flows to the northwest from the former B776 and B777 towards a tributary of North Walnut Creek in the PSA 14 model area. Flow is in both the unconsolidated material and in the weathered bedrock. It should be noted that the Arapahoe Sandstone subcrops in the area and may preferentially direct flow northwest to the tributary of North Walnut Creek.

The maximum observed concentration of 0.620 mg/L (620 ug/L) is in well 5670 which is located between the inferred source locations, though it has been sampled only once (in 1994). The time-averaged concentration in wells not near a simulated source is relatively low, 15 ug/L or less. A comparison of the observed time-averaged concentration data plotted against the simulated concentration data is given in

Figure 3.2. The highest observed TCE concentration, on the bottom of the chart that was not reproduced by simulations, had only three TCE detects in 59 sampling events and only one PCE detect in 59 samples.

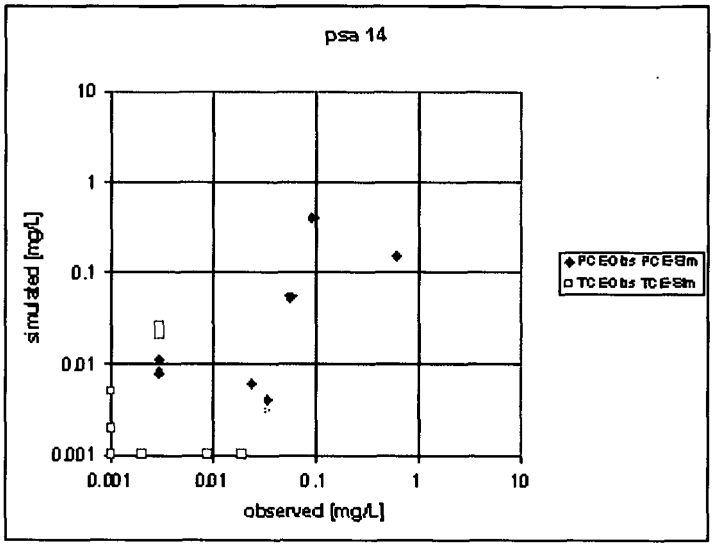


Figure 3.2 Comparison of observed and simulated PCE and TCE concentration data (mg/L) at PSA 14.

A total of 10 transport simulations of the closure configuration were run for 150 years to establish steady long-term concentrations with time at the PSA extents. It took about 50 years to establish steady-state conditions for this PSA. Results were evaluated for simulated closure-condition groundwater PCE concentrations at selected cells within groundwater discharge areas for each of the ten simulations. Results were shown on plots presented in the VOC Modeling Report (K-H, 2004b). Both PCE and TCE had simulated groundwater concentrations above their surface water action level (0.69 ug/L and 2.5 ug/L) for most of the simulations at the downgradient discharge area. The low source concentration case was the only simulation with discharge area concentrations consistently below the surface water action levels.

3.1.2 Former B771Fate and Transport modeling – VC

This report summarizes results of fate and transport modeling of VC in groundwater immediately north of the former B771 area using the most current available land configuration information (Revision 12). VC concentrations in groundwater north of B771 are above surface water standards. The former B771 area is located in the north central part of the IA and was designated as PSA 14 in the VOC Modeling Report (K-H, 2004b). The flow and fate/transport model in this analysis utilizes the same grid resolution as that used in the original PSA 14 model (60-ft by 60-ft).

Contaminant fate and transport modeling, using the reactive transport code, RT3D, was performed to determine whether the VC at inferred source locations will exceed surface water standards (2 ug/L) at downgradient surface discharge areas. The presence of VC north of B771 could be due to either direct release, or through degradation of parent compounds (i.e., PCE, TCE, and cis-1-2-DCE). Because it is not possible to determine the exact nature of the VC in the area, a conservative approach is used to assess long-term downgradient groundwater concentrations at surface discharge areas. The conservative approach simulates both constant and variable VC source concentrations produced by biodegradation from constant PCE and TCE sources based on known VOC releases in the area (K-H, 2004b).

Fate and transport of the VC from inferred source locations north of B771 was modeled only for the most recent closure configuration. No attempt was made to reproduce the current observed VC concentration distribution in the area because even using conservative assumptions about source concentrations and degradation rates does not prevent concentrations from attenuating well before reaching downgradient surface discharge areas. Closure configuration groundwater flow conditions were generated by updating the original integrated flow model used for the VOC modeling with current surface regarding, disruption of footing drains, and drainage modifications in the area. Changes to the groundwater flow system due to the revised closure configuration are described first, followed by a discussion of current VC distribution in the B771 area and results of simulated long-term fate and transport of VC from inferred source areas.

3.1.2.1 Simulated Closure Configuration Groundwater Flow

The integrated flow model extent, shown on Figure 3.3, was defined to include surface drainages to the west and north (North Walnut Creek) and to be large enough so that model boundary conditions do not affect internal model estimates of fate and transport associated with the VC migration. The most significant change to the former B771 model area (Figure 3.3) was the constructed wetland area along the drainage between former B771 and 371 just south of its confluence with North Walnut Creek. Two bermed areas span the width of the wetland before it empties into a drop structure at Walnut Creek. This feature was incorporated into the integrated flow model surface topography and saturated zone model layers.

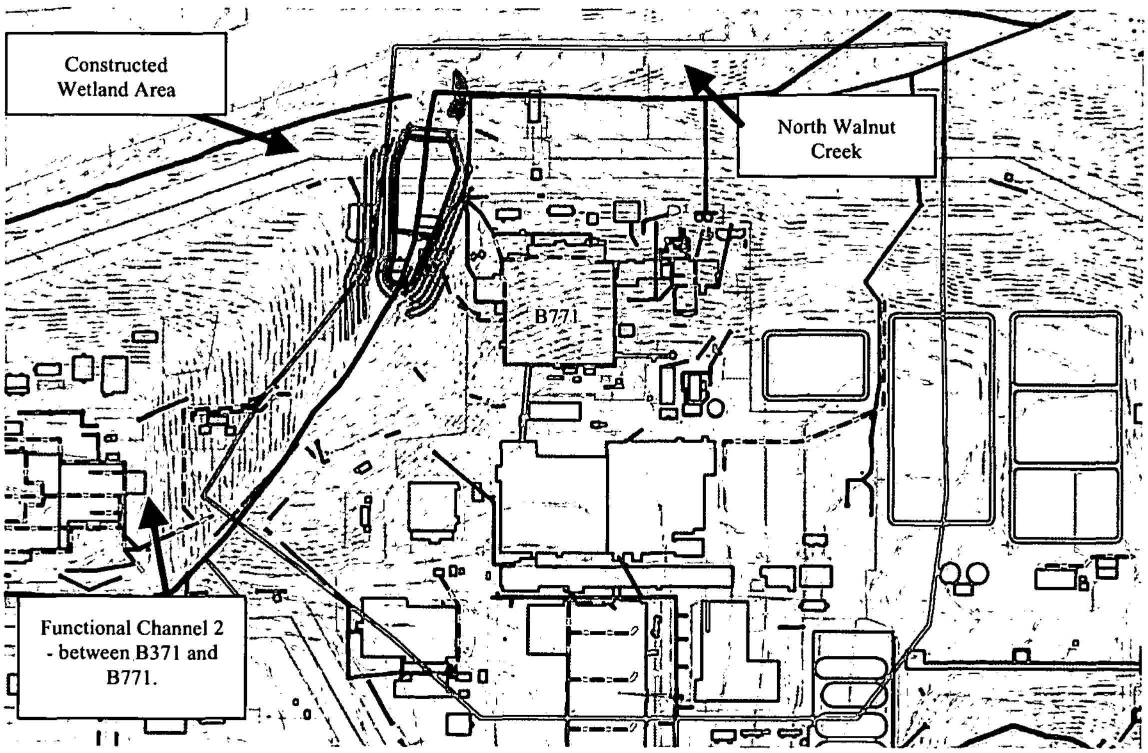


Figure 3.3 Integrated Flow Model Grid and Key Model Features.

Another change to the configuration of the B771 area from the previous closure configuration model was leaving the building footing drain in place. In previous simulations, the footing drain was assumed to be fully disrupted. Recently, footing and storm drains along the northern and northwestern corner of the former B771 footprint were disrupted to prevent preferential discharge along these drains to surface water. In the model, the subsurface drains route groundwater from the south part of the building to low points in the northern part of the building based on drain invert elevations (which decrease to the north). This causes localized increases in groundwater elevations, or mounding which in turn affects groundwater flow gradients and velocities in the area.

Simulated groundwater flow directions within the lower portion of the unconsolidated material, just above the weathered bedrock are shown on Figure 3.4. Groundwater flows from the two inferred source locations is mostly to the north and then northeast where it eventually intercepts North Walnut Creek. Flow magnitudes in the weathered bedrock are less than those in the unconsolidated materials and partially affected by the distribution and subcropping of Arapahoe Sandstone. Available information suggests the Arapahoe Sandstone does not extend much further north past the inferred source locations. As a result, flow rates in the weathered bedrock north of the inferred sources (Figure 3.4) decrease significantly compared to rates in the overlying unconsolidated material. Most advective transport of VC therefore occurs in the unconsolidated material.

3.1.2.2 Vinyl Chloride Groundwater Concentrations

The distribution of VC north of the former B771 area is shown on Figure 3.5. Groundwater from only three wells in the area show detectable levels of VC. Concentrations in each of the wells are greater than the 2 ppb surface water standard. Two sources of VC were inferred (Figure 3.5). One source is located just south of the two western wells (20698 and 20695) where a priority 2 historical release was documented as out of service process waste tanks (K-H, 2004). At this location, constant PCE and TCE concentrations were assigned at 20 ppb and 120 ppb, respectively given observed time-averaged concentrations in the area. At the other inferred location (Figure 3.5), a constant VC concentration of 50 ppb was assigned. This was somewhat higher than the observed time-averaged concentration of 13 ppb at the nearby well (to be conservative). A constant concentration of VC was introduced here because no apparent PCE or TCE sources are present in the area that might cause a degraded source of VC. The source concentrations at both locations was introduced in the upper weathered bedrock as was done in most previous IA VOC PSA models (K-H, 2004).

Two closure scenarios were simulated to evaluate the long-term fate and transport of VC from the inferred source locations. All model input was kept constant in the two scenarios except for the biodegradation rates of VC. In one scenario, an average degradation rate of 0.01 was used based on several previous calibrated models throughout the IA. In the second more conservative scenario, the degradation rate was set lower at 0.002 to allow any VC present in the model to travel further downstream.

3.1.2.3 Fate and Transport Model Results – Closure Conditions

Results of the two closure scenarios indicate that the VC concentrations rapidly decrease downgradient of both inferred sources. At the constant PCE and TCE source location, VC is not produced through biodegradation at high enough concentrations to be above the surface water standards. At the constant VC source location, simulated concentrations decrease to below 2 ppb within 60 feet of the source for both scenarios. This is due to the combination of dispersion, degradation, and loss to ET. As a result of these simulations, VC from these source locations is not expected to reach surface discharge locations at concentrations above surface water standards. This conclusion assumes that no other pathways exist, such as through subsurface utilities that were not disrupted, or via possible slumping and seepage.

3.2 Oil Burn Pit #1 (PSA13 Model)

Results of modeling show that simulated VOC concentrations reproduce time-averaged observed concentrations for higher concentration wells in PSA13 reasonably well. Simulated concentrations for almost all of the lower concentration wells are conservatively over-simulated (as shown in Figure 3.6). This is probably due to a combination of factors such as specifying source concentration too high, degradation rate too low or hydraulic conductivity too high. As a result, groundwater concentrations in closure configuration scenarios are over-simulated, or conservatively high.

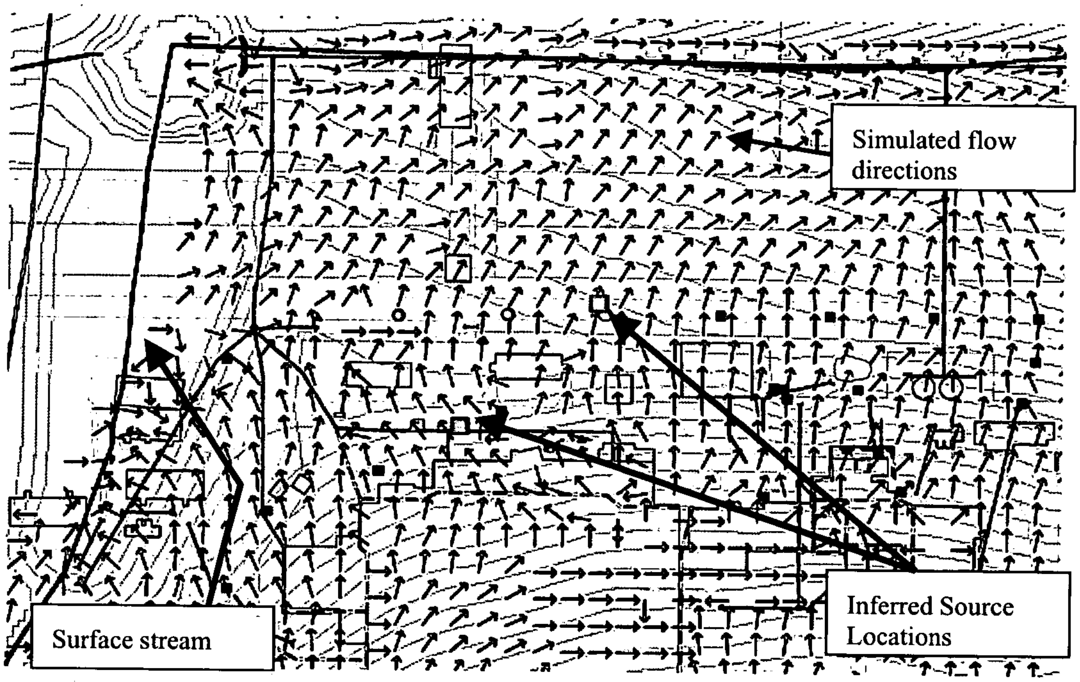


Figure 3.4 Simulated Closure Configuration Groundwater Flow Directions.

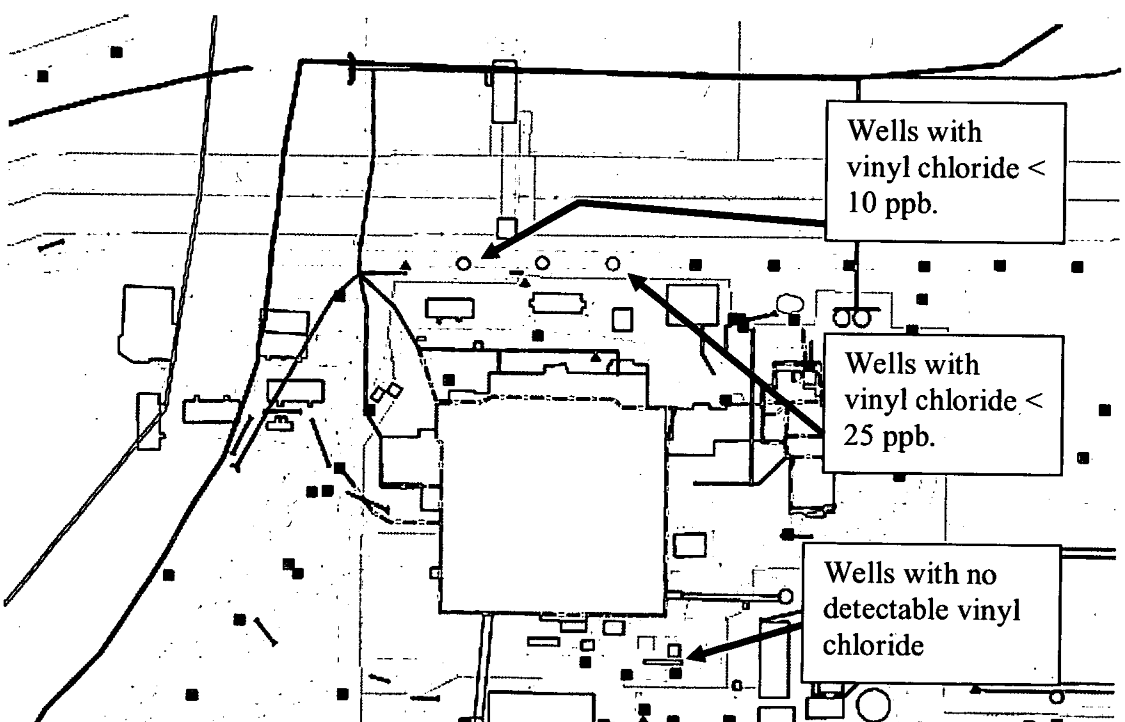
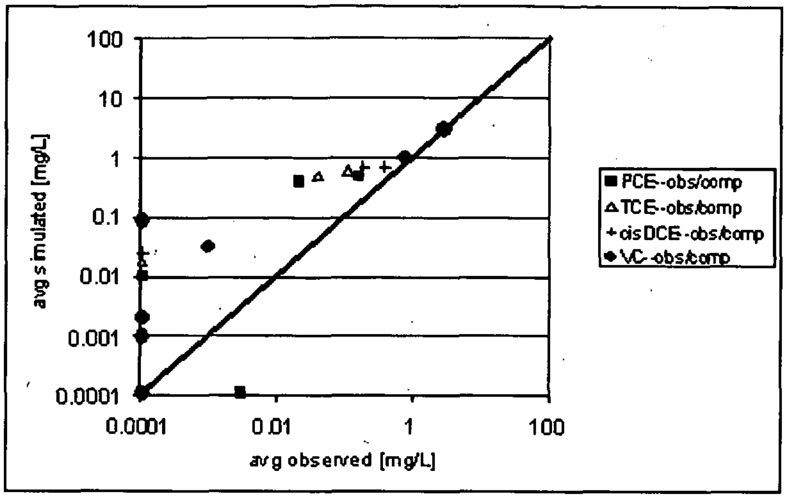


Figure 3.5 Observed Time-averaged VC Groundwater Concentrations.

Figure 3.6 PSA 13 - Simulated versus Time-averaged Observed Concentrations for PCE Degradation



Chain Compounds (PCE – TCE – cis-1,2-DCE – VC).

3.2.1 Fate and Transport Model– Closure Conditions

The groundwater flow distribution changes as the land surface is changed from the current to the closure topography. This changes both the direction and magnitude of groundwater flow (and transport). The closure transport model incorporated the current concentration distribution (simulated by the current transport model) and assumed a constant source concentration. Simulations were run for 100 years so that the PSA13 concentrations could reach a steady configuration (typically in 40 – 60 years). Groundwater concentrations at ground surface discharge locations were then evaluated.

To address uncertainty in fate and transport model parameter values, 10 different models were developed in which key parameters affecting the fate and transport of VOCs are adjusted over high and low values. One of the models represented a 'base case' with parameter values obtained directly from simulating the current condition. In the other nine models, values of porosity, sorption, dispersivity, degradation rates and source concentrations were adjusted within reasonable ranges. The groundwater flow gradient and hydraulic conductivity values were imported directly from the integrated flow model and were not adjusted.

A base porosity of 0.10 from published site estimates (K-H, 2004b). Low and high porosity (0.05 - increases simulated groundwater velocity, 0.20 - decreases simulated groundwater velocity) runs were simulated. The base sorption rates were calculated from site organic content (K-H, 2004b). To simulate faster transport, sorption was decreased (10 percent of the base). Dispersivity accounted for the sub-grid-scale irregularities a finite-scaled model could not simulate and was used as a fitting parameter. The base dispersivity was estimated at 15 meters, slightly less than the maximum cell dimension (18.228 meters). Low and high dispersivity (5 meters and 30 meters) runs were used to bracket the reasonable range of dispersivities.

Probably the greatest uncertainty lay with the assumed source of the observed compounds. Parent compounds were represented as a release whereas daughter compounds occurred as a degradation product from a parent or as a separate release. This required a balance between source concentrations and the degradation rate of each compound in the degradation chain. Cis-1,2-DCE and VC are rarely used and therefore unlikely to be released. However, to produce the observed VC concentrations at PSA 13, conservatively high degradation rates (anaerobic conditions) were used for PCE, TCE, and cis-1,2-DCE. Instead, a source for each of the compounds (from 0.5 to 0.8 mg/L for PCE, TCE, and cis-1,2-DCE to 3 mg/L for VC) was used along with high end degradation rates for PCE, TCE, and cis-1,2-DCE (0.01/day) and a low end rate for VC (0.002/day). High (double) and low (half) source concentration cases were run. Since VC traveled the farthest in the current condition simulation, high and low VC degradation rate cases were run.

3.2.2 Model Results

The near-source gradient for the current topography is about 0.035 to the east northeast. This is towards a downgradient well, 22098 that has had one VC hit (2 ug/L) in six samples, and an integrated model closure configuration predicted discharge location east of B371 (Figure 3.7). Simulated VC reaches well 22098 but concentrations at all predicted discharge areas for the current condition models remain well below surface water standards. The closest predicted surface discharge area (closure configuration) is approximately 400 feet northwest of the PSA 13 boundary (Figure 3.7), but away from the direction of transport under the current flow field.

