SELECT AND OPTIMIZE ENGINEERING DESIGN USING A GROUNDWATER MODEL AT THE ENVIRONMENTAL MANAGEMENT WASTE MANAGEMENT FACILITY (EMWMF), OAK RIDGE, TENNESSEE

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ABSTRACT

A three-dimensional groundwater flow and transport model was developed for use on the Environmental Management Waste Management Facility (EMWMF) at DOE’s Oak Ridge Reservation (ORR) to select and evaluate engineering alternatives for lowering the groundwater level under the EMWMF and to help the performance analyses and monitoring activities. This site-specific flow model was developed from an area regional groundwater flow model and the previous site-specific model used for initial disposal cell conceptual design. The groundwater flow model was developed by (1) revising model input to reflect the local geology based on field reconnaissance and information gained during site development and construction of Phase I of the EMWMF, (2) incorporating the current site topography and engineering features, (3) adding properties to represent the as-built EMWMF, and (4) utilizing latest groundwater monitoring data in and around the EMWMF. The refined model consists of 1.3 million cells with a grid spacing of 10×10 ft (3 m x 3 m) and finer vertical layers (11 layers) to represent more precisely the construction/engineering design features and other site-specific conditions.

The model was used to formulate and evaluate various engineering alternatives for lowering the water table beneath the EMWMF in terms of hydraulic effectiveness and impact on EMWMF performance and waste acceptance criteria (WAC). Fate-transport simulation was used to evaluate the long-term EMWMF performance by predicting the contaminant movement and the future contaminant plume migration. Based on the detailed alternative performance analysis and other qualitative criteria, the undercell drain alternative was selected.

The undercell drain was successfully constructed in early 2004. Following the completion of the undercell drain at the EMWMF, the model was used to conduct the transient modeling analysis on the groundwater level change in response to the installation of the undercell drain. The model was also used as a tool for developing a groundwater-monitoring plan to identify monitoring locations and evaluating the design basis for future cell expansion. The current monitoring data suggest that the implemented alternative has the desired effect on the groundwater levels at the site as predicted by the model.

INTRODUCTION

The EMWMF is an on-site disposal option for the waste generated by cleanup of ORR. It is a four-cell, 1.2-million yd^3 (917,466 m^3) disposal facility that started its operations in May 2002. Reliable disposal capacity, which is provided by the EMWMF, is critical to achieving the milestones of the Accelerated Cleanup Program at Oak Ridge.

Starting in September 2002, significantly above average precipitation (50% above normal amount) occurred continuously at Oak Ridge area for many months. Monitoring well data at the EMWMF indicated that groundwater levels at the facility could be in contact with the upper five feet of a portion of the geologic buffer underneath the facility’s compacted clay liner. In accordance with the groundwater contingent action plan in the facility’s Environmental Monitoring Plan, two consecutive months with groundwater within five feet of the clay liner triggered a feasibility study to determine the appropriate steps towards managing an elevated groundwater condition (Bechtel Jacobs Company, 2003).

A refined three-dimensional groundwater flow model (2003 Model) was developed for the EMWMF area to evaluate engineering alternatives for lowering the water table under the facility. This detailed site-specific flow model was constructed based on the Bear Creek groundwater flow model developed during the Bear Creek Valley Feasibility Study (Jacobs EM Team 1996) and the site-specific model used for initial disposal cell conceptual design (DOE 1998). The model incorporated latest site topography, engineering features, and new hydrogeologic information.

EMWMF SITE

The EMWMF site is located in the upper section of the Bear Creek Valley on the ORR, Tennessee (Figure 1). The ORR is near the western margin of the Valley and Ridge physiographic province that is characterized by steep-sided parallel ridges with broad intervening valleys, generally orientated northeast-southwest; topography is controlled by alternating weak and strong rock units (DOE 1998). Bear Creek Valley is situated between Pine Ridge to the north and Chestnut Ridge to the south. Bear Creek flows southwestward along the valley floor. The EMWMF site lies on the southern slope of Pine Ridge between Bear Creek north tributaries (NTs) NT-3 and NT-5. In the vicinity of the site, the elevation of Pine Ridge ranges from 1180 (360 m) to 1260 feet (384 m). The elevation of the Bear Creek Valley floor ranges from about 940 (287 m) to 1000 feet (305 m).