Results of the integrated modeling of groundwater flow indicate that changes to the surface topography and drainage in the closure scenario land configuration affect groundwater flow and subsequently influence surface discharge area groundwater concentrations. The closure gradient decreases from 0.025 ft/ft to 0.035 ft/ft and the direction shifts northeast. This decreases groundwater transport velocities and increases the distance from the inferred source area to the discharge location. Consequently groundwater in simulated discharge areas is not impacted above surface water standards (Figure 3.8).

3.2.3 Summary

PSA 13 is the only model area at the Site that displays VC concentrations that are higher than its parent compounds. It is subject to aerobic degradation which is common across the site. Parent compounds PCE and TCE degrade anaerobically. It is likely that there is a localized anaerobic area in the vicinity of the oil burn pits where PCE and TCE rapidly degrade to VC while limiting the degradation of VC. Results of long-term closure configuration simulations indicate that VOC concentrations will be well below surface water standards before discharging to surface water.

3.3 PSA East Model

The PSA E model area is located in the eastern part of the Site (Figures 2.3 and 3.9). It is east of all previously modeled areas (K-H, 2004b). It covers a fairly large area but was previously screened-out (not modeled) because there were no wells with VOC concentrations above the PRGs used for the initial modeling. However, using surface water standards, several wells have average PCE and CCl_4 concentrations above these values. Both the PCE and CCl_4 degradation chains were modeled for this study.

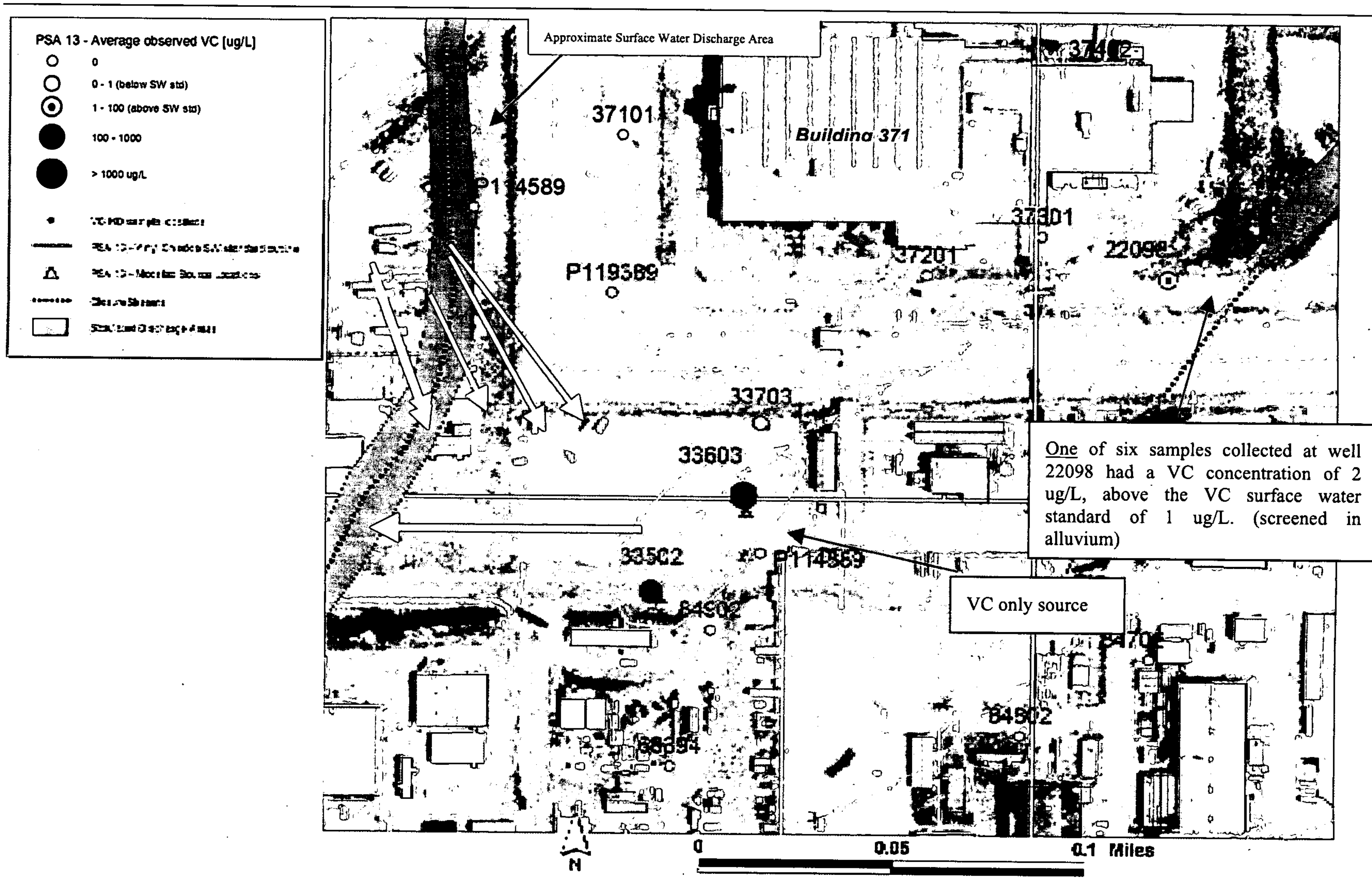


Figure 3.7 PSA 13 – Current concentration distribution of VC with integrated model predicted closure discharge areas.

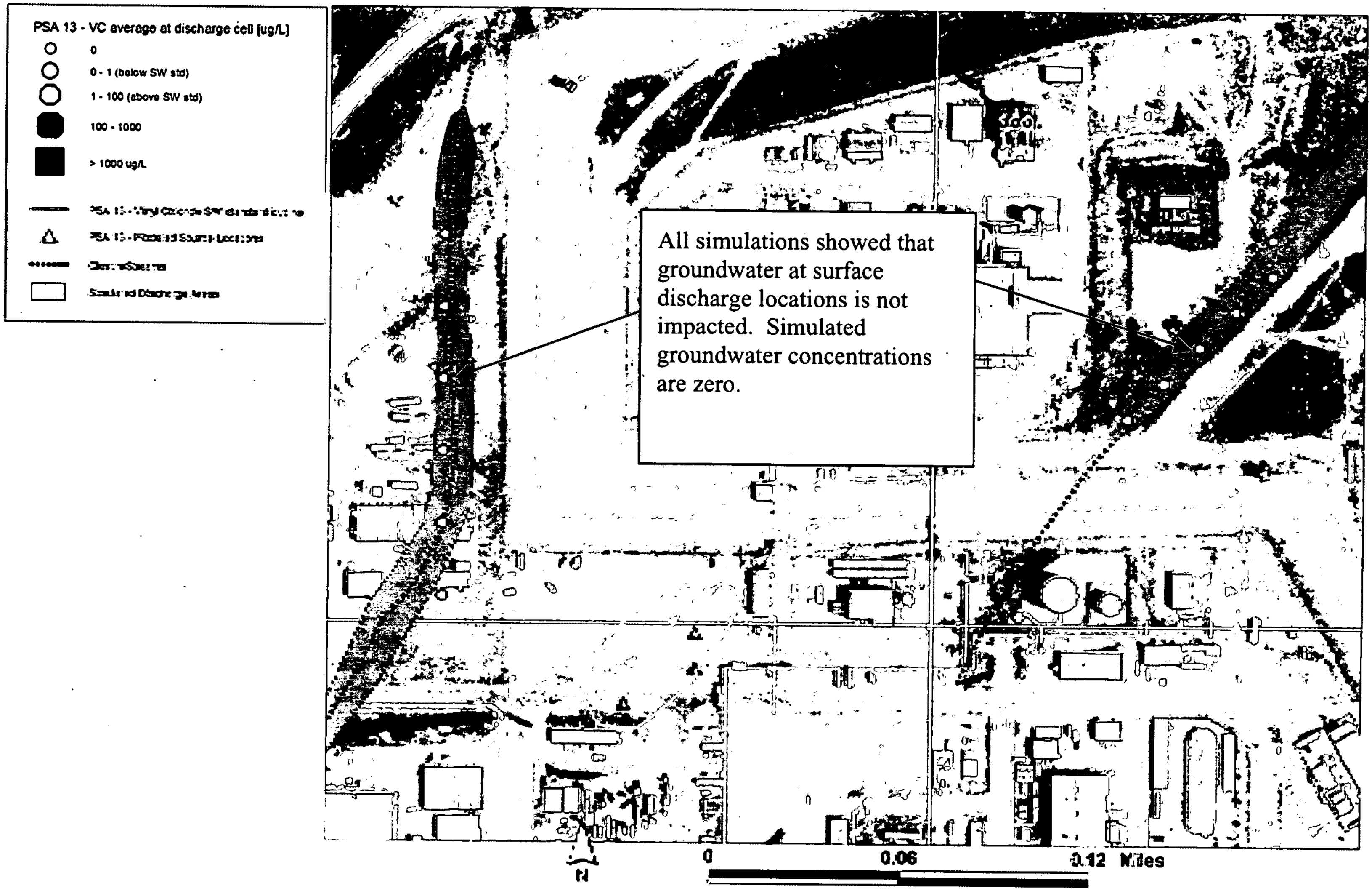


Figure 3.8. PSA 13 – Simulated VC concentrations in groundwater at surface discharge locations - 100 years.

3.3.1 PSA E - Simulated Groundwater VOC Sources

Three separate PCE and CCl_4 sources were inferred for the PSA E model area due to its large extent and relatively low observed concentrations. One was located at the east end of a series of trenches, about 750 feet east of the East Trenches that were the inferred source for PSA 6 and 7. It coincided with a Priority 1 release location and was simulated by constant sources in two model cells. Two additional sources were simulated south and north of the main access road. They were inferred based on the east spray fields, IHSS 162, and were simulated as constant but low concentration sources. The East Spray Fields information documents only the release of oil, grease, and nitrates over a 10-year period (1980-1990) south of the access road and over a few years (1979 to early 1980's) north of the access road.

3.3.2 PSA E - Transport Model Results

Under current conditions, groundwater flows predominantly to the east - northeast. Flow is in both the unconsolidated material and in the weathered bedrock. Arapahoe Sandstone does not subcrop in the area but is present in the lower weathered bedrock in the northern part of the PSA. The maximum observed time-averaged PCE concentration of 0.305 mg/L (305 ug/L) occurs in well 8391 and the maximum observed time-averaged CCl_4 concentration of 0.080 mg/L (80 ug/L) occurs in well 774. A comparison of the observed time-averaged concentration data plotted against the simulated concentration data for PCE and TCE is given in Figure 3.9 and for CCl_4 is given in Figure 3.10.

The PSA East model is not located within, or immediately downgradient of significantly modified areas due to closure. As such, long-term local groundwater flow directions and gradient magnitudes won't change.

A total of 10 transport simulations of the closure configuration were run for 150 years to establish steady long-term concentrations with time at the PSA extents. It took at nearly 100 years to establish steady-state conditions. The average simulated groundwater concentrations for PCE at integrated flow model groundwater discharge areas are shown on Figure 3.11. The bar chart on Figure 3.11 shows simulated closure-condition groundwater concentrations at a cell within a current potential discharge area. The long-term concentration for all simulations was below the surface water action level at this location. The average simulated groundwater concentrations for CCl_4 at integrated flow model groundwater discharge areas are shown on Figure 3.12. Simulations did not show concentrations reaching simulated discharge areas for the closure configuration or potential discharge areas for current conditions. The low-level groundwater contamination at PSA E should not be of concern with respect to its impact on surface water.

3.4 Former B444/443 – Uranium Model

Several simulations were conducted to assess the possible fate of uranium in groundwater. Details of model input for these simulations are summarized in Table 3.1 below. The first five runs were specified in the more likely fate scenario (using RT3D) that includes sorption (i.e., Kd values from 30 to 170), while the last run (run 6) specifies input for the conservative advective-dispersive transport simulation (no Kd value) using the MIKE SHE Advective-Dispersive transport module. These Kd values represent a reasonable range for uranium (K-H, 2002a). Source mass was specified assuming current estimates (2620 gm) of uranium inventory (walls and slab), and for the uranium inventory of the plenum area only (1410 gm). These source masses were used to calculate the source concentration in a single model cell (dimensions are 25-ft x 25-ft x 1-foot) located in the southern part of the basement area. Dispersion values were generally kept at 5 based on VOC transport modeling (K-H, 2004b), though a value of 15 was also used in the likely scenario with sorption, and a value of 10 was used in the advective-dispersive simulation.

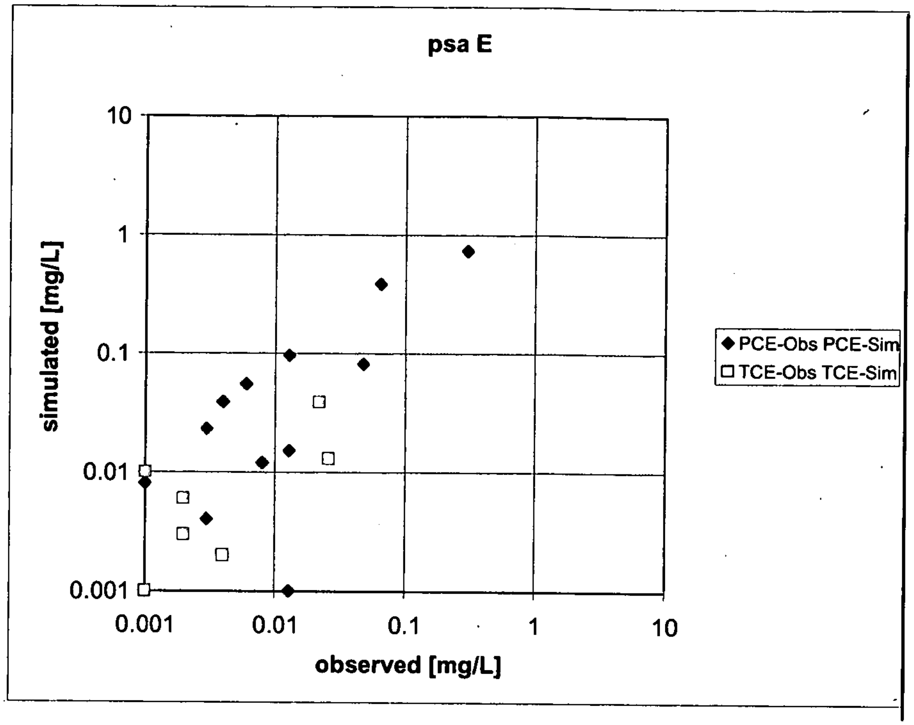


Figure 3.9 Comparison of observed and simulated PCE/TCE concentration data(mg/L) - PSA E.

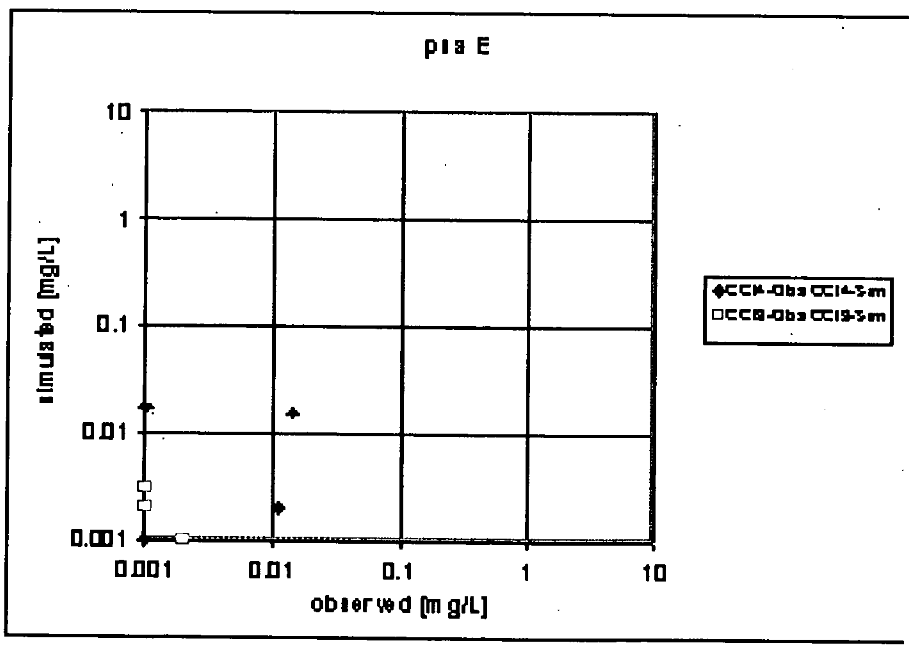


Figure 3.10 Comparison of observed and simulated CCl_4 concentration data (mg/L)- PSA E.

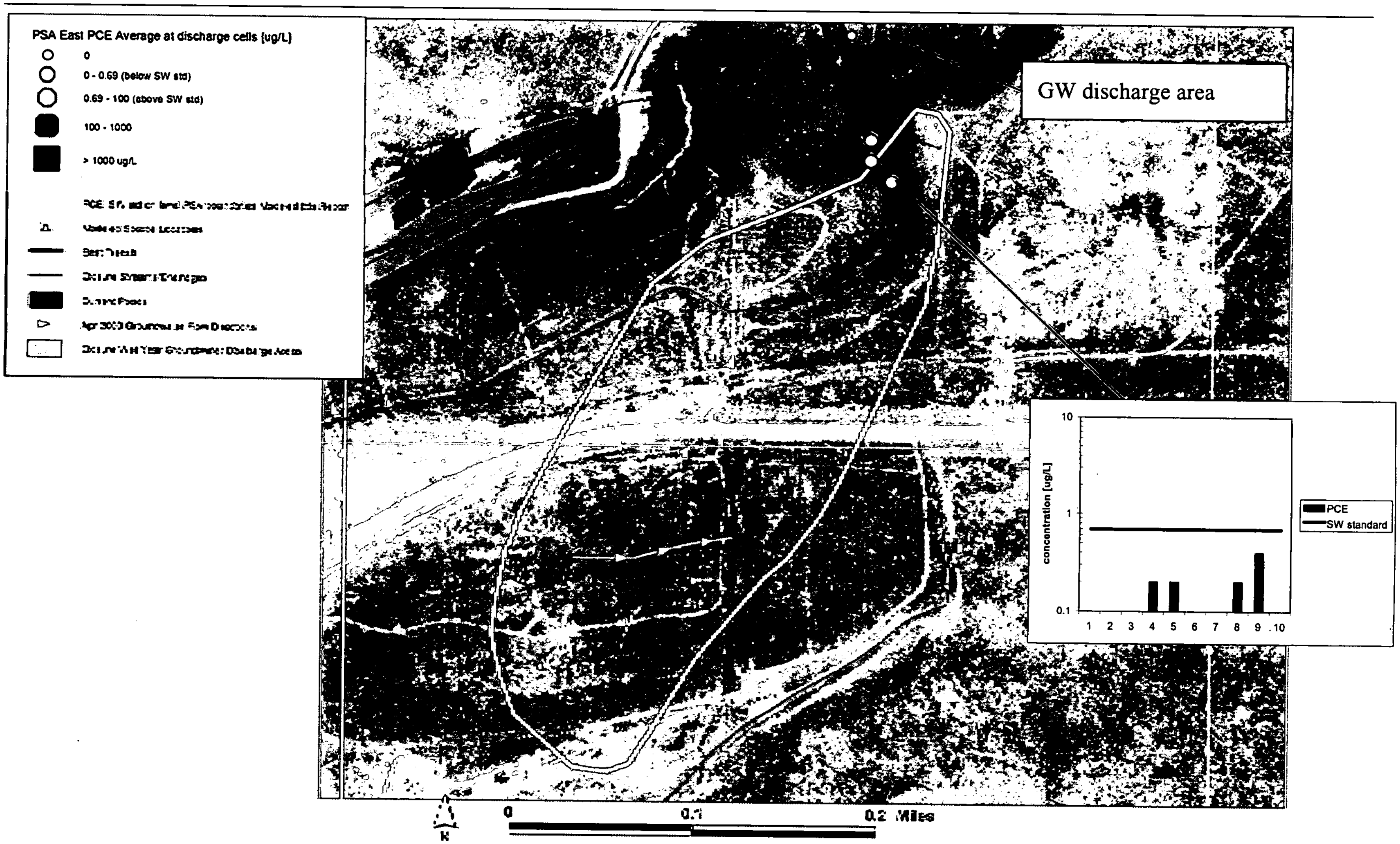


Figure 3.11 Simulated PCE concentrations at groundwater discharge cells in the PSA East area (area to the east of the IA).

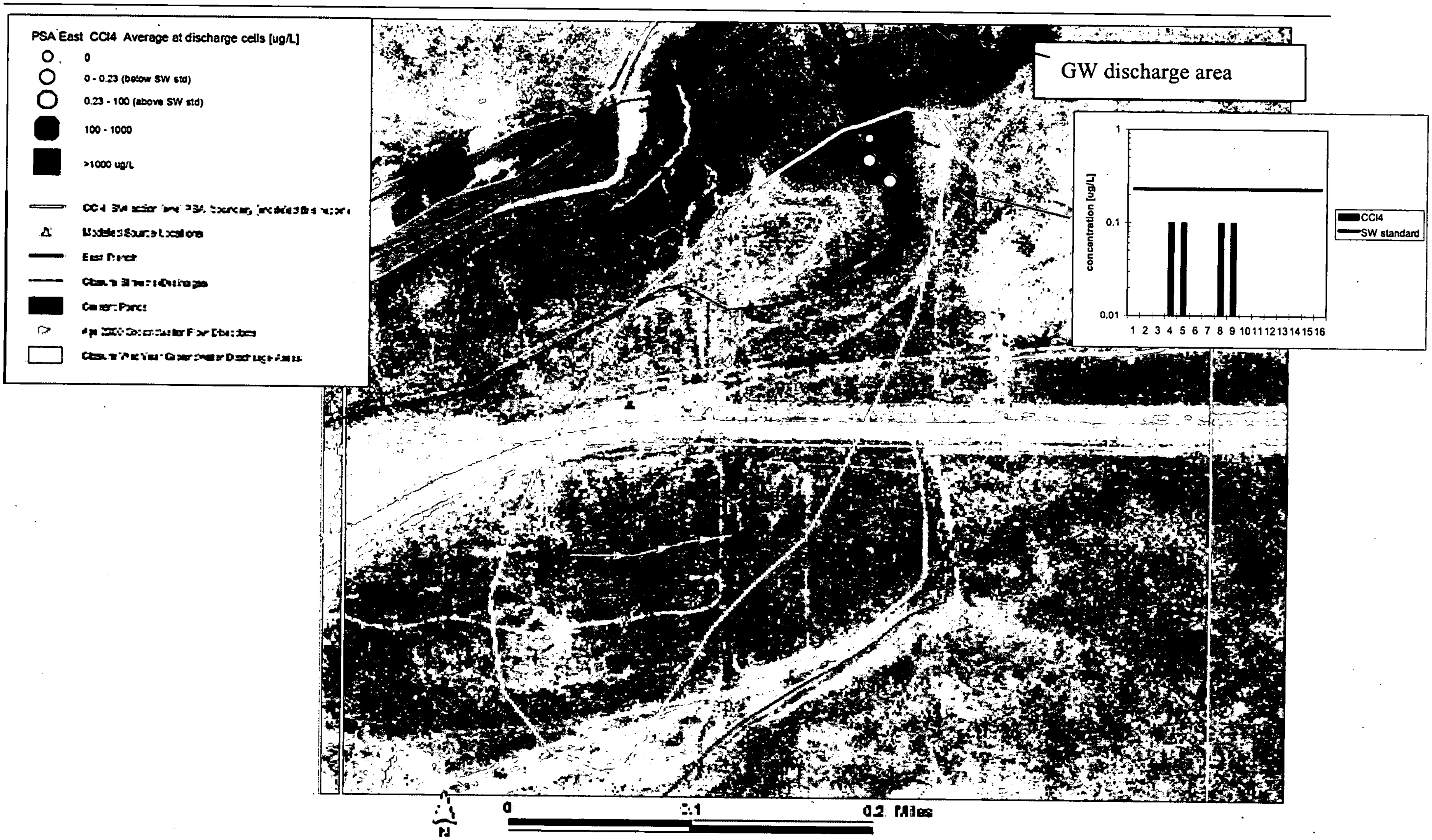


Figure 3.12 Simulated CCl_4 concentrations at groundwater discharge cells in the PSA East area (area to the east of the IA).

Table 3.1 Parameter values for the fate and transport model scenarios.

Model Run	Transport Processes	Kd (mL/g)	Source (grams)	Source Concentratio n (mg/L)	Dispersivity [meters]
1	AD, sorption	30	2620	5000	5
2	AD, sorption	170	2620	5000	5
3	AD, sorption	30	1410	2666	5
4	AD, sorption	170	1410	2666	5
5	AD, sorption	170	2620	5000	15
6	AD only	-	2620	5000	10

Note: AD refers to advection-dispersion processes

Advective-Dispersive Transport Model ("Worst-Case" Scenario)

Results of the "worst-case" scenario (i.e., simulated advection-dispersion transport only, without sorption) showing uranium transport modeling from the former B444 basement area, are illustrated on Figure 3.13. Uranium distributions are shown as a factor of the RFCA surface water action level (10 pCi/L total U). The uranium source was introduced at the southernmost end of the former B444 basement. Three hundred years were simulated with the transport model so that a clear distribution and migration pathway could be determined. The simulated plume shape and extent are consistent with the overlying groundwater flow paths shown. Uranium migrates east and then northeastward into the South Walnut Creek watershed, despite specifying a source in the southernmost basement footprint area of former B444.

Temporal plots of the simulated advection-dispersion uranium concentration (μg /L) with time at the source location, and a location 100 feet downgradient are shown on Figure 3.14. Results show that after 300 years, concentrations decrease to below the uranium surface water Action Level at the original source location. Although maximum uranium plume concentrations are still above the 15 μg/L level (15 ug/L is approximately equal to 10 pCi/L if the source material is depleted uranium, as occurs in B444. 10 pCi/L is the surface water action level for total uranium) after 300 years (i.e., ~1000 μg/L), the plume concentration centroid has only moved about 100 feet east-northeast and decreased nearly three orders of magnitude. Based on these concentration trends and distance traveled, uranium concentrations in groundwater will continue to decrease to below the surface water action level well before reaching the nearest surface water feature (South Walnut Creek, located over 2,500 feet downgradient from former B444 as shown on Figure 3.15).

Advection/Dispersion and Sorption Model ("Likely Scenario" Model)

Results of the "more likely" uranium fate and transport model simulations, for a range of model parameter values and model layers, are presented on Figures 3.16 through 3.18:

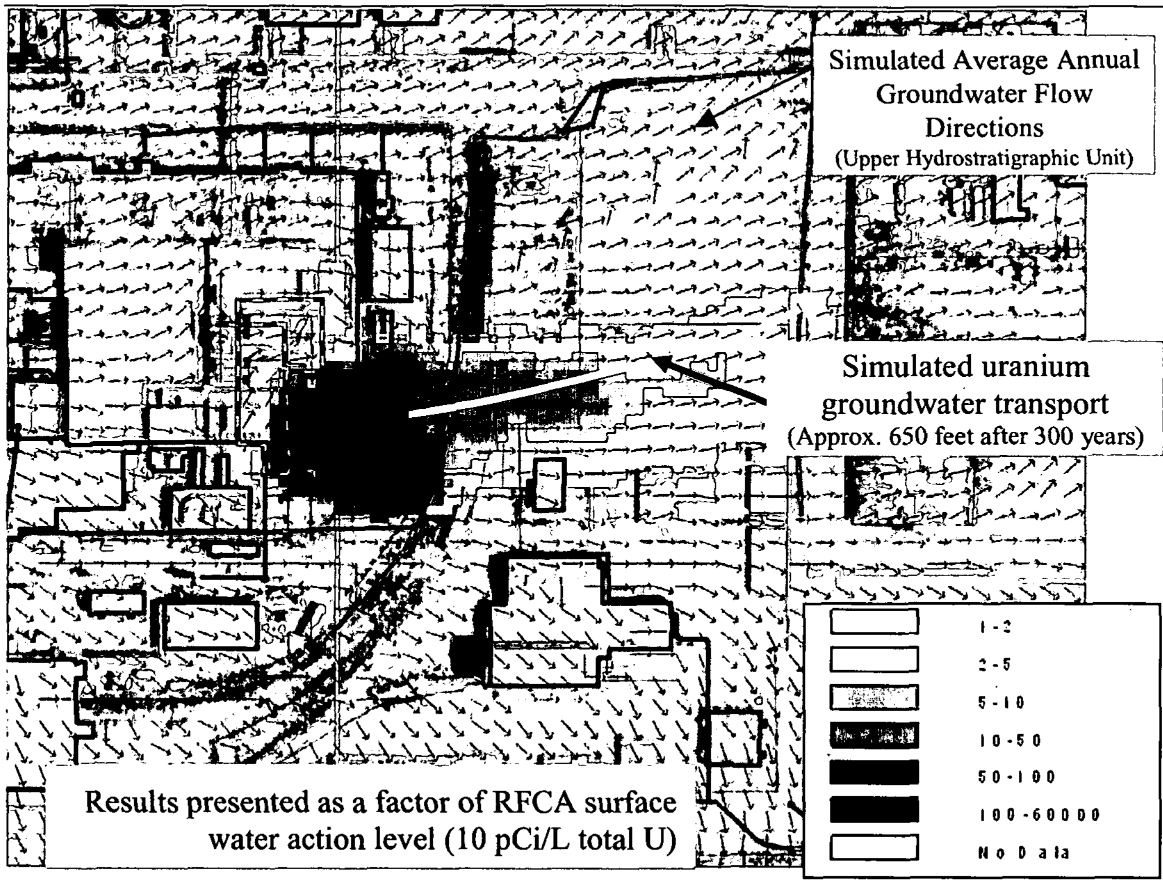


Figure 3.13 Advective-Dispersive Model ("Worst-Case" Scenario) –(pCi/L) - 300-Year Simulation.

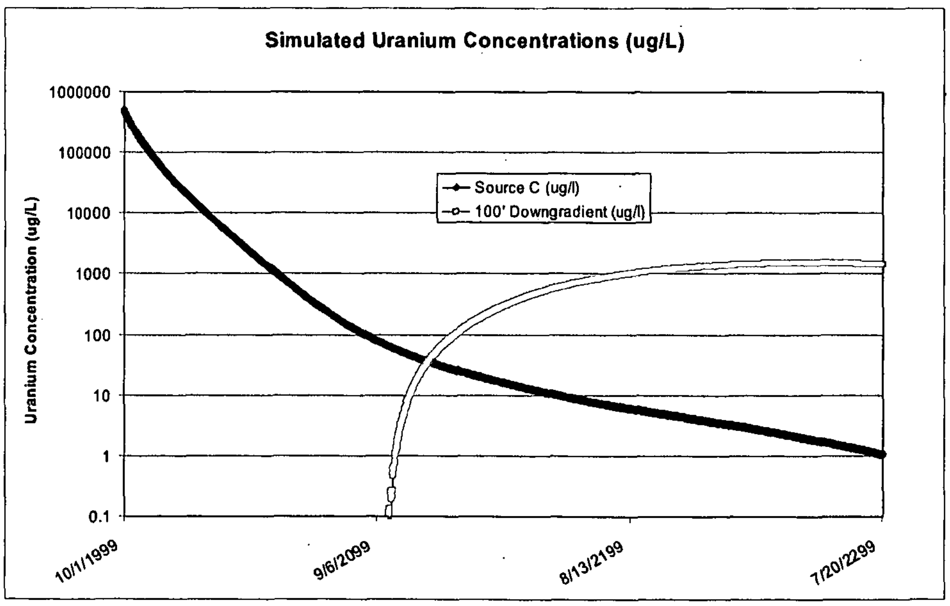


Figure 3.14 Simulated Conservative Uranium Concentrations with Time (run 6).

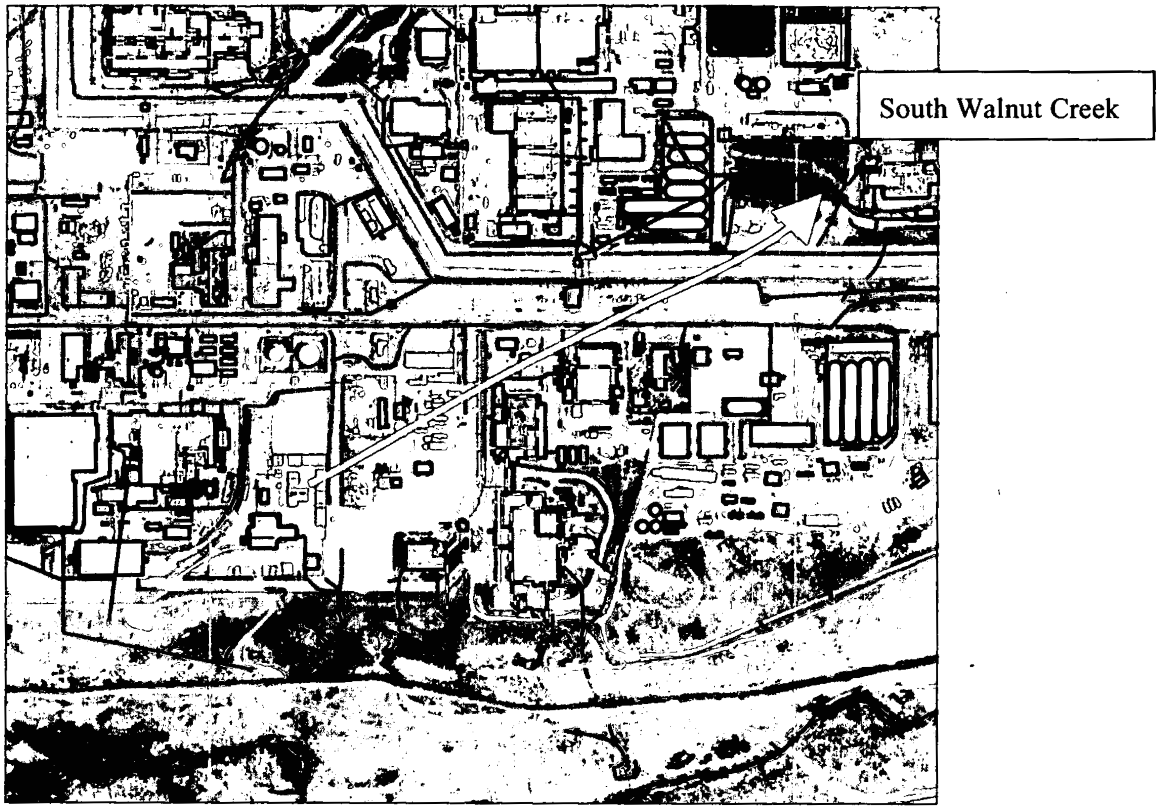


Figure 3.15 Approximate Flow Path to South Walnut Creek (>2,500 feet).

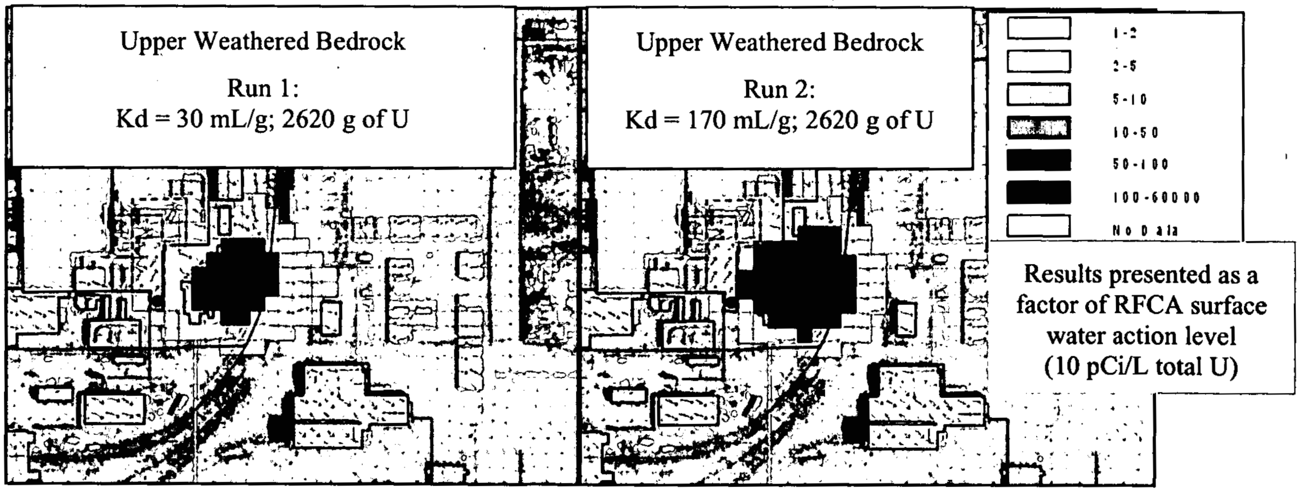


Figure 3.16 Simulated uranium distribution in Upper Weathered Bedrock, entire basement uranium source, varying Kd values.

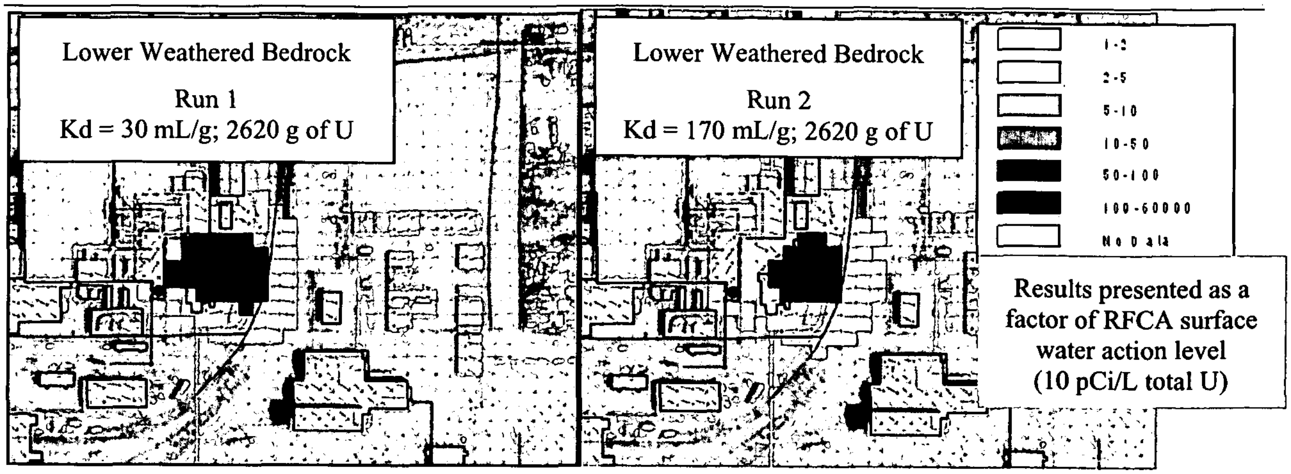


Figure 3.17 Simulated uranium distribution in Lower Weathered Bedrock, entire basement uranium source, varying Kd values.

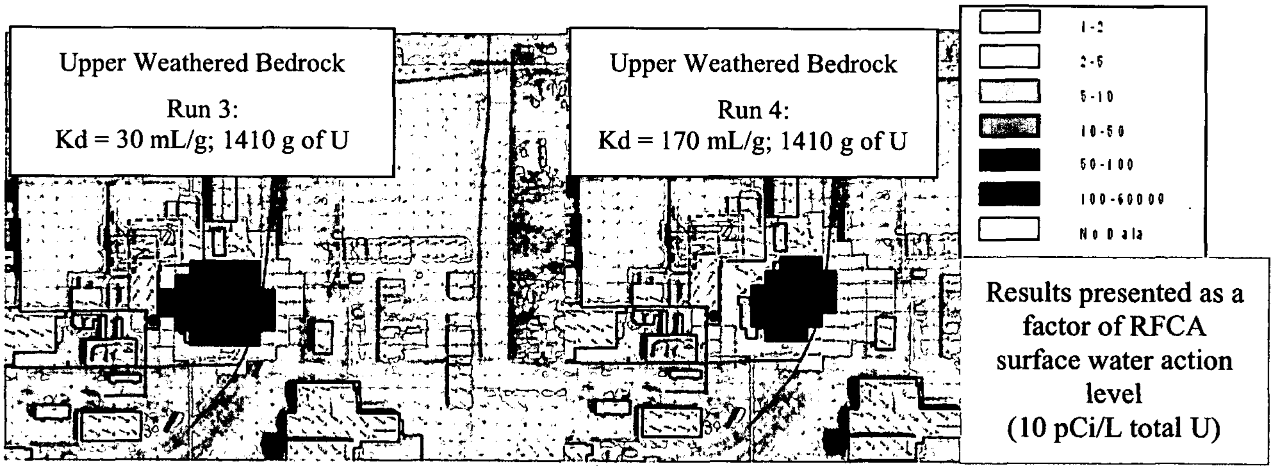


Figure 3.18 Simulated uranium distribution in Upper Weathered Bedrock, plenum area U source, varying Kd values.