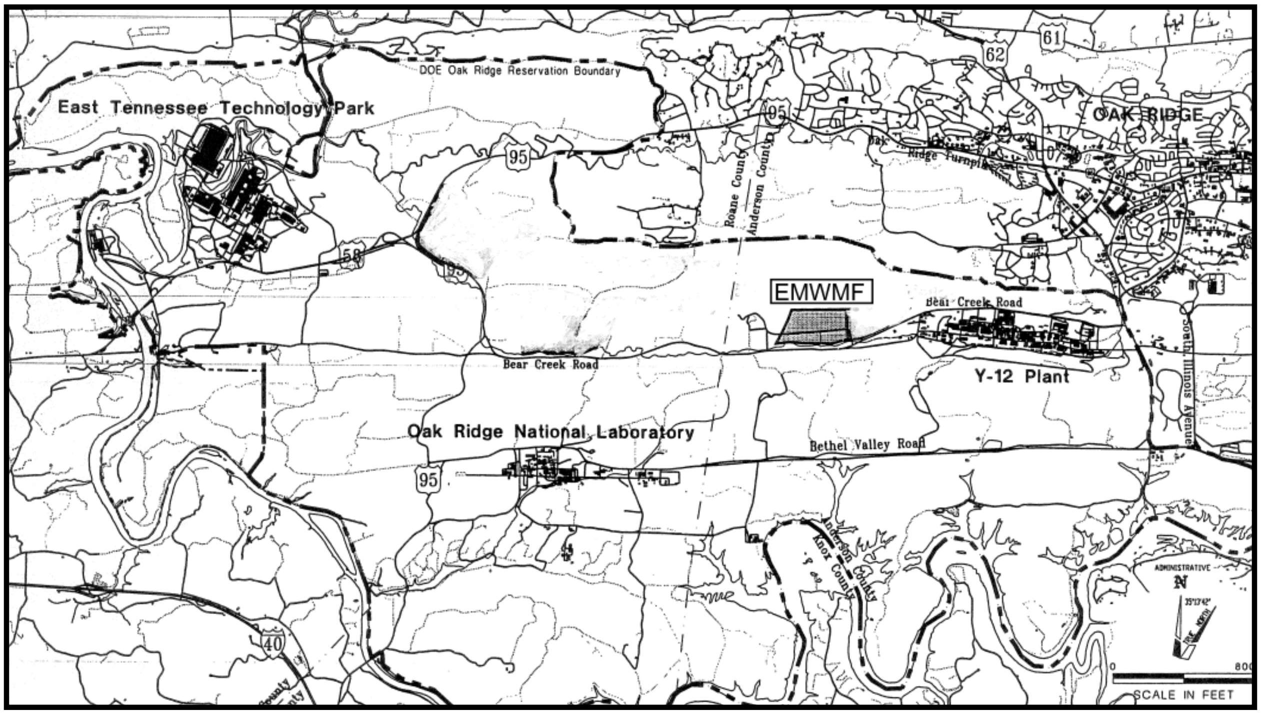

Fig. 1. EMWMF Site Location.

The stratigraphic section exposed in Bear Creek Valley includes rocks ranging in age from Early Cambrian to Early Mississippian. The three rock sequences in the EMWMF area—the Rome Formation, Conasauga Group, and Knox Group—comprise a complex assemblage of lithologies, including shales, limestones, dolomites, siltstones, and sandstones (DOE 1998). The early Cambrian Rome Formation, which is the oldest unit exposed in the site area, underlies Pine Ridge and dips to the southeast. The Rome Formation consists of variegated shale, interbedded with siltstone, sandstone, and minor amounts of dolomite. Overlying the Rome Formation, and underlying the southern slope of Pine Ridge, is the middle to late Cambrian Conasauga Group, a sequence of primarily shales with some interbedded limestones and dolomites. Within the Bear Creek Valley, the Conasauga Group is subdivided into six formations: Pumpkin Valley, Rutledge, Rogersville, Maryville, Nolichucky, and Maynardville. The EMWMF overlies mostly the Maryville Formation, a shale-dominated unit with minor interbedded carbonate layers and lenses. The Maynardville Formation underlies the valley floor. The unconsolidated materials underlying bedrock in the EMWMF site include mostly saprolite mixture of residuum and bedrock remnants and weathered bedrock.