Results of the model simulations summarized in Figures 3.16 through 3.18 showed that the effect of sorption significantly reduces the downgradient migration of the uranium compared to the advective-dispersive simulation (Figure 3.13). Simulated plume centroids (i.e., highest concentration area of plume) in the cases with sorption were similar to that used in the advective-dispersive model run (run 6). The centroid moved about 100 to 150 feet east/northeast of the source. However the maximum distance the plume traveled before concentrations are less than the RFCA action level was about half the distance as run 6 (i.e., ~300 feet). Reducing the source concentrations did little to reduce the overall plume shape after 300 years as indicated by comparing Figure 3.16 (uranium source from entire basement) and Figure 3.18 (uranium source from plenum area only).

One reason that concentrations diminish over time as the plume migrates is due to the vertical mixing. As the plume migrates east/northeast, a downward gradient causes it to mix with groundwater in lower portions of the weathered bedrock. This decreases the uranium concentration as the plumes migrate towards South Walnut Creek. Finally, modeling showed that increasing the dispersion (i.e., from 5 to 15 m) caused the uranium to disperse after 300 years to concentrations below the surface water concentrations.

Based on the modeling conducted for the former B444 area, several conclusions can be drawn. These include the following:

- Advective-dispersive transport modeling suggests that uranium will migrate east-northeast from the B444 basement area into the south Walnut Creek area. Simulations showed that uranium concentrations will not impact the Woman Creek surface drainage. Conservative transport simulations indicate that uranium concentrations will decrease below surface water Action Levels, well before intercepting the South Walnut Creek drainage. Less conservative simulations, using a range of reasonable parameter values for sorption, show that concentrations of uranium will decrease even more rapidly than the advective-dispersive modeling as it moves from the basement area; and
- The transport and flow paths and groundwater levels within the former B444 area may be impacted differently than indicated by the modeling performed here, given the specific closure configuration for the Original Landfill.

3.5 Original Landfill Model

3.5.1 Model Development

The fate and transport of VOCs detected in the OLF area were evaluated for closure Scenarios 2 and 3 described in Section 2.5.2. These two scenarios were selected for fate and transport simulations because they represented configurations with the greatest potential for producing higher downgradient VOC concentrations. Specifically, impacts to surface water (Woman Creek, or seeps) were assessed. Available groundwater sampling data indicate elevated concentrations of PCE were detected in the central portion of the OLF waste area (see Figure 3.19).

The approach used to model the fate and transport of PCE (and its daughter products) from the waste area is consistent with that described in detail in the IA VOC fate and transport modeling (K-H, 2004b). The RT3D code is used to model the reactive fate and transport of PCE so that advection and attenuation processes including degradation, sorption, diffusion, and dispersion could be considered.

Three-dimensional time-averaged water levels (WY2000), estimated using the integrated flow model for Scenarios 2 and 3, were first used to define approximate steady-state velocity fields for the RT3D simulations. A number of conservative fate and transport simulations were then conducted to estimate a range of long-term groundwater concentrations at surface water discharge locations given uncertainties in source location, depth and timing, and other parameters controlling fate/transport. Source locations simulated in the model are based on inferred locations (shown on Figure 3.19) and long-term concentrations are assumed constant. This assumption is reasonable because concentrations at wells in the OLF show no clear increasing or decreasing trends in time.

The following long-term simulations were conducted for Scenarios 2 and 3:

- Scenario 1 - Basecase;
- Scenario 2 - Low degradation (one tenth of basecase);
- Scenario 3 - Low porosity (halved for all layers);
- Scenario 4 - Low degradation and increase in hydraulic conductivity (one tenth and three times for all layers, respectively);
- Scenario 5 - Advection-dispersion only (no sorption, degradation, or ET loss), increase in hydraulic conductivity (2 times all layers); and
- Scenario 6 – Advection dispersion only.

Fate and Transport Simulation Results

Results from both simulations show that neither PCE, nor its daughter products, reach Woman Creek at concentrations above surface water action concentrations for any of the conservative simulations considered. Results are summarized on Figures 3.20 and 3.21, for Scenarios 2 and 3, respectively. For Scenario 3, with the buttress fill and buttress drain, more conservative simulations indicate it is possible for concentrations to reach the drain, but they are likely to be lower than the surface water action levels.

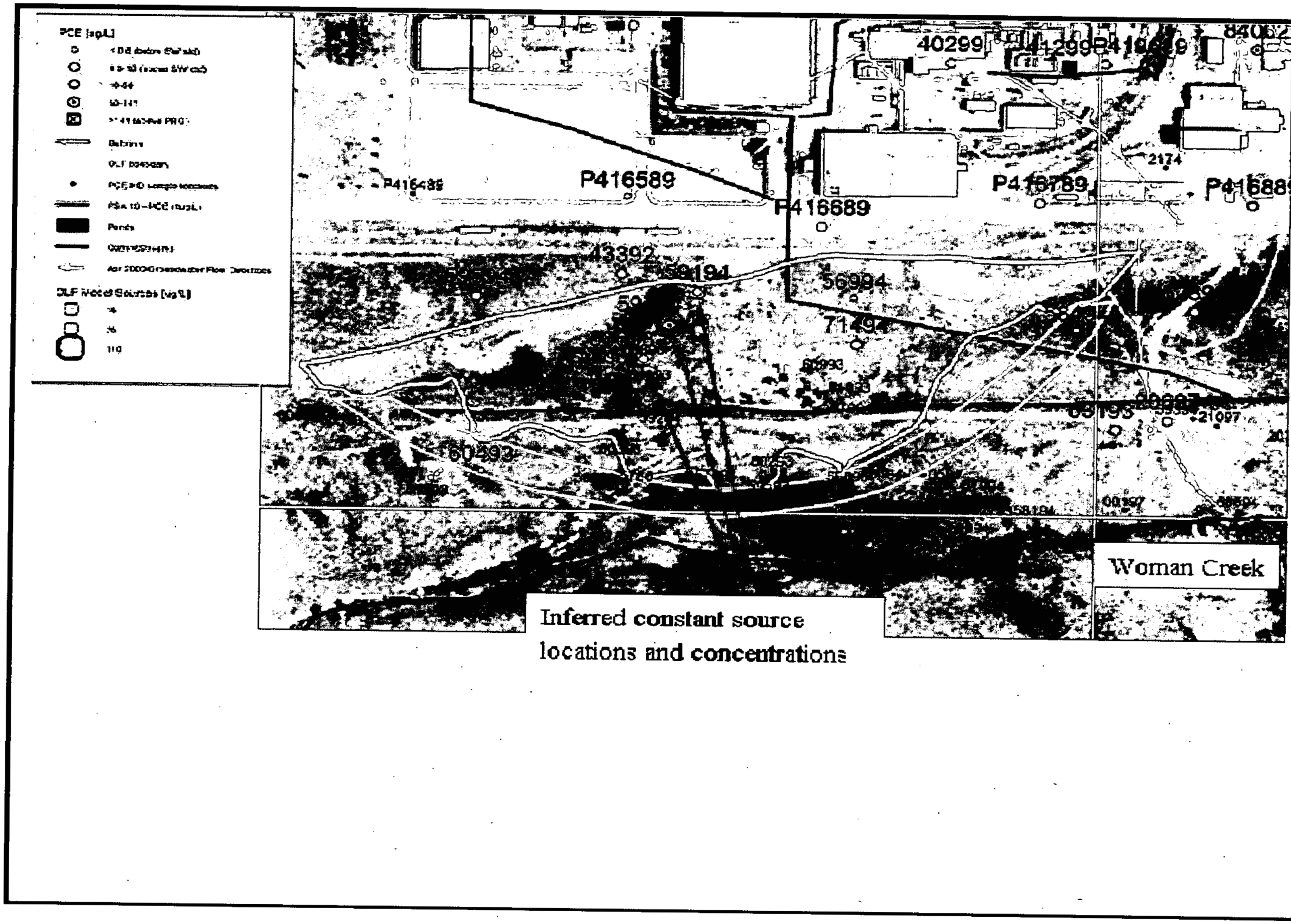


Figure 3.19 Inferred location of VOC sources in the OLF area.

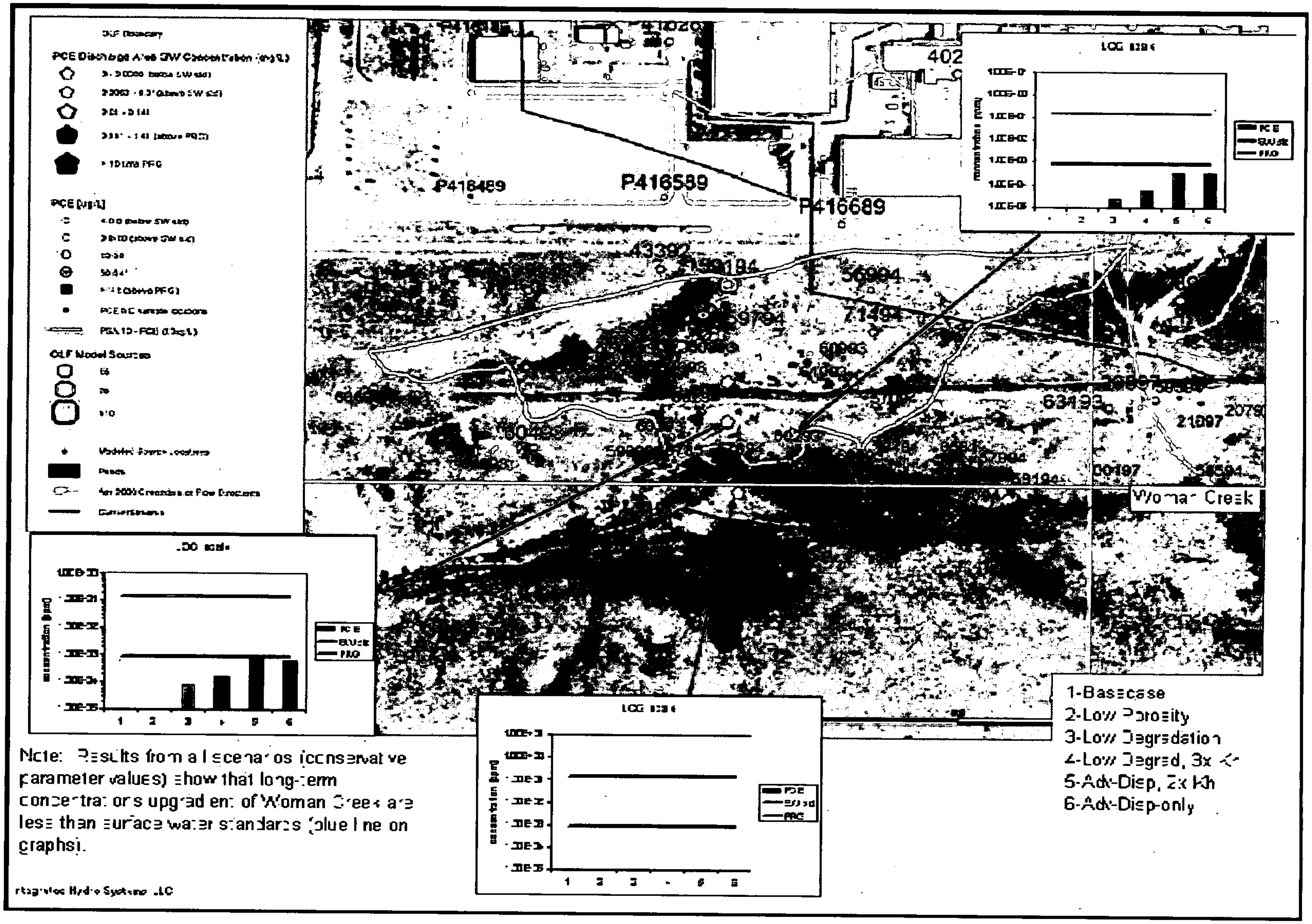


Figure 3.20 OLF Modeling Fate and Transport Results – Scenario 2.

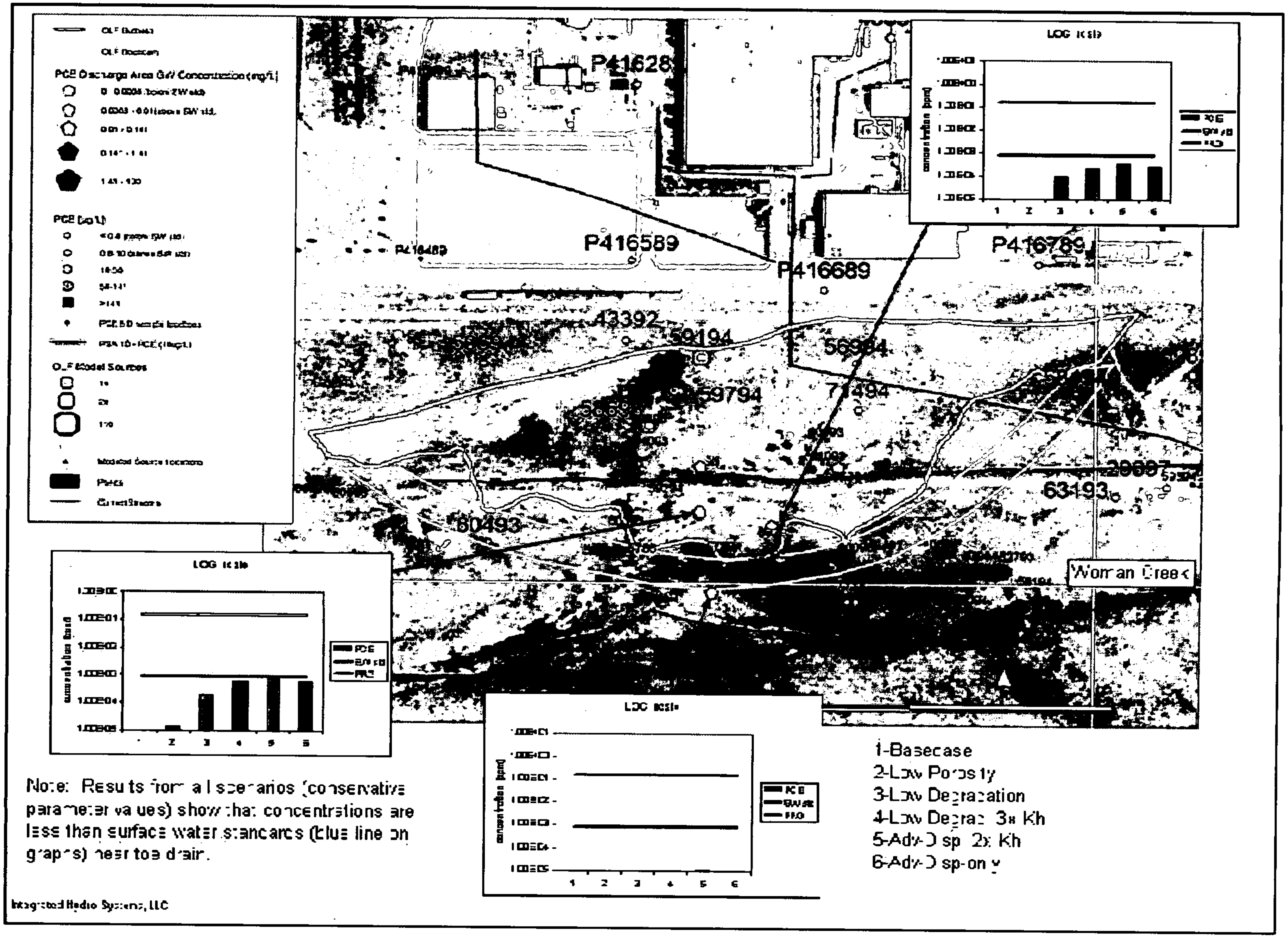


Figure 3.21 OLF Modeling Fate and Transport Results – Scenario 3.

4.0 PAST HYDROLOGIC FLOW AND TRANSPORT MODELING AT RFETS

A significant number of hydrologic flow and transport modeling studies have been conducted at the RFETS. Most of these studies have focused on characterization, rather than on closure-specific evaluations. A review of modeling documentation is unique in the number and varying levels of sophistication of different hydrologic and fate/transport methods used to assess both surface and subsurface flow and fate/transport of different types of contaminants at the site.

The report includes only surface and subsurface water flow modeling. Air flow and transport modeling performed at RFETS is not described here. A database of water flow and transport modeling conducted at RFETS was prepared in Table B.1. The table includes the following field names:

- Author;
- Date;
- Description;
- Modeled Process(es);
- Purpose of Modeling;
- Modeling Results; and
- Modeling Tools Used.

More than 50 water hydrologic flow and/or transport modeling studies have been conducted and documented at RFETS. These studies were conducted by various groups summarized below.

Author	Total Studies
ASI	2
CDPHE	1
Daniels, Hans.	1
Department of Energy	4
Earth Tech, Inc.	1
EG&G	8
Fedors, R.A., Warner, J.W. Roberts, B.L and Berzins, A.	1
Illangasekare, T., Prucha, Robert, Danish Hydraulic Institue (DHI).	1
Integrated Hydro Systems, LLC	4
Kaiser-Hill, LLC	12
Koffer, James.P.	1
Lee Wan and Associates	1
Moffit, J.A.	1

Muller Engineering	1
RMRS	7
Roberts, B.L.	3
S.S.Papadopulos & Associates, Inc.	1
U.S. Army Corps of Engineers	2
USGS, Jim Ball	1
USGS, Ken Lull	2
Wright Water Engineers.	1
TOTAL	56

Hydrologic flow and/or transport studies at RFETS started as early as 1987 and have continued into 2004. Figure 4.1 summarizes the frequency by year. A number of studies were conducted in 1995 and 1996 (~7 to 8), while subsequent years average about 2 to 5 reports per year.

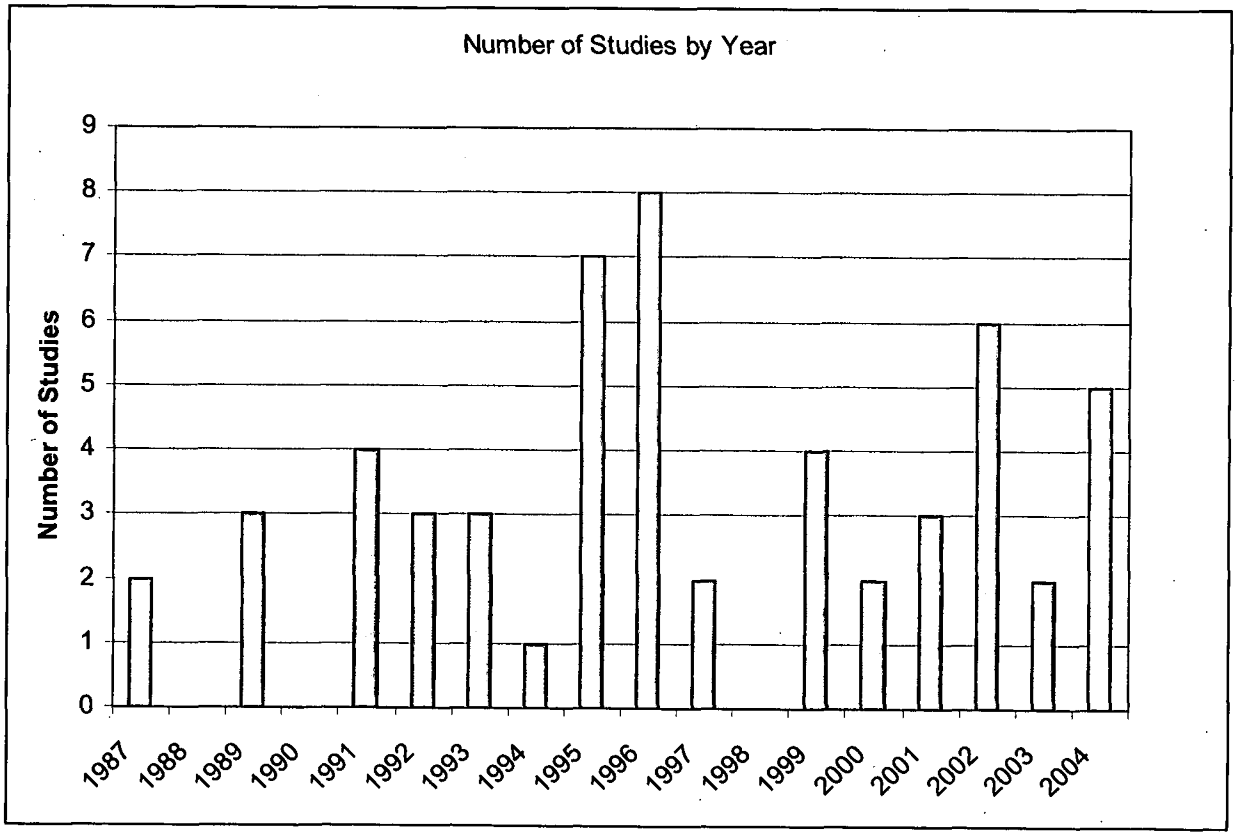


Figure 4.1 Number of flow and/or transport studies conducted per year at RFETS.

Many types of modeling studies have been conducted at RFETS, depending on the specific objectives of interest. Several broad categories include:

- Surface flows:
  - -Overland flow and
  - -Channel flow;
- Snow melt;
- Macropore modeling;
- ET;
- Groundwater flow;
- Infiltration studies;
- Flows associated with subsurface utilities;
- Vadose Zone flows; and
- Contaminant fate and transport.

RFETS modeling studies have conducted to evaluate a broad range of objectives. Objectives can be broadly categorized into the following areas:

- Assessing current water balance and system dynamics;
- Approximating water balance;
- Assessing current versus future closure conditions;
- Assessing fate and transport of contaminants;
- Explaining the distribution and migration pathways of contaminants;
- Assessing flood potential and maximum flows;
- Assessing pond operations;
- Assessing remedial action alternatives;
- Supporting risk assessments; and
- Estimating erosion loading and distributions.

The sophistication of methods used in each modeling study conducted at RFETS range from simple to complex. These include the following, from simple to complex:

- Simple water balance methods;
- Analytic, or semi-analytic methods;
- Single-process numerical methods;
- Coupled process numerical methods; and
- Fully integrated process numerical methods.

Types of fate and transport models include:

- Simple analytic solutions;
- One-dimensional to three-dimensional single-process fate and transport methods;
- Reactive transport models; and
- Geochemical models.

A variety of codes were used to support the modeling studies and include:

- Single-Process Codes:
  - MODFLOW and
  - HEC;

- Coupled-Process Codes;
- Fully Integrated Codes:
  -MIKE SHE,
  -SWMM, and
  -HSPF;
- Transport Codes:
  - MT3D,
  - MOC, and
  - RT3D.

Some of the more significant and sophisticated modeling studies conducted at RFETS include the following:

- SWWB fully integrated, physically-based modeling;
- Groundwater VOC fate/transport modeling;
- Landfill modeling;
- Building decommissioning modeling; and
- Actinide Migration Evaluation erosion/transport modeling,

5.0 REFERENCES

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APPENDIX A – SUMMARY TABLE OF RECENT INTEGRATED FLOW AND FATE AND TRANSPORT MODELING AT RFETS

Table A.1 - Integrated Hydrologic Flow and Fate/Transport Models
Rocky Flats Environmental Technology Site

No.	Modeling Project	Model Type	Modeling Tasks/Purpose	Model Details	Key Conclusions	Completion Date/Status	Report
Integrated Flow Models							
1.	Site-Wide Water Balance Model	Integrated Flow, Calibrated	1a. The original model was developed as a decision tool to assess major hydrologic changes within the Industrial Area (IA) and Buffer Zone caused by hypothetical site closure configuration modifications and for different annual (continuous) climate sequences (wet, typical and dry). 1b. A second objective was to better understand the nature of pre-closure integrated flow conditions at RFETS. 1c. Conduct a sensitivity analysis, model validation, and uncertainty analysis for hypothetical closure configuration model.	A fully integrated model was developed coupling channel flow, overland flow, pond operations, unsaturated and saturated zone flow, evapotranspiration, and snowmelt processes. A grid resolution of 200- x 200-foot was used for all processes except channel flow. The model extended from near the west RFETS boundary to Indiana so that all surface flows into Woman and Walnut Creek at Indiana were included in the model.	1. Direct recharge from precipitation is the primary source of groundwater (not from lateral inflow from the west as previously thought in other studies), 2. Most annual discharge from the system is evapotranspiration, concentrated along creeks, but also occurring in upland areas, 3. Increased runoff from Industrial Area (IA) due to pavement, baseflow and drain inflow, 4. Closure configuration simulation showed Woman Creek flows largely unaffected by IA closure, but Walnut Creek flow substantially decreased (elimination of Waste water, pavement, and drain discharges). Terminal pond discharges decrease for Walnut. 5. groundwater levels increased overall in IA, though some areas decreased.	Completed May 2002.	Site-Wide Water Balance Model, Rocky Flats Environmental Technology Site, Kaiser-Hill, May 2002.
		Integrated Flow	2. Gravel Quarry Simulation	Use closure configuration model as basis for simulation. Assume excavation and dewatering along entire westernmost extent of model from 18 to 25 meters (59 to 82 feet) below grade. Levels are kept constant in time.	Simulation showed that dewatering has virtually no effect on downstream IA/Buffer Zone surface water, or groundwater flow conditions. This is mostly due to strong localized precipitation recharge and deeper UHSU thickness upgradient.	Completed January 2003	White Paper on Site-Wide Water Balance Model Applications - I Rocky Flats Environmental Technology Site Golden, CO Final, January 30, 2003.
		Integrated Flow	3. Assess hydrologic response to a 100-year event for current conditions and at closure.	Use calibrated model and hypothetical closure configuration. Lower soil infiltration rates were used in these simulations to more directly compare against former Actinide Migration Evaluation (AME) soil erosion modeling. Storm event was placed in may, but magnitude of response would change depending on where it is placed in time (i.e., antecedent unsaturated and saturated conditions would be different).	1. Simulated peak flows are higher for current condition due to pavement. 2. Capacities are exceeded for some structures (i.e., A-1, McKay bypass) for the closure configuration. In addition, other structures flow for current conditions (Ponds A-3, B-3, and B-5).	Completed January 2003	White Paper on Site-Wide Water Balance Model Applications - I Rocky Flats Environmental Technology Site Golden, CO Final, January 30, 2003.
		Integrated Flow	4. Simulate effect of using current topographic surface at closure.	Use closure configuration model, but use original topography smoothed at former building locations.	The difference in hydrologic response between this run and proposed land surface reconfiguration simulated in surface water modeling is minimal.	Completed January 2003	White Paper on Site-Wide Water Balance Model Applications - I Rocky Flats Environmental Technology Site Golden, CO Final, January 30, 2003.

Table A.1 - Integrated Hydrologic Flow and Fate/Transport Models
Rocky Flats Environmental Technology Site

No.	Modeling Project	Model Type	Modeling Tasks/Purpose	Model Details	Key Conclusions	Completion Date/Status	Report
	Site-Wide Water Balance Model (cont'd)	Integrated Flow	5. Simulate effect of leaving all subsurface drains active at closure.	Use the calibrated surface water water balance (SWWB) flow model with drains left on.	1. Groundwater levels in IA decrease; no change in levels in Buffer Zone, 2. Decrease in baseflow within IA (~20%); ~6% decrease in ET loss as a result. 3. Increase in drain discharge to surface water093, GS10 increase 140% and 40%; GS03 increases 50%; no increase noted at surface water027, or GS01.	Completed January 2003	White Paper on Site-Wide Water Balance Model Applications - I Rocky Flats Environmental Technology Site Golden, CO Final, January 30, 2003.
		Integrated Flow	6. Assess the hydrologic response of a hypothetical slurry wall immediately upgradient of the Original Landfill (OLF). Also assess the hydrologic response of a low permeability evapotranspiration (ET) cover over the OLF.	Local area model around the OLF/B460/B444 area. Slurry wall assumed to extend to the top of the unweathered bedrock surface. Simulation also included evaluation of an ET cover over the OLF.	1. Groundwater levels increase about 3 feet north of the wall. 2. Effects of the slurry wall on groundwater levels limited to 200-300 feet laterally. 3. Recharge not completely eliminated in OLF with ET cover. 4. Dewatering will take decades to occur in OLF with ET cover/slurry wall.	Completed August 2002	White Paper on Site-Wide Water Balance Model Applications - Rocky Flats Environmental Technology Site Golden, CO Final, January 30, 2003.
		Integrated Flow	7. Assess topography/drainage-Rev12 update w/wetlands in functional channel (FC) 2 and 4 (June-August 2005 update)	The former SWWB closure configuration model was updated with the Rev12 surface topography and revised Functional Channel (FC) drainages with two new wetland areas including bermed areas.	1. Only South Walnut Creek showed notable decrease in flows. 2. No flow downstream of Pond B-5 (no releases) even for wet-year climate sequence. 3. Only one release occurs in Pond A-4, though with dry-year climate no release occurs. 4. Updated configuration has little impact on surface flow at SW093 (north Walnut), or in Woman Creek and the SID.	Completed September 2005	No formal report.
2.	IA VOC Flow Model	Integrated Flow, Calibrated	1. Integrated flow model developed of the IA to produce long-term closure configuration groundwater flow conditions as a basis for later reactive fate/transport modeling of volitile organic compounds (VOCs) to support Comprehensive Risk Assessment (CRA). Increased model resolution required recalibration of saturated zone parameters.	The model extent was limited to current and possible future areas impacted by VOCs (Northern boundary is North Walnut Creek, South bounded by Woman Creek, and the east is bounded by plume extents. Four saturated model layers at a grid resolution 60 feet by 60 feet were simulated. Only IA surface channels were simulated. The most current closure configuration information was used at the time (i.e., Rev 6/7).	1. The recalibrated model reproduced observed groundwater levels within the IA well. 2. Seepage areas only occur within FCs 1, 2 and 4 (west of B371, between B371 and B771, and just south of B991, respectively). 3. Simulated groundwater flows are mostly downward in the IA within Upper Hydrostatigraphic Unit (UHSU), and then upward as flows near creeks.	April 2004	Final Fate and Transport Modeling of Volatile Organic Compounds at Rocky Flats Environmental Technology Site, April 2004.

No.	Modeling Project	Model Type	Modeling Tasks/Purpose	Model Details	Key Conclusions	Completion Date/Status	Report
		Integrated Flow	2. Rev 12 topography/drainage update with FC 2 and 4 constructed wetlands.	This model was used as the basis for developing long-term three-dimensional groundwater flow conditions for subsequent updates to reactive transport VOC simulations in 2005.	1. Simulated seepage areas do not change significantly, though, surface seepage does occur in central IA west of South Walnut (consistent with pre-RFETS development) and in borrow pit (FC-1) west of former B371. 2. Local flow directions do not change significantly, 3. Groundwater levels change most in areas where footing drains removed (increased). 4. Annual simulated surface flows from IA through FC-1, FC-2 and FC-4 (GS10 gage) suggest little if any flow will occur when wetland/vegetation is fully established.	Aug-05	No formal report.
3.	Building 991 Closure Configuration	Integrated Flow	1. Assess the integrated flow response to proposed closure configuration for B991 Area (B991, B985, Tunnel Corridor and Vaults 996, 997, 998 and 999) for a 100-year wet year climate (conservative extreme climate conditions leading to highest groundwater levels).	To simulate the concrete structure left in-place and material over the slabs, gravel beneath the slabs, and native material, seven saturate model layers were defined. The increased grid resolution eliminated the need to simulate surface channel flow. Only overland flow was simulated along with unsaturated and saturated flow. No attempt was made to calibrate flows within the system as drains were not simulated.	1. Simulations show that groundwater levels can reach ground surface above western-most vault and tunnel, but not for most of 997 tunnel and B991. This is mostly due to shallow bedrock in western building area. Tunnel itself is mostly embedded within weathered bedrock and didn't cause backup of groundwater levels behind it during wet year.	Completed January 2004	No formal report.
4.	Building 771/774 Closure Configuration	Integrated Flow, Calibrated	1a. Determine effect of building closure and carbon tetrachloride (CCl_4) removal on plumes in the area - Rev 6/7. Assess the sensitivity of hydrologic response to different input assumptions; a) holes in the slab, b) variations in hydraulic conductivity, and c) active vs. inactive drains (footing, storm and sanitary). 1b. Determine the basic configuration of a groundwater interception trench along the north and west side of B771 and B774 necessary to prevent groundwater saturation at surface and to collect IHSS118.1 VOCs in groundwater.	Given the complexity of subsurface drains/utilities, this model was calibrated against available groundwater levels and drain discharge. A fully integrated model, including channel flow was simulated. A seven layer saturated zone model was also specified in this model to account for native material, slabs and underlying gravel. Initially, subsurface drains (i.e., footing, storm, sanitary) were assumed left in-place. Later, during discussions with CDPHE, all drains were assumed disrupted to prevent development of a preferential pathway.	1. Groundwater can saturate surface soils at northern edge of B771/B774 slabs, even in typical climate year. 2. Groundwater levels can reach ground surface south of the B771 wall, even for a typical year. 3. Groundwater doesn't saturate surface behind B771-B776 tunnel and B771-stack, even during typical climate year. 4. Arapahoe Sandstone in area could preferentially route groundwater and contaminants below B771, though, occurrence/extent somewhat uncertain. 5. The calibrated 'current-condition' model reproduced observed flow and head data well.	August 2003	No formal report.

Table A.1 - Integrated Hydrologic Flow and Fate/Transport Models
Rocky Flats Environmental Technology Site

No.	Modeling Project	Model Type	Modeling Tasks/Purpose	Model Details	Key Conclusions	Completion Date/Status	Report
		Integrated Flow	2a. Evaluate the hydrologic response following actual closure - drains were not disrupted as assumed for final closure configuration simulations in the initial analysis. 2b. Assess hydrologic response of proposed disruption locations.	ER provided new information on proposed disruption points along north side of B771 from Manhole 3. Disruptions were made to both backfill material and footing/storm drains.	1. Model results showed that limited leaving drains active actually decreases groundwater levels around upgradient (south) part of building. 2. Levels on the north side of B771 increase to within 1 m of ground surface for mean wet year conditions. 3. No significant change to levels if area over Manhole 3 is compacted. 4. Recommended not disrupting drains at one location, but at many to avoid local groundwater	February 2005	No formal report.
		Integrated Flow	3. Provide updated steady three-dimensional groundwater flow condition for additional reactive transport in the area using the Rev 12 topography/drainage update with FC 2 and 4, and new constructed wetland west of B771.	Final configuration of where footing/storm drains were disrupted were included in this simulation. A typical climate sequence was used to generate long-term steady groundwater flow conditions.	No comparison to previous modeling output was performed, but results were used in evaluation of fate/transport of vinyl chloride north of the building.	May 2005	No formal report.
5.	B883/B881 Closure Configuration	Integrated Flow	1. Assess long-term integrated hydrologic response related to closure of Buildings B881/B883. a) Specifically assess groundwater flows and levels for typical and wet-year climate, and b) assess difference in response between permeable (i.e., holes in them) and impermeable basement walls.	A local integrated flow model was developed with overland flow, unsaturated zone flow and saturated zone flow using a seven layer model. All subsurface drains were assumed disrupted completely in the typical and wet-year climate scenarios. A 1-foot thick gravel layer beneath basement slabs was assumed for both buildings. A 20-foot gravel layer thickness was assumed beneath B883.	1. Results showed that minimum annual groundwater levels on the west, south and east sides of B881/B883 remain below 1 meter below grade. groundwater northeast of these buildings can saturate surface soils due to shallow bedrock. 2. Modeling showed permeable North and South walls in B881 cause flows from B883 area flow south through the building more readily. 3. To reduce southward migration of possible VOCs in groundwater north of B881, walls were left impermeable. 4. Levels also buildup at south end of B881 where continuous gravel layer ends (pressure increase at north end is translated to south end via gravel layer beneath B881).	June 2005	No formal report.
6.	Building 371 Closure Configuration	Integrated Flow	Evaluate long-term hydrologic effects of: a) B371/B374 closure configuration; b) two different surface drainages; c) different basement access hole placement; and d) permeable verses impermeable basement walls.	Seven saturated zone layers were used to simulate concrete slabs, gravel material below slab, and native material. Two regrade surface topographies and drainages were used as input to overland flow. No channelized flow considered.	a. groundwater depths lower for permeable walls, b. Scenario with drainage west of B371 reduces groundwater levels locally along western B371, c. Access holes help reduce groundwater levels around B371/B374 during wet years, d. During wet year, groundwater levels can reach ground around B371 and shallow bedrock areas North and West of B371, but not east along hillslope into FC 2.	March 2005	No formal report.

Table A.1 - Integrated Hydrologic Flow and Fate/Transport Models
Rocky Flats Environmental Technology Site

No.	Modeling Project	Model Type	Modeling Tasks/Purpose	Model Details	Key Conclusions	Completion Date/Status	Report
		Integrated Flow	Evaluate hydrologic effects of adding constant (three months continuous) dust-suppression water within footprint of B371/B374.	The same seven-layer model was used to assess groundwater level change with time for different assumptions about dust suppression application rate.	1. Sub-basement would fill within 10 to 20 days. 2. Little effect of external groundwater levels - sub-basement entirely within weathered bedrock limits inflow/outflow, 3. Basement level could fill from within 40 to greater than 90 days. Modeling suggested keeping footing drains active, and dewater basement from gravel layer.	March 2005	No formal report.
		Integrated Flow	Evaluate long-term hydrologic effects of updated closure configuration. Specifically, modifications included FC 2, new regrade surface and 6 feet additional soil cover over Building footprint, basement/sub-basement access hole locations, footing drain disruptions, and revised bedrock configuration.	Used updated closure configuration information.	Increased soil cover over building and previous hillside excavation east of building limit groundwater seep development even for wet year climate. Permeable backfill trench material has only limited effect on flow from building to surface water.	May 2005	No formal report.
7.	Present Landfill Model	Integrated Flow, Calibrated	Evaluate current conditions to better understand system flows. Evaluate closure configuration to assess effects of different modifications such as regrade and impermeable surface liner.	Four-saturated model layers (includes waste material), East Pond not explicitly simulated (no Mike11); groundwater, slurry walls, seep, gravel drain included; Fully integrated, Fully distributed unsaturated zone and vegetation, WY1993 to WY1995 - calibration WY2000 validation; Sensitivity analysis	Groundwater within waste area effectively contained. All groundwater discharges to the seep or via groundwater flow to East Pond area. One low permeability cover simulation was performed, but was not fully evaluated.	Completed 2003. No further runs considered.	FINAL Interim Measure/Interim Remedial Action for IHSS 114 and RCRA Closure of the RFETS Present Landfill, August 2004.
8.	Original Landfill Model	Integrated Flow, Calibrated	Calibrate current flow conditions within the OLF and the upgradient IA area to observed data. Evaluate and compare hydrologic response for several different long-term closure configurations including: a) no modifications except IA closure; b) regrade only; c) regrade with buttress and drain; and d) regrade, slurry wall, clay buttress and drain. All scenarios were simulated for typical and 100-year wet-year climate sequences.	A refined grid was used (25- x 25-foot) to better capture OLF features. A four-layer, saturated zone model was used to describe waste, clay buttress and sub-drain in model area. A calibrated model was developed first for current conditions. Several closure configurations were compared against a scenario where no OLF modifications assumed, except IA closure changes.	1. Calibrated model able to reproduce observed water levels well. 2. Initial regrade surface caused groundwater levels to generally increase ~2 feet for typical year climate and another 2 feet for wet year climate. Locally this was greater, or less. This created seepage areas for average conditions due to shallow bedrock areas. 3. Effect of upgradient slurry wall on reducing levels in waste was small, 4. Effect of buttress and drain caused levels to decrease more within waste than with slurry wall. 5. Sub-surface drain produces < 1 gpm.	October 2004	Integrated Flow and VOC Fate and Transport Modeling for the Original Landfill at the Rocky Flats Environmental Technology Site, Golden, Colorado, Technical Report, December 6, 2004. This report was included in: Final Draft Interim Measure/Interim Remedial Action for the Original Landfill (Including IHSS Group surface water-2; IHSS 115, Original Landfill and IHSS 196, Filter Backwash Pond).