Small-scale geologic structures, such as fractures and solution features, are a major factor in groundwater movement through the formations underlying the EMWMF. These bedrock features provide the pathways for groundwater flow through geologic formations that have little primary porosity and permeability. Fractures are well developed in all stratigraphic units and are the most pervasive structure (Hatcher et al. 1992). The orientations of well connected fractures or solution conduits are predominantly parallel to geological strike and enhance the effect of anisotropy caused by layering, resulting in dominance of strike-parallel groundwater flow paths. Fracture aperture width and frequency generally decreases with depth in all formations and thus restricts the depth of active groundwater circulation. The Maynardville Limestone and overlying Knox Group exhibit widespread evidence of dissolution, which is manifested as enlarged fractures and well developed, well-connected cavity systems

Groundwater movement under the EMWMF site is controlled by the nature of the geologic units underlying the site and the hydrogeologic properties of the geologic units. The geologic units in the EMWMF site comprise two broad categories that affect groundwater movement: the unconsolidated materials that cover bedrock and the predominantly siliciclastic units of the Conasauga Group.

Groundwater movement within the siliciclastic units is dominated by fractured flow (Solomon et al. 1992). Although only limited hydraulic testing has been done on the site, there have been many hydraulic tests conducted in the similar geologic units in the Bear Creek Valley. The types of tests that have been conducted include pumping, slug, packer, bailer, and tracer tests. The data have been compiled and summarized by the Jacobs EM Team during the Bear Creek Valley regional groundwater development (Jacobs EM Team 1996). Hydraulic conductivities calculated from the tests range over five orders of magnitude, from 10^{-3} to 10^{-8} cm/s. The hydraulic conductivities also vary over several orders of magnitude within each hydrostratigraphic unit. Overall, the wide range in hydraulic conductivity values is due to the heterogeneous distribution of fractures and the scale at which many of the tests were performed. The relationship between hydraulic conductivity and depth shows a correlation between the hydraulic conductivity and depth, where the average hydraulic conductivity in the first 100 feet (30 m) appears to be higher than the hydraulic conductivity in the deeper portions of the bedrock aquifer system. This is expected in bedrock aquifer systems where the size and abundance of fractures usually decreases with depth.

Within Bear Creek Valley, the majority of groundwater flow occurs primarily within the upper 100 feet (30 m) of the aquifer system. The occurrence and movement of groundwater in the bedrock aquifer system is closely related to the presence of bedding planes, joints, fractures, and solution cavities. In general, groundwater in the bedrock occurs under water-table conditions but becomes increasingly confined with depth. Downward recharge to the groundwater system occurs along the flanks of Pine Ridge and Chestnut Ridge.

Bear Creek Valley hydrogeologic units behave as an anisotropic system in all three dimensions, evidenced by the elongated drawdown along strike direction observed during pumping tests and the spatial distribution of contaminant plumes. The anisotropic nature of hydraulic conductivity associated with the bedrock-underlying Bear Creek Valley is apparently caused by the orientation and intersection of fractures, joints, and/or bedding planes. Due to this anisotropy, groundwater flow is primarily along strike (i.e., east to west) and a large portion of the shallow groundwater discharges into the north-south flowing tributaries and eventually flows into Bear Creek.

Bear Creek flows southwestward from its headwaters east of the EMWMF site for approximately 4.5 miles (7.2 km) along the Bear Creek Valley axis, then turns northward to flow into East Fork Poplar Creek by cutting through Pine Ridge. The drainage area of Bear Creek in Bear Creek Valley is approximately 5.5 square miles (14.2 km^2)) (Robinson and Johnson 1995). Most of the tributaries of Bear Creek originate along the flanks of the Pine Ridge. The 13 north tributaries are spaced in nearly equal distance from one another. EMWMF site is located between NT-3 and NT-5.