Table A.1 - Integrated Hydrologic Flow and Fate/Transport Models
Rocky Flats Environmental Technology Site

No.	Modeling Project	Model Type	Modeling Tasks/Purpose	Model Details	Key Conclusions	Completion Date/Status	Report
		Integrated Flow	Several updates to the surface regrade, clay buttress and sub-drain were evaluated iteratively and results provided to Earthtech for further geotechnical evaluation.	The same model was used to simulate all subsequent simulations except surface regrade, drain and clay buttress information was modified.	1. Seepage areas eliminated upgradient of buttress for new regrade surface, and decreased lateral extent of buttress. 2. Simulated heads buildup above ground surface downgradient of the buttress, at subsurface drain ending within stream alluvium	Finished final OLF modeling of final buttress, drain and topography	None
9.	B444 Flow Model	Integrated Flow	1. Evaluate long-term, conservative fate/transport of Uranium in groundwater from B444 basement. Develop a fully integrated flow model and determine long-term steady, three-dimensional, groundwater flow conditions for use in transport simulations.	The B444 integrated flow model is based on the same model as the OLF (25 x 25 ft resolution).	1. Groundwater flows from the B444 basement structure towards the east-northeast, while flows immediately south of the B444 flow east-southeast. Long-term groundwater conditions were determined by using average annual levels. 2. Groundwater levels inside basement buildup relative to external levels. Long-term, causing continuous outward flux.	July 2004	White paper entitled "Analysis of Fixed Uranium Contamination in the Building 444 Basement and its Potential Impact on Surface Water Quality, RFETS, July 12, 2004".
		Integrated Flow	2. Evaluate long-term closure configuration effects on local hydrology around B460 slab left in place.	This modeling used the most recent OLF model (eight above) to evaluate B460 building closure configuration. This modeling did not assume holes in slab, though recent information suggests the slab was penetrated in many locations. This effect would reduce mounding effects and changes in flow direction.	1. Groundwater levels mound at perimeter of B460 reach ground surface for wetter periods of typical and wet-year climate sequences. 2. Flow directions immediately south and east of B460 shift slightly from east-northeast to east-southeast. Flows in the OLF area remain unaffected by this configuration change.	July 2005	
10.	B776/777 Model	Integrated Flow	Dust suppression effects. Model evaluation of saturated ground conditions for 3 months. Subsurface utility trenches assumed disrupted. Recent information suggests significant flow has leaked along Tunnel between B776/B777 and B771.	Model based on calibrated current condition IA VOC model (60- x 60-foot grid). Overland flow is simulated, channel flow is not. groundwater levels within footprint of B777 and B776 assumed constant at surface for 3 months continuous dust suppression. Localized details associated with the former tunnel between B776 and B771 was assumed completely disrupted. Recent data suggests this still acted as a preferential channel, causing increased levels and slumping at B771.	1. Groundwater levels after 3 months increase between 1 to 2.4 meters within about 70 to 100 meters. 2. Levels increase more to the north of B777/B776. 3. Levels decrease after spraying ceases mostly within the B777/B776 footprint, and in other areas at a rate slower than the earlier increase.	August 2004	White paper entitled "Integrated Flow Model Analyssi of Ipmacts from B777/776 decommissioning, August 11, 2004".
11.	Dewatering of Tank 9 & 10/CCL4-118.1	Groundwater Flow Model (GMS, MODFLOW)	Estimate the time and volume associated with dewatering an excavation of Tank 9 and 10 associated with the IHSS118.1 area for 3 months.	Information on the excavation area and depth was assumed based on data provided by Environmental Restoration. The GMS MODFLOW code was use to simulate three-dimensional groundwater flow conditions for the excavation. Calibrated hydraulic values from the localized B771 integrated flow model were used in the MODFLOW model.	1. It takes 1 to 2 days to dewater most of the excavation 15 ft below grade using two pits. 2. Approximately ~35,000 gallons would need to be removed after 3 months of dewatering. 3. About 200 gal/day required to keep dewatered at times longer than 90 days. 4. Dewatering to 21 ft, below grade requires about 20-30% more water.	June 2003	Simulation of Groundwater Dewatering Associated with Removal of the IHSS 118.1 Tank 9 and 10. June 16, 2004.

Table A.1 - Integrated Hydrologic Flow and Fate/Transport Models
Rocky Flats Environmental Technology Site

No.	Modeling Project	Model Type	Modeling Tasks/Purpose	Model Details	Key Conclusions	Completion Date/Status	Report
12.	Mound Integrated Hydrologic Modeling	Integrated Flow, Calibrated	1. Assess current Mound Plume Groundwater Treatment System integrated flow conditions. 2. Then assess long-term integrated hydrologic flow and performance of groundwater collection system using the most recent Rev12 closure configuration. 3. Assess hydrologic effect of 72" storm drain line on groundwater flows	1. This model grid was defined at a 10-foot grid resolution (the highest of any model) to more accurately simulate flows associated with the local trench/drain system. 2. Four saturated zone layers were used to describe unconsolidated material, drain/trench, claystone and arapahoe sandstone in area. 3. A fully integrated and distributed model was developed with all processes, except channelized flow (accounted for using overland flow).	1. Calibrated flow model reproduces observed head and mound treatment system groundwater collection trench flows well. 2. Both current and closure configuration simulations show that the french drain and collection trench appear to capture most groundwater from Oil Burn Pit #2, and Mound area source VOCs. 3. 72" storm drain utility trench may preferentially route groundwater in northern part - recommended tying this into existing collection trench.	May 2005	Final Interim Measure/Interim Remedial Action for Groundwater at the Rocky Flats Environmental Technology Site, June 21, 2005.
13.	A/B Pond Model - integrated transport evaluation and Pond reconfiguration/operation evaluation	Integrated Flow, Calibrated	Initially to evaluate Point of Compliance/Point of Evaluation (POC/POE) water quality due to VOC transport. In addition, tool can also now be used to assess flood-dynamics, pond operation, wetland sustainability.	Includes all A and B ponds and Walnut Creek from the IA (I.e., SW093 (N. Walnut) and GS10 (S. Walnut)) to Indiana street. Resolution of grid is 50- x 50-feet.	Only initial model input prepared.		No formal report.

Table A.1 - Integrated Hydrologic Flow and Fate/Transport Models
Rocky Flats Environmental Technology Site

Fate and Transport Modeling

No.	Modeling Project	Model Type	Modeling Tasks/Purpose	Model Details	Key Conclusions	Completion Date/Status	Report
14.	Plume Signature Area (PSA) 2S (Ryan's Pit/Southern 903 Pad Area (IHSS 109)	Fate/Reactive Transport, Calibrated	1. Infer likely sources at Ryan's Pit and the 903 Pad that migrate east-southeast and calibrate fate/transport model. Parameters using current and historical concentration distributions and via groundwater flow path analysis. 2. Evaluate long-term fate and transport from inferred sources for closure configuration.	1. Develop localized, three-dimensional GMS-MODFLOW model using time-averaged groundwater levels from the IA volitile organic compound (VOC) integrated flow model (#2 above). 2. Use MODPATH to assess source location and release times. 3. Use GMS-RT3D fate/transport code to assess historical concentration distributions. 4. Use GMS-RT3D to assess closure configuration based on updated MODFLOW model with closure IA VOC integrated model groundwater levels.	1. Initial fate/transport modeling from 903 Pad area indicated divergent flow (north and south). PSA2S model was created to track east-south migration from inferred sources. 2. Release times likely 30-50 years ago. 3. Most of the sixteen closure simulations showed concentrations of CCl_4, tetrachloroethene (PCE), and trichloroethene (TCE) > surface water standards along South Interceptor Ditch (SID), South Woman Creek and the surface ditch just southeast of the 903 Pad. Groundwater discharge is intermittent in surface ditch. 4. Travel time > 100 years.	Originally completed as part of IA VOC Modeling Report (completed April 2004).	Final Fate and Transport Modeling of Volatile Organic Compounds at Rocky Flats Environmental Technology Site Golden, Colorado. April 2004.
15.	PSA2N (903 Pad /East Trenches Areas)	Fate/Reactive Transport, Calibrated	1. Infer likely sources at the 903 Pad that migrate east-northeast and calibrate fate/transport model parameters using current and historical concentration distributions and via groundwater flow path analysis. 2. Evaluate long-term fate and transport from inferred sources for closure configuration.	Same as PSA2S (#1 above). One exception was that downgradient migration of VOCs from inferred sources associated with PSA6 and 7 (within footprint of 903 Pad plume) could not be adequately assessed with PSA2N. Therefore a separate model (PSA6/7) was developed (see below).	1. Although the calibrated model was able to reproduce observed concentration distributions within 30-50 years, it was unable to account for higher concentrations near the East Trench System. As a result, the PSA6/7 Model area was developed (see below) to more accurately represent the area. 2. In addition, preliminary closure configuration simulations showed that concentrations at South Walnut Creek were not impacted above surface water standards. Therefore, 16 sensitivity simulations were not conducted.	Originally completed as part of IA VOC Modeling Report (completed April 2004).	Final Fate and Transport Modeling of Volatile Organic Compounds at Rocky Flats Environmental Technology Site Golden, Colorado. April 2004.
16.	PSA67 - East Trenches Area – Sub-Scale Model	Fate/Reactive Transport, Calibrated	1. Infer likely sources within PSA6/7 and calibrate fate/transport model parameters using current and historical concentration distributions and via groundwater flow path analysis. 2. Evaluate long-term fate and transport from inferred sources for closure configuration.	Same as PSA2S (#1 above). 1. A high permeability zone was simulated in the model to better represent observed localized high VOC concentrations, and increased surface discharge at Pond B-2. 2. Sources were assumed at former East Trenches.	1. Particle tracking results showed preferential flow through high permeability zone, but suggested release locations and timing were reasonable. 2. Sensitivity simulations showed the revised local model bracketed the range of observed concentrations. 3. None of the 14 closure sensitivity simulations produced PCE, nor CCl_4 concentrations > surface water preliminary remediation goals (SWPRGs) values. 4. Most of the 14 closure simulations showed TCE > SWPRG values in the Pond B-1 to B-2 area. 5. Almost all simulations showed PCE and CCl_4 > surface water standards.	Originally completed as part of IA VOC Modeling Report (completed April 2004).	Final Fate and Transport Modeling of Volatile Organic Compounds at Rocky Flats Environmental Technology Site Golden, Colorado. April 2004.

No.	Modeling Project	Model Type	Modeling Tasks/Purpose	Model Details	Key Conclusions	Completion Date/Status	Report
17.	PSA5 (Mound-IHSS 113, Oil Burn Pit #2)	Fate/Reactive Transport, Calibrated	1. Originally modeled with IA VOC integrated flow model (see above) to assess effects of sources at Mound/Oil-Burn Pit #2.	Same as PSA2S (#1 above). One exception is that the Mound Plume Treatment System was not modeled so that maximum groundwater concentrations at surface water areas could be determined. (Remodeled later in 2005 with system and french drain included.)	1. Particle tracking (MODPATH) analysis showed inferred source locations could produce downgradient PSA. 2. Sensitivity simulations showed it was possible to bracket range of observed concentrations. 3. 16 closure configuration sensitivity simulations showed that only the section northwest of Oil Burn Pit #2 (along functional channel 4) showed PCE and TCE concentrations > SWPRGs.	Originally completed as part of IA VOC Modeling Report (completed April 2004).	Final Fate and Transport Modeling of Volatile Organic Compounds at Rocky Flats Environmental Technology Site Golden, Colorado. April 2004.
	PSA5 (Mound-IHSS 113, Oil Burn Pit #2)	Fate/Reactive Transport, Calibrated	2. Re-assess long-term fate/transport of VOCs from Mound/Oil Burn Pit #2 areas using new data and a new calibrated, higher-resolution (10- x 10-ft) integrated flow model (with Rev12-wetland closure configuration). The Mound Plume Treatment System/french drain was included in these model simulations.	1. A GMS-MODFLOW groundwater flow model and Reactive Transport model (RT3D) were developed in a similar manner to PSA2S (see #1 above). New top of weathered bedrock data was used in model. 2. Limited calibration simulations were conducted given prior modeling. 3. Only PCE and TCE evaluated.	1. The calibrated fate/transport model reproduced observed VOC concentration distribution well, except for some downgradient low values near trench (probably due to trench effects). 3. Modeling showed that all 10 closure sensitivity simulations show that PCE and TCE concentrations along FC 4 remain below surface water standards.	2005	Final Interim Measure/Interim Remedial Action for Groundwater at the Rocky Flats Environmental Technology Site, June 21, 2005.
18.	PSA9 - 881 Hillside Area	Fate/Reactive Transport, Calibrated	1. Infer likely sources in the 881 Hillside area, and calibrate fate/transport model parameters using current and historical concentration distributions, and via groundwater flow path analysis. 2. Evaluate long-term fate and transport from inferred sources for closure configuration.	Same as PSA2S (#1 above). Simulate PCE, TCE, and CCl_4. The 881 Hillside groundwater collection trench was not modeled to simulate maximum downgradient concentrations.	1. Particle tracking (MODPATH) analysis confirmed the very limited downgradient migration from inferred source (due to groundwater flow mostly in low permeability claystone in weathered bedrock. 2. Sensitivity simulations showed it was possible to bracket range of observed concentrations. 3. 16 closure configuration sensitivity simulations showed neither PCE/TCE nor CCl_4 chains impact downgradient surface water at Woman Creek or the SID (i.e., < surface water standards). 4. Only 1 to 2 of the 16 simulations showed TCE and CCl_4 above surface water standards.	Originally completed as part of IA VOC Modeling Report (completed April 2004).	Final Fate and Transport Modeling of Volatile Organic Compounds at Rocky Flats Environmental Technology Site Golden, Colorado. April 2004.

Table A.1 - Integrated Hydrologic Flow and Fate/Transport Models
Rocky Flats Environmental Technology Site

No.	Modeling Project	Model Type	Modeling Tasks/Purpose	Model Details	Key Conclusions	Completion Date/Status	Report
19.	PSA10 - B444 Area	Fate/Reactive Transport, Calibrated	1. Infer likely sources in the 881 Hillside area, and calibrate fate/transport model parameters using current and historical concentration distributions, and via groundwater flow path analysis. 2. Evaluate long-term fate and transport from inferred sources for closure configuration.	1. Same as PSA2S (#1 above). Simulate PCE and TCE. Three source areas were simulated (B444, B447, and B444 Drum Storage area). 2. Closure configuration did not consider effects of recent OLF/SID area modifications effects, nor actual closure configuration for B460 and B444 structures).	1. Particle tracking (MODPATH) analysis confirmed that the PSA distribution could be produced by inferred sources. 2. Sensitivity simulations showed it was possible to bracket range of observed concentrations. 3. 16 closure configuration sensitivity simulations showed neither PCE, nor TCE impact downgradient groundwater at Woman Creek, or the SID (i.e., < surface water standards). 4. Only one to two closure simulations showed PCE and TCE greater than surface water standards.	Originally completed as part of IA VOC Modeling Report(completed April 2004).	Final Fate and Transport Modeling of Volatile Organic Compounds at Rocky Flats Environmental Technology Site Golden, Colorado. April 2004.
	PSA10 - B444 Area	Fate/Reactive Transport	Assess long-term conservative fate/transport of uranium from basement of B444 (i.e., dirty closure).	1. Initially, assess only 'conservative' advective dispersive transport using the MIKESHE AD Module. Assume instantaneous release of entire uranium inventory (in concrete) into groundwater as source. 2. Later, effects of sorption were evaluated using GMS-RT3D model. 3. Closure configuration did consider effects of OLF area (regrade) and SID removal, but not other effects (i.e., OLF clay buttress/drain, latest surface OLF regrade, and actual closure configuration for B460 and B444 structures).	1. Conservative advective-dispersive simulations showed that uranium transport from B444 migrates east and then north-east eventually into South Walnut Creek. 2. Concentrations at Walnut Creek would be well below surface water action levels due to dispersion. 3. Adding sorption dramatically reduces the downgradient concentrations (less conservative, but more realistic). The plume stagnates within a few hundred feet of B444.	7/1/2004	White paper entitled "Analysis of Fixed Uranium Contamination in the Building 444 Basement and its Potential Impact on Surface Water Quality, RFETS, July 12, 2004".
20.	PSA12 - Central IA	Fate/Reactive Transport, Calibrated	1. Infer likely sources in the Central IA area (draining to FC 2), and calibrate fate/transport model parameters using current and historical concentration distributions, and via groundwater flow path analysis. 2. Evaluate long-term fate and transport from inferred sources for closure configuration.	1. Same as PSA2S (#1 above). Nine TCE sources and three CCl_4 sources were simulated. 2. PSA12 Model area also included PSA 13 (now B371 vinyl chloride (VC) model area), and PSA 11. Both of these model areas have been updated in subsequent modeling (see PSA11 and PSA13 modeling below).	1. Particle tracking (MODPATH) analysis indicated that source release ~50 years was reasonable. 2. Initial fate/transport modeling indicated that multiple sources are required to account for current distribution of VOCs in the area. 3. Current condition sensitivity simulations - bracketed the range of observed concentrations. 4. 16 closure simulations - all TCE and CCl_4 groundwater discharge concentrations less than surface water PRG values. 5. Updated results to surface water standards show several areas impacted by CCl_4 along FC-2, though concentrations are low.	Originally completed as part of IA VOC Modeling Report (completed April 2004).	Final Fate and Transport Modeling of Volatile Organic Compounds at Rocky Flats Environmental Technology Site Golden, Colorado. April 2004.

Table A.1 - Integrated Hydrologic Flow and Fate/Transport Models
Rocky Flats Environmental Technology Site

No.	Modeling Project	Model Type	Modeling Tasks/Purpose	Model Details	Key Conclusions	Completion Date/Status	Report
21.	PSA14 - B771 – IHSS118.1 Area	Fate/Reactive Transport, Calibrated	1. Infer likely CCl_4 sources near B771 and at IHSS118.1, and calibrate fate/transport model parameters using current and historical concentration distributions and via groundwater flow path analysis. 2. Evaluate long-term fate and transport from inferred sources for closure configuration.	1. Same as PSA2S (#1 above). Nine TCE sources and three CCl_4 sources were simulated.	1. Particle tracking analysis indicated that sources at IHSS118.1 and additional location to west and north were required to reproduced observed VOC distribution. Results showed these assumed source release time was reasonable. 2. Current condition sensitivity simulations - bracket the range of observed concentrations. 3. 16 closure simulations - average of CCl_4 groundwater discharge concentrations less than surface water PRG values. Some were higher in FC-2. 4. Most simulations showed CCl_4 greater than surface water standards along FC-2 and North Walnut Creek.	Originally completed as part of IA VOC Modeling Report (completed April 2004).	Final Fate and Transport Modeling of Volatile Organic Compounds at Rocky Flats Environmental Technology Site Golden, Colorado. April 2004.
		Fate/Reactive Transport	3. Updated Model for Rev 12 closure configuration to assess whether CCl_4/PCE would be modified.	Only closure configuration simulated using regrade information and same source locations.	1. Updated results to surface water standards show average CCl_4 along FC-2 and North Walnut Creek greater than standards. 2. Updated results show most closure simulations PCE greater than surface water standards along FC-2.	February 2005	Final Interim Measure/Interim Remedial Action for Groundwater at the Rocky Flats Environmental Technology Site, June 21, 2005.
		Fate/Reactive Transport	4. Updated Model for Rev 12 wetland configuration and additional modifications to footing/storm drains post-closure. Modeled fate/reactive transport of Vinyl Chloride source north of B771.	1. Used average annual groundwater levels from updated seven-layer B771 model as input to modified (closure configuration) GMS MODFLOW/RT3D four-layer models. 2. Only two closure configuration models, using conservative assumptions for VC, were simulated.	1. Results show VC rapidly degrades below surface water standards before reaching North Walnut Creek.	April 2005	Final Interim Measure/Interim Remedial Action for Groundwater at the Rocky Flats Environmental Technology Site, June 21, 2005.
22.	PSA15 - Western Solar Ponds Area)	Fate/Reactive Transport, Calibrated	1. Infer likely sources in the former Western Solar Pond area, and calibrate fate/transport model parameters using current and historical concentration distributions, and via groundwater flow path analysis. 2. Evaluate long-term fate and transport from inferred sources for closure configuration.	Same as PSA2S (#1 above). Simulate TCE and CCl_4. The Solar Ponds groundwater collection trench was not modeled so that maximum downgradient concentrations could be simulated.	1. Particle tracking showed assumed release time was reasonable, though, migration was slightly east of plume area. 2. Sensitivity simulations showed the model could bracket concentration distributions, 3. Results showed that all closure sensitivity simulations for TCE and CCl_4 were below SWPRG values. 4. Updated results show several locations along North Walnut Creek where average CCl_4 greater than surface water standards. All PCE less than surface water std, and only some simulations show TCE greater than surface water standard (but average less than standard).	Originally completed as part of IA VOC Modeling Report (completed April 2004).	Final Fate and Transport Modeling of Volatile Organic Compounds at Rocky Flats Environmental Technology Site Golden, Colorado. April 2004.