ORR is part of the southeastern U.S. climatological region, which is characterized by a moderate continental forest climate with mild winters. The ORR area has a temperate climate that is moderated by the Blue Ridge Mountains and the Cumberland Plateau. Mean monthly temperatures range from 38^o F in January to 77^o F in July. The average wind speed in the area is 4.3 mph (6.9 kmph), and the predominant wind directions are west to southwest and east to northeast. Precipitation in the area is seasonally distributed with mean annual rainfall of 54.4 inches (138.2 cm). The greatest rainfall occurs in January through March. September and October are the driest months.

Since late September 2002, there has been greater than normal amount of rainfall in the Oak Ridge area. For the last few years (2002-2004), the precipitation is about 30% more than the 30-year annual average.

2003 EMWMF SITE-SPECIFIC FLOW AND TRANSPORT MODEL

In preparation for the evaluation of options to lower site groundwater, the extensive changes in the EMWMF site in topography, site soil condition, and recharge pattern that resulted from the cell construction and operation required the construction of new site-specific groundwater model that represented the 2003 site conditions. This 2003 flow model was constructed based on the Bear Creek groundwater flow model developed during the Bear Creek Valley Feasibility Study (Jacobs EM Team 1996) and the previous site-specific model used for initial disposal cell conceptual design (DOE 1998). The 2003 model was developed by (1) revising model input to reflect the local geology based on field reconnaissance and reliable references, (2) adding properties to represent the as-built EMWMF, (3) correlating the model to recently acquired data from existing groundwater monitoring wells in and around the EMWMF, (4) enlarging the model boundaries to include the zero flow boundary at the crest of Pine Ridge, and (5) increasing the model grid resolution by reducing model cell size.

Simulation of groundwater flow within Bear Creek Valley was performed using MODFLOW (McDonald and Harbaugh 1988), a finite-difference groundwater flow code developed by the U.S. Geological Survey (USGS). MODFLOW is capable of simulating both transient and steady state saturated groundwater flow in one, two, or three dimensions. MODFLOW was selected for this analysis because it is in the public domain, is widely used by the scientific community, has been rigorously tested and verified, and a variety of software tools are publicly available for graphical pre-processing and post-processing. The Bear Creek Valley regional model also used the MODFLOW code.

MODFLOW implicitly considers that the aquifer can be characterized as a porous medium. The application of a porous medium code to a fractured system, such as Bear Creek Valley, is termed the equivalent porous medium (EPM) approach. This approach assumes that the medium is fractured to the extent that it behaves hydraulically as a porous medium. Given the high degree of fracturing of the geologic units underlying the site, the EPM approach is a reasonable modeling approach.

Model Development Procedure

A telescopic mash refinement (TMR) modeling approach was applied to develop the 2003 Model from the 1996 calibrated Bear Creek Valley flow model. The 1996 Bear Creek Valley regional model was developed based on all data collected during the Bear Creek Valley remedial investigation/feasibility study (RI/FS). The TMR approach allows focus on a critical area of interest with increased model grid resolution and more accurate representation of site-specific features. The TMR approach utilizes the results from the calibrated Bear Creek Valley flow model to initialize boundary conditions (constant heads) and model parameters in the refined model. An advantage of the TMR approach is that a high-resolution (small scale) model can be easily developed that retains the regional flow characteristics.

The construction of the 2003 Model consisted of the following steps:

The TMR method was used to develop the 2003 Model from the calibrated Bear Creek Valley flow model by extracting boundary conditions and model properties. A much reduced grid space was used for the model domain.

Refinement in the vertical direction was made by dividing the former Model Layer 1 into three separate layers and former Layer 2 into five separate layers to better represent the current site conditions and engineering features and to meet the need for risk/performance evaluation.

Parameters representing the surface water features at the site (creeks and tributaries, drainage ditches, channels) were incorporated into the new model.

The recharge zone (primarily the Rome Formation) was refined for the study area based on EMWMF design and field reconnaissance.

Parameters representing the current construction/engineered features at the site (such as the lined waste disposal cells, filled areas and the former NT-4 channel) were incorporated into the model.