No.	Modeling Project	Model Type	Modeling Tasks/Purpose	Model Details	Key Conclusions	Completion Date/Status	Report
23	Peoperty Utilization and Disposal (PU&D) Yard	Fate/Reactive Transport, Calibrated	Assess the long-term closure configuration fate and transport of VOCs in groundwater within the PU&D Yard Area.	Same as PSA2S (#1 above). Simulate PCE and TCE. Three-dimensional groundwater flow conditions from the integrated flow model for the PU&D Yard included all relevant groundwater features (i.e., interceptor trench, flow in waste, clay barrier, slurry walls, and internal gravel drain. No particle tracking was conducted because constant heads were imposed over entire model - honored integrated flow better.	Simulation results suggest: 1. Five sources were inferred. 2. flow and transport is slow in the PU&D area. 3. Sensitivity simulations show model is able to bracket observed concentration distribution. 4. Closure simulations show that all VOCs simulated attenuate well before reaching North Walnut Creek, the Present Landfill seep, or East Landfill Pond.	Originally April 2004, then subsequently updated to reflect Surface Water Action Levels for	Fate and Transport of VOCs in groundwater in the vicinity of the Property, Utilization and Disposal (PU&D) Yard Areas, RFETS, April 2004. Updated results included in "Final Interim Measure/Interim Remedial Action for Groundwater at the Rocky Flats Environmental Technology Site, June 21, 2005".
24.	PSA East	Fate/Reactive Transport, calibrated	1. Originally VOC concentrations in groundwater here were not modeled because maximum levels were less than PRG values. 2. Infer likely sources and calibrate fate/transport model parameters using current and historical concentration distributions, and via groundwater flow path analysis. 3. Evaluate long-term fate and transport from inferred sources for closure configuration.	Same as PSA2S (#1 above). Simulate PCE and CCl_4. Sensitivity simulations for current conditions were not conducted in this analysis given the relatively low groundwater concentrations in the area.	1. Three sources were identified to account for existing PCE/CCl_4 distribution in the area, 2. The model was able to reasonably reproduce observed PCE and CCl_4 distributions. 3. Long-term closure simulations showed that none of the 10 sensitivity simulations showed PCE or CCl_4 concentrations greater than surface water standards.	December 2004	Final Interim Measure/Interim Remedial Action for Groundwater at the Rocky Flats Environmental Technology Site, June 21, 2005.
25.	PSA11 (Central IA)	Fate/Reactive Transport, Calibrated	1. Originally VOC concentrations in groundwater here were not modeled because maximum levels were less than PRG values. 2. Infer likely sources and calibrate fate/transport model parameters using current and historical concentration distributions, and via groundwater flow path analysis. 3. Evaluate long-term fate and transport from inferred sources for closure configuration.	1. Same as PSA2S (#1 above). Only PCE simulated. Sensitivity simulations for current conditions were not conducted in this analysis given the relatively low groundwater concentrations in the area. 2. Simulation used updated topographic/drainage (Rev 12) results from IA VOC model (compared to initial VOC modeling).	1. Seven distributed sources were necessary to account for the existing PCE distribution in the area, 2. The model reasonably reproduced observed PCE and CCl_4 distribution. 3. Long-term closure simulations showed that none of the 10 sensitivity simulations caused PCE concentrations greater than surface water standards along FC4 (South Walnut Creek). Though, upgradient wet year seep areas could have average PCE greater than surface water standard.	Originally completed as part of IA VOC Modeling Report (completed April 2004).	Final Interim Measure/Interim Remedial Action for Groundwater at the Rocky Flats Environmental Technology Site, June 21, 2005.
26.	PSA13	Fate/Reactive Transport, Calibrated	1a. Infer likely sources in the Oil Burn Pit #1 area south of B371 (high VC concentrations), and calibrate fate/transport model parameters using current and historical concentration distributions, and via groundwater flow path analysis. 1b. Evaluate long-term fate and transport from inferred sources for closure configuration.	1. Same as PSA2S (#1 above). Only TCE, VC, and cis-1,2-dichloroethene (cis-1,2-DCE) were simulated. 2. This model did not consider recent modifications to FC1 (borrow pit west of B371) and 2.	1. Particle tracking showed source locations and release times were reasonable. 2. A total of 14 sensitivity simulations showed current condition model was able to bracket range of observed concentrations. 3. All 14 sensitivity closure simulations showed VC attenuates (less than surface water standard) well before reaching the original FC 2.	April 2004	Final Fate and Transport of VOCs in Groundwater South of Building 371, Rocky Flats Environmental Technology Site Golden, Colorado, April 2004.

Table A.1 - Integrated Hydrologic Flow and Fate/Transport Models
Rocky Flats Environmental Technology Site

No.	Modeling Project	Model Type	Modeling Tasks/Purpose	Model Details	Key Conclusions	Completion Date/Status	Report
	PSA13 (cont'd)	Fate/Reactive Transport, Calibrated	2. All PCE chain compounds greater than surface water standards. This model was updated to assess the long-term fate/transport associated with these compounds using the most recent land configuration information. (i.e., FCs 1/2, wetland modification).	1. The model area was enlarged to include effects of all recent local modifications related to B371 closure.	1. All VOCs from two inferred source areas migrates toward FC 2. 2. The updated model slightly over-estimated observed concentration distributions (i.e., conservative). 3. All 10 closure sensitivity simulations show PCE chain concentrations well below surface water standards.	April 2005	Final Interim Measure/Interim Remedial Action for Groundwater at the Rocky Flats Environmental Technology Site, June 21, 2005.
27.	OLF	Fate/Reactive Transport, Calibrated	1a. Assess the long-term fate and transport of PCE in the OLF waste material for two proposed scenarios: •surface regrade only; and •surface regrade, clay buttress, and drain.	1. The OLF closure configuration simulated in the two model scenarios does not consider the latest modifications. 2. A new GMS-MODFLOW and RT3D model were prepared based on the OLF integrated flow model.	1. Three PCE source locations were simulated. 2. None of the six closure simulations for the two scenarios considered caused PCE or degradation product concentrations > surface water standards.	October 2004	Integrated Flow and VOC Fate and Transport Modeling for the Original Landfill at the Rocky Flats Environmental Technology Site, Golden, Colorado, Technical Report, December 6, 2004. This report was included in: "Final Draft Interim Measure/Interim Remedial Action for the Original Landfill (including IHSS Group Surface Water-2, IHSS 115, Original Landfill and IHSS 196, Filter Backwash Pond), December 6, 2004.

APPENDIX B – SUMMARY TABLE OF OTHER HYDROLOGIC, HYDRAULIC AND FATE/TRANSPORT MODELS AT RFETS

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Table B.1 - Other Hydrologic, Hydraulic, and Fate/Transport Models Developed for Rocky Flats Environmental Technology Site (Site or RFETS)

No.	Author	Date	Title	Modeled Process(s)	Modeling Purpose	Modeling Results/Conclusions	Codes Used
1.	Earth Tech, Inc.	2002	Design of an Engineered Cover For the Present Landfill Rocky Flats Environmental Technology Site. 60% Design Submittal, November 2002.	Unsaturated Flow and Evapotranspiration (ET)	To evaluate the preliminary performance of potential ET cover configurations, by predicting ET cover water balance based on cover configuration, soil and plant characteristics, and climatic conditions.	Daily climate data (temperature, dew point, precipitation, solar radiation, wind speed, and dew point temperature) were input to the UNSAT-H over a five-year wet period determined based on Fort Collins data (1995 to 1999). The model calculated evaporation, transpiration, infiltration (recharge) given external calculated potential evapotranspiration (PET) data from daily climate input, and different leaf area index (LAI) values (vegetation) growth cycles. Results were used to determine a preliminary landfill ET cover configuration that prevents any recharge to groundwater.	UNSAT-H code (Fayer, 2000) developed by the Pacific Northwest National Laboratory in Richland, WA. One-dimensional Richard's based unsaturated zone code
2.	Kaiser-Hill	2002	Actinide Migration Evaluation Pathway Analysis Report, Technical Appendix	Transport of Plutonium (Pu) -239/240, Americium (Am) -241, Uranium (U) -233/234, U-235, and U-238 via surface water, groundwater, airborne, and biological transport processes. Both measured data and model predictions are used.	Provide a quantified understanding of the relative magnitude of various pathways by which actinides are transported in the environment.	Surface erosion mechanisms (i.e., air and surface water) are the dominant transport pathways for Pu and Am, which are essentially insoluble. Groundwater is a more important pathway for U, which is more soluble relative to Pu and Am. The biological pathway is not a major transport mechanism for any of the actinides studied.	WEPP(USDA), HEC-6T(USACE), ISCST3, version 98356(EPA), MIKE SHE, version 2001 (DHI)
3.	Kaiser-Hill	2002	Soil Erosion and Sediment Transport Modeling of Hydrologic Scenarios for the Actinide Migration Evaluation at RFETS, Golden, CO.	Infiltration, Overland Flow, ET, Channel Flow, Sediment Transport.	The WEPP code was used to estimate overland flow and sediment transport, while HEC-6T was used to route flows and estimate sediment transport in stream channels. Various scenarios were evaluated, including the effect of grassland fires, extreme storm events, and modifying watersheds (e.g., vegetating gravel roads)	Revegetating roads in the Buffer Zone will reduce runoff and associated sediment transport. A range fire in the 903 Lip Area is predicted to increase actinide concentrations in the South Interceptor Ditch (SID) by as much as 50%. Revegetation of the Industrial Area (IA) will reduce runoff and actinide loads in surface water, though actinide concentrations may increase slightly if existing source material remains, because of reduced clean runoff from pavement and buildings.	WEPP (USDA), HEC6T (USACE)
4.	Illangasekare, T., Prucha, Robert, DHI.	2001	MIKE SHE Code Verification and Validation for RFETS Site-wide Water Balance Model (SWWB). September 2001. Report for Kaiser-Hill to support SWWB flow modeling.	Integrated Flow	The purpose of the report was to test and evaluate the MIKE SHE integrated flow code for use in developing the SWWB integrated flow model at RFETS.	Results of the study showed that MIKE SHE is capable of simulating the integrated semi-arid response at RFETS.	MIKE SHE, MIKE 11, VS2DTI (USGS two-dimensional unsaturated zone code), MODFLOW 2000.
5.	Kaiser-Hill	2001	Model Code and Scenario Selection Report Site-Wide Water Balance Rocky Flats Environmental Technology Site (Final Revision). May 31.	Integrated Flow	Several integrated codes were identified and evaluated for possible use as the SWWB model.	The MIKE SHE code was selected for use as the integrated code for developing the SWWB RFETS model.	Several codes identified and reviewed, including MIKE SHE.
6.	Kaiser-Hill	2001	Risk-Based Approach for In-Situ Backfill of Polychlorinated Biphenyls (PCB) - Based Painted Concrete	Groundwater flow, Transport	Assess migration of PCBs in groundwater to support backfilling of painted concrete containing PCBs in basement of demolished buildings (specifically B111).	Modeling showed PCBs in groundwater is nearly immobile, event with conservative Assumptions for input parameters. Simulations conducted for 30 years.	MOC

Table B.1 - Other Hydrologic, Hydraulic, and Fate/Transport Models
Developed for Rocky Flats Environmental Technology Site (Site or RFETS)

No.	Author	Date	Title	Modeled Process(s)	Modeling Purpose	Modeling Results/Conclusions	Codes Used
7.	Kaiser-Hill	2000	Report on Soil Erosion and Surface Water Sediment Transport Modeling for the Actinide Migration Evaluations at the Rocky Flats Environmental Technology Site. August 2000. 00-RF01823.	Infiltration, Overland Flow, ET, Channel Flow, Sediment Transport	The WEPP code was used to estimate overland flow and sediment load mass load to streams, by particle size. HEC-6T was used to route flows and estimate sediment mass transport, by particle size, through stream channels. WEPP and HEC-6T model output was coupled with soil actinide data (Pu and Am) distributed across the site to develop estimates of actinide concentrations in surface water.	Results of 100 years continuous simulation of runoff and erosion were used to generate 100-year annual average erosion maps and 100-yr Pu-238/240 and Am-241 mobility maps. In addition, six single storm events were modeled, with return frequencies varying from a 1-year, 2-hour storm up to a 100-year, six-hour storm. Model estimates of surface water concentrations of Pu-239/240 and Am-241 were generated for each of the storms. Areas with the highest amount of model-predicted actiinide mobility are locations on hillslopes with relatively high concentrations of actinides in the soil (e.g., the 903 Lip Area).	WEPP (USDA), HEC6T (USACE)
8.	USGS, Jim Ball	2000	Geochemical Modeling of Solar Ponds Plume Groundwater At the Rocky Flats Environmental Technology Site. Part I: Ion Plots and Speciation Modeling, Final Letter Report.	Groundwater flow and geochemical speciation	Inverse Modeling to investigate mobility of Pu, Am, and U at RFETS to support Actinide Migration Studies (AMS).	Groundwater of Rock Creek is reasonable analogue for natural background; modeling may distinguish composition of contaminants in the plume; and U not expected to attenuate other than by sorption.	PHREEQCI, WATEQ4F
9.	RMRS	1999	Draft Final Solar Ponds Plume Decision Document. RF/RMRS-98-286.UN., April 1999 - for Kaiser-Hill.	Groundwater flow and transport	1. Estimate plume cleanup time (solar ponds dissolved phase contaminants), 2. two-dimensional plan-view plume model to estimate migration rates, parameter values, sensitivity analysis of key transport parameters, 3. two-dimensional profile model - evaluate three remedial alternatives.	Analyze groundwater flow and dissolved transport within a two-dimensional vertical cross-section of aquifer extending from the Solar Ponds Plume area to Walnut Creek. Particle tracking to evaluate flow directions. No action, managed release and treatment at B995 were evaluated with models.	
10.	RMRS	1999	Estimation of depletions and off-site discharge of surface water for current (FY99) and post-closure configurations at the Rocky Flats Environmental Technology Site. RF/RMRS-99-382.UN Revision 1, September 1999. Replaces first Revision June 1999.	Surface water flow - Ponds	To estimate changes in depletion and off-Site discharge of surface water resulting from Site-closure activities for use in a Biological Assessment.	A spreadsheet model was developed to estimate depletions and discharge for a typical year, given current and closure configuration (where Site Landfill and C-1 Ponds removed, impervious surface area removed, reconfiguration of interceptor trench system, discontinuation of DWB water, and completion of McKay Bypass ditch). Results predict evaporative depletions and discharge decrease for Walnut and Woman Creeks. Estimated evaporative depletions decrease by ~29%, and annual discharge decreases by 28%).	Simple water-balance method, neglects groundwater influence.
11.	RMRS	1999	Loading Analysis for the Actinide Migration Studies at the Rocky Flats Environmental Technology Site. Revision 1. January 1999.	Surface water flow and actinide transport.	Analyze actinide loading to 'channelized' surface water at RFETS to support actinide transport modeling for the AMS. Actinide loads were calculated on storm-specific and annual basis.	Loadings of actinides to Woman Creek, South Interceptor Ditch and Walnut Creek were estimated. The analysis indicated load and yield calculations were most sensitive to variability of flow and radiochemical measurements (which vary orders of magnitude).	Simple analytic load and annual yield equations for actinides were used to estimate loadings based on historical stream flow measurements.
12.	RMRS	1999	Rocky Flats Environmental Technology Site - Estimation of Evaporative Depletions of Surface Water for Current (FY99) and Post-closure (2007) Configurations at the Rocky Flats Environmental Technology Site. Rev. 1. September.	Surface water flow, Evaporation	Estimate changes in depletion and off-site discharge of surface water resulting from site closure activities for use in preparation of a Biological Assessment.	Results predict Site closure will decrease both evaporative depletions and discharge along Walnut and Woman Creeks. Evaporative depletions were estimated to decrease by 29% (from 65 ac-ft/year to 46 ac-ft/year). Annual discharge off-Site estimated to decrease by 28% (882 ac-ft/year to 635 ac-ft/year).	Spreadsheet models based on simple water balance.
13.	RMRS	1997	Appendix A. Estimation of Surface Water Depletions Resulting from Implementation of the Pond Operations Plant at the Rocky Flats Environmental Technology Site.	Surface water flow, Evaporation	Estimate changes in depletion and off-site discharge of surface water resulting from Site closure activities for use in preparation of a Biological Assessment.	Results predict Site closure will decrease both evaporative depletions and discharge along Walnut and Woman Creeks. Evaporative depletions were estimated to decrease by 29% (from 65 ac-ft/year to 46 ac-ft/year). Annual discharge off-Site estimated to decrease by 28% (882 ac-ft/year to 635 ac-ft/year).	Spreadsheet models based on simple water balance.

Table B.1 - Other Hydrologic, Hydraulic, and Fate/Transport Models
Developed for Rocky Flats Environmental Technology Site (Site or RFETS)

No.	Author	Date	Title	Modeled Process(s)	Modeling Purpose	Modeling Results/Conclusions	Codes Used
14.	Roberts, B.L.	1997	ASAP Groundwater Flow Modeling Documentation. RMRS. September 30, 1997. Prepared by Principia Mathematica Division of Terranext.	Groundwater flow	Provide a synopsis of site-wide groundwater modeling using modflow.	Only steady-state groundwater flow model (calibrated against only water level information). Report suggests future modeling should be calibrated against groundwater discharge and streamflow measurements. Does not consider closure conditions.	USGS Modflow model. Also uses HELP model to estimate recharge rates to groundwater.
15.	Daniels, Hans.	1996	The role of ET in the geohydrologic budget at Rocky Flats. M.S. Thesis, Department of Civil Engineering, University of Colorado, Boulder, pp 244.	ET	To investigate the role of ET in the geohydrologic budget at RFETS.	Actual ET calculated using weighing lysimeter. Study area located east of 903 pad on mesa. Various methods were compared against weighing lysimeter (most accurate method of actual ET). Main conclusion is that ET plays significant role in water balance at RFETS.	Various physical equations used to calculate potential and actual ET.
16.	DOE	1996	Phase I IM/IRA Decision Document and Closure Plan for Operable Unit 7 Present Landfill. Revised Draft Report, March 8, 1996.	Groundwater flow	To estimate flow volumes into landfill, seep discharge rates, estimate time required to dewater landfill, and to evaluate flow conditions for three possible closure conditions (no-action, cap-only, and cap/north slurry wall scenario. Objectives were also to determine transport sensitivity to parameters, determine pathways, develop strategies to intercept contaminants, compare remedial action alternatives.	Several simplifications were made in modeling the saturated zone flow.	MODFLOW Version 3.3, March 1991 - IGWMC, MODELCAD386 (J.O. Rumbaugh, III, 1993), POSTMOD V2.21 (Stan Williams, IGWMC), PATH3D (Zheng, 1991 - steady state Papadopulous & Assoc.), One-dimensional Dominico analytical solution for advective-dispersive transport.
17.	Moffit, J.A.	1996	Monitoring and Modeling of Snowmelt at Rocky Flats. M.S. Thesis, University of Colorado, Boulder. 253p.	Snowmelt	To quantify snowmelt rates and to assess potential melt rates from extreme snow events. Useful information in fate/transport of contaminants in soils at RFETS.	Model reproduced seven snow-events well. Modeling showed that radiative components were dominant factor in snowmelt. Melt of snowdrifts can produce high localized recharge of groundwater.	Snowtherm, U.S. Army Corp of Engineers, Cold Regions Research and Engineering Laboratory)
18.	RMRS	1996	Waste Management Facility Particle Tracking Model, Rocky Flats Environmental Technology Site, Golden, CO, March 1996.	Groundwater flow	Assess the flowpath of contaminants that could potentially migrate from the Waste Management Facility (WMF) - Operable Unit (OU) 4 (east of Solar Ponds, North of B991).	Particle tracking for 500, 1000 and 10000 years w/30 year interval using different retardation coefficients (1 to 5000). Conclusion - volitile organic compounds (VOCs) could reach Woman/Walnut Creek within 30 years, Metals and Radionuclides within 1000 years.	MODFLOW, PATH3D (Zheng, 1989)
19.	RMRS	1996	White Paper. Analysis of Vertical Contaminant Migration Potential, Final Report. RF-ER-96-0040.UN. Golden, CO: Rocky Mountain Remediation Services. August 16, 1996.	Dense non-aqueous phase liquid (DNAPL) migration, dissolved phase transport	Assess the potential for migration of dissolved and free-phase DNAPL from the Upper Hydrostatigraphic Unit (UHSU) through the Lower Hydrostatigraphic Unit (LHSU) and into the regional aquifer systems. Simple analytic relationships describing DNAPL and dissolved migration were used to assess the potential for deep migration of contaminants to regional aquifer system.	Using very conservative assumptions, migration potential of contaminants through low permeability LHSU material would take very long times and is therefore very unlikely to impact the deeper, underlying regional aquifer system.	Simple analytic flow/transport calculations.
20.	Roberts, B.L.	1996	Recommendations of Recharge Estimates for the Rocky Flats Alluvium. Preliminary Draft. April 15, 1996.	Groundwater Recharge	Provide additional estimates of water recharge to the saturated zone by percolation of precipitation (snowmelt and rainfall). Results to be compared against RESRAD model calculated recharge rates.	Two HELP model scenarios run (1. Vertical soil profile and vegetation consistent w/Qrf in OU-2 area, 2. Soil profile and vegetation for 6" soil cap over Qrf). 100 year simulation results showed infiltration rates range from 0 to 4.3 in/year (60% of years no recharge) and from 0 to 3.9 in/year for both scenarios, respectively.	HELP code (Ver 3.04) - Hydrologic Evaluation of Landfill Performance
21.	Roberts, B.L.	1996	Industrial Area Groundwater Mass Balance	Groundwater flow	Using a simple water-balance approach, estimate the net gain or loss to the groundwater system from IA piping systems. Piping systems considered included water supply system, sanitary, storm and foundation system drains.	Much of the groundwater recharge from leaky water supply lines is captured by foundation and sewer drains and then transported to major surface water drainages (Woman and Walnut Creeks). Overall impact to the IA water balance is insignificant. There is a net loss of groundwater due to the subsurface piping system. This analysis did not consider precipitation infiltration, ditch conveyance loss, or depression storage effects.	Simple mass balance approach, Spreadsheet solution

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No.	Author	Date	Title	Modeled Process(s)	Modeling Purpose	Modeling Results/Conclusions	Codes Used
22.	USGS, Ken Lull	1996	Memorandum from USGS to DOE dated February 14, 1996. Subject is evaporation calculations of natural water from ponds, water year 1993-94 -- RFETS.	Surface Water, Evaporation	Calculate evaporation from all 'natural-water' in ponds at RFETS.	Evaporation of water from 'natural-water' in Ponds (A-1 to A-4, B-1 to B-5, C-1 and C-2, and the Landfill pond) calculated for each pond. Mean monthly surface areas were calculated, Pond B-3 volumes were adjusted, and mean daily evaporation calculated using simple mass balance equation.	Simple mass balance method for calculating water loss to evaporation based on monthly percentage of net annual evaporation (3.25 ft) times pond surface area, divided by number of days per month. This method does not consider different pond evaporation rates affected by pond depths, or changes in anuual evaporation.
23.	DOE	1995	Final Corrective Measures Study/Feasibility Study Groundwater Flow Modeling Report For Operable Unit 2 (OU2). U.S. DOE, Rocky Flats Environmental Technology Site Golden, CO June 1995.	Groundwater flow	To support screening assessments of various remedial action alternatives considered in the Corrective Measure Study/Feasibility Study (CMS/FS) to remediate UHSU groundwater contamination in OU2. Modeling team: Belcher, Zhang, Newill, Warner, Lan, Schreiber.	Four remedial alternatives evaluated: 1) no action; 2) groundwater extraction to dewater the UHSU; 3) installation of upgradient barrier-slurry wall; and 4) reduction of infiltration through surface cover/ET enhancement. Groundwater flow fields developed for Qrf and Arapahoe Sandstone. Two-layer model, Seven zone recharge, transient wet/dry simulations. Steady-state and transient-step (TS) calibration considered adequate for fate/transport simulations.	Modified MODFLOW version. Modified to prevent dry/wet cell problems, vertical conductance estimates during TS simulations
24.	DOE	1995	Phase II RFI/RI Report 903 Pad, Mound, and East Trenches Area. Operable Unit No. 2. Volume 14 Appendix E - Groundwater Modeling, Appendix F. Surface Water Modeling, Appendix G - Air Modeling, October 1995.	Groundwater Flow	Occurs after June 1995 Final CMS/FS modeling with Modflow, but different model, objectives. Three steps to simulating VOC contaminants in UHSU/Arapahoe Sandstone in Qrf down to creeks; a) simulate steady state groundwater flow in Qrf/Arapahoe Sandstone, b) simulate contaminant (VOC) transport in Qrf/Arapahoe Sandstone seeps, c) simulate 'colluvium' transport from seep to creek using ONE3D.	A two-layer, steady-state groundwater flow model was used to support MT3D transport simulations (assumed constant sources, source over entire UHSU, retardation low estimates, no degradation) run for 20 years - to compare against historic levels and to demonstrate conservative chemical of concern (COC) concentration distributions. Then 150 years and 1000 years for future predictions (VOCs and radionuclides, respectively). Conservative ONE3D transport in 'colluvium' from seeps to produce total loading at creeks.	MODFLOW, MT3D (Zhang, 1990), ONE3D (Beljin, 1991)
25.	DOE	1995	Phase II RFI/RI Report 903 Pad, Mound, and East Trenches Area. Operable Unit No. 2. Volume 14 Appendix E - Groundwater Modeling, Appendix F. Surface Water Modeling, Appendix G - Air Modeling, October 1995.	Surface water flow	NA	NA	NA
26.	EG&G	1995	1994 Well Evaluation Report for the Rocky Flats Environmental Technology Site. Final. Volume 1 - Text. March 1995.	Groundwater flow	Assess existing monitoring well network at RFETS. Flow path analysis to identify major groundwater flow paths associated with contaminated regions within unconsolidated materials.	Simulated area includes most of IA east of Building 444 to Indiana Street and Buffer zone associated with Woman and Walnut Creek drainages. Single-layer model with grid size from 75 to 200 feet. Steady state conditions simulated to 1992 water level data. Recharge and ET simulated using 'net recharge' (from 0 to 1.6e-4 ft/day). Stream package in MODFLOW used to simulate stream-routing. Unsaturated areas simulated as no-flow boundaries. Tetrachloroethene (PCE), Amercium (Am)-241, total dissolved solids (TDS), and Nitrate/Nitrite pathways assessed with PATH3d.	MODFLOW (USGS, 1988), PATH3D (Zheng, 1989)

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No.	Author	Date	Title	Modeled Process(s)	Modeling Purpose	Modeling Results/Conclusions	Codes Used
27.	EG&G	1995	Groundwater Modeling Section 5.3.1 of the Phase-I RFI/RI Report. Compilation and Assessment of: Model Parameters, Chemicals of Concern, and Modeling Results. RFETS Woman Creek Priority Drainage (Operable Unit No. 5). Draft, Rev. 1:June 9, 1995).	Groundwater flow	Evaluate contaminant transport via the groundwater pathway (where contaminated groundwater discharges to Woman Creek) to support the OU5 Human Health Risk Assessment (HHRA).	An east-west rectangular MODFLOW model boundary included Woman Creek, the SID and south IA hillside area. A 50-foot grid spacing was used in key areas, and only one layer was assumed above the impermeable claystone bedrock. Only steady-state simulations were run. Constant head cells were used at all boundaries, except no-flow and 881 hillside system. Recharge was a calibration parameter, but spatially defined based on vegetation. Recharge refined using Blaney Criddel PET method. The flow model was calibrated against available average well water levels. Calibration was most sensitive to bedrock elevations. 11 COCs modeled against time-averaged concentrations (no trends observed) from different IHS locations. An uncertainty analysis was performed.	MODFLOW (USGS, 1988), MODPATH (Pollock, 1989), MT3D (Papadopolous and Assoc., 1992). ONED-3 was used to simulate transport from Pond C-1.
28.	EG&G	1995	Surface-Water Modeling Section 5.3.2 of the Phase-I RFI/RI Report. Compilation and Assessment of: HSPF10 Model Parameters, Chemicals of Concern, and Simulation Modeling Results. RFETS Woman Creek Priority Drainage (Operable Unit No. 5). Draft, Rev. 1:June 9, 1995).	Surface water flow	1. Characterize general surface water system of OU5 with surface water flow and transport model. 2. Support HHRA of Resource Conservation and Recovery Act (RCRA) facility Remedial Investigation/Feasibility Study (RI/FS) - through simulation of COCs from OU5 to exposure points. 3. Support evaluation of potential remedial alternatives for FS at OU5.	Input variables were input at hourly intervals, while HSPF output was generated at daily intervals. Woman Creek upstream of Indiana to Coal Creek was considered in the model. Six land basins and five stream/reservoir segments, or reaches were defined in HSPF. 15-minute precipitation, dew point temperature, wind speed, solar and temperature data were aggregated into one-hour time series. Three years of hourly potential ET were calculated and input to the model. Several COC sources were identified (Barium, Lithium, Strontium, Am-241, Ur-233/234, U-238. Surface water flows (gaging station [GS] gages), sediment transport (transient state and C-1 pond sediment accumulation) and COC water quality fate/transport were calibrated. Calibration was considered reasonable for flow and sediment transport. Simulated concentrations appeared to be under simulated. 30-year future simulations for 11 COCs were calculated - mean daily concentrations were given.	HSPF10 (Bicknell and others, 1993). ANNIE (Lumb and others, 1990) used to manipulate meteorological data input to HSPF10. HSPF10 simulates branching, one-dimensional stream/reservoir systems, with groundwater and pond simulation (groundwater is lumped approach, not explicit).
29.	USGS, Ken Lull	1995	Memorandum from Ken Lull (USGS) to Cheryl Row, Ecology Management Team, dated November 13, 1995, regarding Preliminary Water Budget - Rocky Flats Environmental Technology Site.	Surface water flow	Preliminary calculation of the surface-water budget for water years 1993 to 1994 for RFETS along Woman and Walnut Creeks (5.4 square mile area).	Simple water balance equations were used to estimate surface-water budget. Surface inflows at GS05 and GS06, direct surface runoff, waste water treatment discharge, pond evaporation, and surface runoff leaving the site at GS01, GS02, and GS03 were considered in the analysis. Results generally show that more water left RFETS (during 1993-94) than was available from natural sources (i.e., Denver Water Board)	Simple water balance method based on Viessman and others, 1989 water budget equations for above the land surface. Surface inflow plus precipitation runoff plus treatment system discharge minus pond evaporation mines stream discharge at Indiana Street is equal to the change in storage.
30.	CDPHE	1994	Rocky Flats Groundwater Team Interim Modeling Report. Modeling Groundwater Flow Beneath Rocky Flats Plant Using the Modular Three-Dimensional Finite Difference Groundwater Flow Model. March 29.	Groundwater flow	To assess groundwater flow conditions at RFETS.	Modeling results inconclusive. Did not complete effort.	MODFLOW

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No.	Author	Date	Title	Modeled Process(s)	Modeling Purpose	Modeling Results/Conclusions	Codes Used
31.	EG&G	1993	Draft Water balance and chemical mass balance for Operable Unit 2. Prepared for EG&G by Environmental Restoration Management, ESE, April 1993.	Groundwater flow, Contaminant Transport	As part of the OU2 risk assessment of the RI/FS for the site, provide bounding estimates of the potential exposure point concentrations in the streams resulting from groundwater seepage entering the streams.	A conceptual model for flow and chemical transport was developed. Simple water balance equations were used to estimate seepage rate to the creeks. Net recharge and vertical leakage were also calculated using simple mass balance equations to support the seepage rate calculations. Baseflow in the creeks was also used to constrain seepage rates. A simple chemical mass balance equation was then used to estimate groundwater discharge concentrations at the creeks. Results indicated predicted chemical concentrations at both creeks are lower than 'ambient water quality criteria' for trichloroethene (TCE) and PCE for both low and median flow conditions. Predicted discharge concentrations were only higher than MCLs under low flow conditions. The analysis predicted two-thirds of recharge is transmitted to the bedrock.	A simple water balance equation for groundwater assumes seep rate to creeks is equal to the net annual recharge plus horizontal inflow minus vertical leakage to the underlying formation (bedrock). Net recharge equation assumes net recharge times area contributing to recharge is equal to seasonal rise in water table (at wells) times average aquifer area times the available pore space. Vertical leakage calculated using darcy's equation. Time-varying seepage concentration was calculated using a continuous stirred-tank reactor (CSTR) equation (EPA, 1992) model using a first order decay assumption.
32.	EG&G	1993	Drainage Study for South Interceptor Ditch Rocky Flats Plan Golden, CO. Authorization No. 986847-3A, August 23, 1993. Prepared by Plant Civil Engineering EG&G Rocky Flats Plant, Inc.	Surface water flow	Provide a comprehensive analysis of hydrology and hydraulics for the 25-year storm event for the SID. Provide supportable basis for improvements to the ditch.	CUHP (Colorado Urban Hydrograph Procedure) output was routed to SWMM (Stormwater Management Model), and output from SWMM routed to HEC2 to calculate velocity distributions and potential for erosion. Recommendations were provided for improving SID performance (i.e. prevent over-topping, reduce erosion, bank stability).	CUHP, SWMM, HEC-2
33.	Fedors, R.A., Warner, J.W. Roberts, B.L and Berzins, A.	1993	Numerical Modeling of Variably Saturated Flow and Transport - 881 Hillside, Rocky Flats Plant, Jefferson County, Colorado. June. Colorado State University. Groundwater Technical Report #20.	Variable saturation, Dissolved transport	Characterization of groundwater flow and contaminant transport on 881 Hillside area.	Migration of non-conservative solutes modeled over 40 year period from former barrel storage area (TCE and PCE) using two-dimensuional vertical profile along hillslope to Woman Creek.	SOILSIM2
34.	EG&G	1992	Rocky Flats Plant Drainage and Flood Control Master Plan - Woman Creek, Walnut Creek Upper Big Dry Creek and Rock Creek. Prepared by Wright Water Engineers, April 1992.	Surface water flow	Flood hydrology, water rights and ditches, channel hydraulics and floodplain delineation, core area drainage, water quality and management options evaluated for RFETS.	Many previous hydrologic and hydraulic reports reviewed. Simulated SWWM peak flows along different reaches compared against other modeling (i.e. Woman Creek at Indiana Street ranges from 1300 to 4630 cfs, and Walnut Creek at Indiana Street ranges from 1160 to 3080 cfs). Snowmelt not considered. Ditches largely insignificant impact on floodplain hydraulics. Hydraulic effects of 100-yr, 6-hr storm event developed (i.e.., extent) using HEC-2 for different reaches. Ponds were assumed full, and small culverts plugged. The SID and Walnut Creek Diversion Canal won't spill, Indiana street topped by 1.6 and 2.4 ft at Walnut and Woman, respectively. Differences between USACE study.	CUHP, SWMM. HEC-2 model (USACE). HydroCAD (Applied Microcomputer Systems, 1990) used to simulate IA (Core) sub-basin hydrograph routing using storage-indicator (Mod. Puls) method - like SWMM. NOTE: SWMM used to estimate peak flows, hydrographs, storage volumes, flow depths, but used idealized trapezoidal channel dimensions. HEC-2 was used to more accurately estimate flood water surface, velocities and inundation areas, velocities, backwater, and peak flows consistent with FEMA criteria.

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No.	Author	Date	Title	Modeled Process(s)	Modeling Purpose	Modeling Results/Conclusions	Codes Used
35.	U.S. Army Corps of Engineers	1992	Floodplain Delineation. Hydrologic Analysis I.A.G. No. DE-AI34-90RF 57446. U.S. Department of Energy Rocky Flats Plan, Colorado. September 1992.	Surface water flow	Develop water surface profiles for the 10-, 50-, 100- and 500-yr flood events and flood boundaries for the 100-yr and 500-yr flood events for major surface water drainages in on the Department of Energy's Rocky Flats Plant.	100-yr floodplain is delineated for Core and Buffer zones. Peak flow values provided for all events. Water surface elevations provided 10-, 50-, 100-, and 500-year events.	HEC-1 and HEC-2, to predict stream flows and backwater effects, respectively.
36.	Wright Water Engineers.	1992	Technical Memorandum, To Robert James, EG&G, from WWE, Dated February 7, 1992, regarding Flood Runoff from Coal Creek.	Surface water flow	1. Estimate peak 100-yr Coal Creek flood flows. 2. Use HEC-2 to study base flood elevations, channel velocities and flow potential in McKay, Upper Church and Kinnear Ditches. 3. HEC-2 model evaluation of ditch capacities - clear water. 4. Erosion evaluation and potential blockage along Coal Creek and ditches. Sediment transfer to Big Dry Creek basin considered.	100-yr peak flows calculated for Coal Creek. Tables of water surface elevations and velocities calculated for each ditch. Although substantial sediment load possible in Coal Creek, it is limited in ditches because of comparatively flat slopes. Clear-water flood flow transfer from Coal Creek to ditches is also limited/negligible (i.e. culvert dimensions, or weir). Peak Q in ditches is 48, 18, and 124 cubic feet per second (cfs), respectively (McKay, Upper Church, and Kinnear Ditches)	HEC-2.
37.	ASI	1991	Bypass upstream flows around Rocky Flats Plant Study. ASI Task 24, January 15, 1991.	Surface water flow	Hydrologic analysis of Walnut Creek Diversion Canal (north of Core area) and Woman Creek bypass (around Pond C-2) for 100-yr, 500-yr, and Probable Maximum Precipitation (PMP), 24-hour precipitation events.	Assumptions - flows exceeding 600 cfs in Coal Creek spill into Upper Church, McKay, and Kinnear ditches, limited to their capacities. South Boulder Diversion Canal assumed breached during PMP. Results of modeling indicated existing bypass structures inadequate for all precipitation events analyzed.	SCS TR-20
38.	ASI	1991	Storm-Runoff Quantity for Various Design Events - Rocky Flats Plant Site - Task 6 of the Zero-Off-site Water-Discharge Study. September 30, 1991.	Surface water flow	Hydrologic analysis of Woman and Walnut Creek, prepared for EG&G Facilities Engineering in response to the Agreement in Principle between CDPHE and USDOE.	Estimated overflow from Coal Creek for 25-, 100-, 500-, and PMP recurrence intervals for 2-, 24- and 72- hour durations. Different A-4, B-5 and C-2 pond levels were assumed empty, 1/2 and full for each simulation. Western RFETS inflows would be 3200 cfs and 1100 cfs along Woman and North Walnut Creek, respectively.	TR-20
39.	EG&G	1991	Rainfall-runoff Relationship Study. Rocky Flats Plant. Task 5 of the Zero-Offsite Water-Discharge Study. Prepared for EG&G by ASI. June 18, 1991.	Surface water flow	A simple linear regression was developed to correlate storm rainfall to storm runoff at selected locations at RFETS.	The study concluded that insufficient data were available to determine a quantitative relationship between rainfall and runoff at RFETS. Additional data were recommended for precipitation, pond, and runoff data.	A regression equation described by Viessman and others, 1977 was used in the analysis. Runoff from precipitation equals the slope of the rainfall-runoff line times the precipitation plus a base precipitation below which flow rate (Q) is zero.
40.	EG&G	1991	Surface-Water Evaporation Study Rocky Flats Plant. Task 15 of the Zero-Offsite Water-Discharge Study. Prepared by Advanced Sciences, Inc., for EG&G, Final May 7, 1991.	Surface water flow, Evaporation	Evaluates regional sources of free-water surface evaporation data and spray evaporation data. Data are used with existing RFETS data to estimate on-site net annual reservoir and spray evaporation which are then used to size ponds for evaporation of sanitary treatment plant, storm runoff and groundwater inflows.	RFETS net annual reservoir evaporation rates estimated to be either 31.34 or 28.28 in/year, depending on pan evaporation coefficient used. Assessing pond depths of 5 to 35 feet, spray evaporation areas of 2 to 17 acres were needed for 250 ac-ft/year flows, 5 to 34 acres were needed for 500 ac-ft/year, and 10 to 68 acres were needed for 1000 ac-ft/yr. Pan evaporation coefficients used were 0.7 and 0.74.	Dalton's law of evaporation and vapor pressure (Dalton, 1982) used to estimate surface water evaporation. Temperature, wind-speed, and dew point were used in calculation.
41.	Koffer, James.P.	1989	Investigation of the Surface and Groundwater Flow Mechanics of an Evaporation Spray Field at the Rocky Flats Nuclear Weapons Plant, Jefferson County, Colorado. Master's Thesis, Colorado School of Mines, Colorado. 81p.	ET	Determine flow path and water balance for spray-field disposal of sanitary sewer treatment plant effluent.	1. A significant amount of spray results in groundwater recharge. 2. ET rate estimated to be 39 inches a year (twice previous estimates). 3. Rate of runoff and infiltration dictated by spray rate. 4. A continuous bed of caliche beneath the spray field affects infiltration rate. Koffer suggested 'breaking' caliche. PET estimates ranged from ~39" for 24-yr average, and 50" for 1988.	Energy budget method (Penman Equation) selected for estimating PET. An analytical recharge rate to the water table was based on Hantush (1967) method.

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No.	Author	Date	Title	Modeled Process(s)	Modeling Purpose	Modeling Results/Conclusions	Codes Used
42.	Muller Engineering	1989	Outfall Systems Planning. Big Dry Creek (ADCO) and Tributaries UDFCD. August 1987, revised January 1989.	Surface water flow.	To provide preliminary designs for drainage and flood control for Big Dry Creek and tributaries.	Study area extends from groundwater outlets to 144th Ave. 100-yr inflow flood to Great Western Reservoir estimated (1940 cfs). Surface detention not considered.	SWMM/CUHP
43.	U.S. Army Corps of Engineers	1989	Review Report of the Great Western Reservoir Pre-Feasibility Study. Pre-decisional draft. Interagency No. DE-AI04 89 AL32905. October 1989.	Surface water flow. 1) channel flow; and 2) overland flow.	To assist in assessing hydrologic and hydraulic engineering work by Rocky Mountain Consultants in regard to the diversion of flood waters from RFETS around Great Western Reservoir.	Hydrologic analysis of Walnut Creek basin - analysis of RMC's three proposed diversion/detention facilities. Flood discharges and volumes in Walnut Creek at Indiana St. calculated for 100-yr, 3-hr and PMP (16-hr) storms.	SWMM, HEC-1
44.	Lee Wan and Associates	1987	Instruction Manual for Site Drainage Computer Model - Rocky Flats Plant, Golden, Colorado, February 13, 1987.	Surface water flow	To establish TR20 computer model of existing storm drainage at RFETS, and analyze adequacy of existing drainage system for 25-yr design storm.	Existing site drainage system is adequate for 25-yr flood event, except three specific locations.	TR-20
45.	S.S.Papadopulos & Associates, Inc.	1987	Ground-Water Modeling of Impacts of Proposed Spray Irrigation. Prepared for Rockwell International Rocky Flats Facility Golden, Colorado. December 1987.	Groundwater flow	To assess impacts of proposed spray irrigation on groundwater flow at RFETS.	Several scenarios were simulated for two areas. Different recharge rates and hydraulic properties were assumed in the model. Maximum recharge rates (without overland runoff) were estimated for each scenario. Maximum recharge rates and annual totals were provided.	Analytical groundwater flow model (based on Walton, 1984 solution).