2003 Model Discretization

The 2003 Model covers an area from NT-1 to NT-6 (east to west) and from the northern base of Chestnut Ridge to top of the Pine Ridge (south to north) (Figure 2). The grid sizes of 10 feet × 10 feet (3 m x 3 m) to 20 feet × 20 feet (6 m x 6 m) were used for the model domain. The 2003 Model has 11 model layers. The top of the Model Layer 1 reflects the current topography. The first three model layers represent the placed fills, the saprolite and weathered bedrock zone. Thus, the bottom of layer 3 corresponds approximately to the fresh bedrock surface. The top three model layers have variable thickness. The Model Layer 1 is approximately 20 feet (6 m) thick in most areas. Layers 2 and 3 vary in thickness from 15 (4.5 m) to 25 feet (7.5 m). Layers 4 through 8 are 20 feet (6 m) in thickness. Layers 9, 10, and 11 have thickness of 150 (45.7 m), 200 (60.1 m), and 300 feet (91.4 m), respectively. There are a total of 1,296,416 cells in the 2003 Model; 1,253,125 of the cells are active.

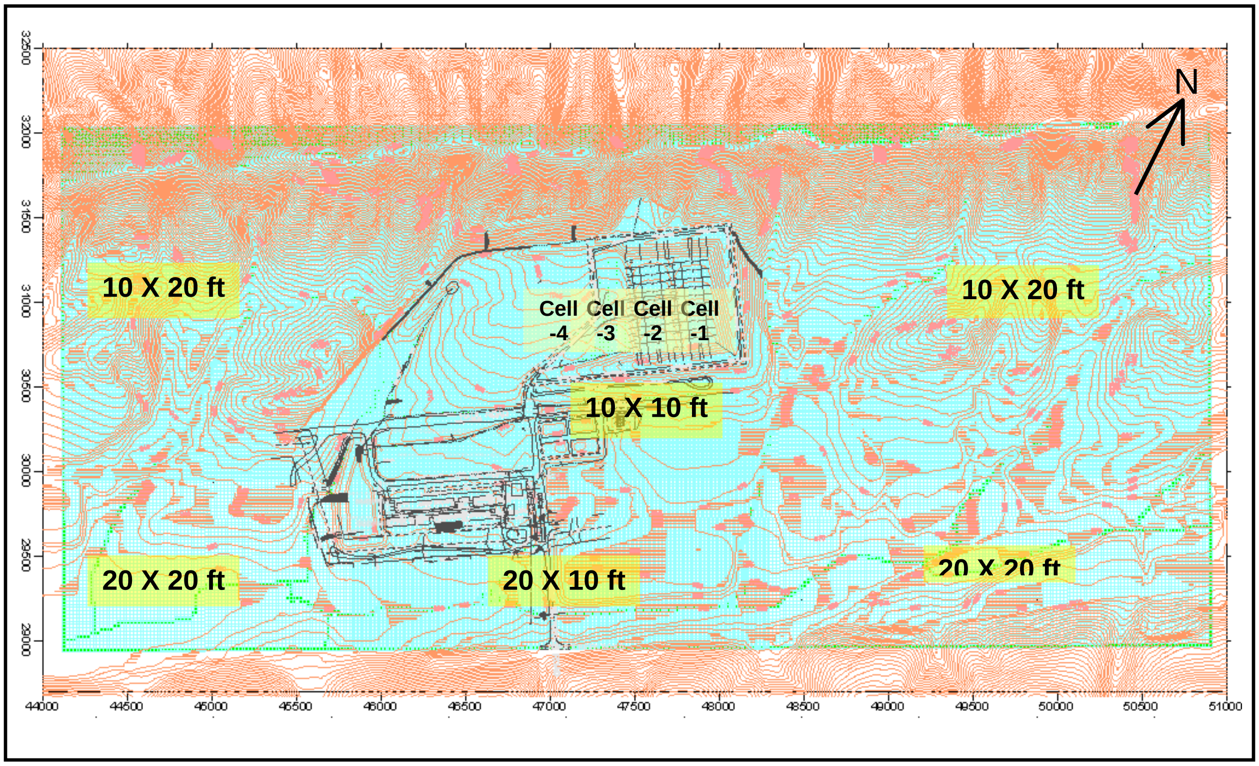

Fig. 2. Model Representation of the EMWMF.

Model Boundary Conditions

The 2003 Model has a no-flow boundary at top of the Pine Ridge and constant head boundary conditions at the other three sides. The constant head condition was extracted from the result of a steady state simulation of the calibrated regional Bear Creek Valley groundwater flow model. The model boundary was established at a distance from the EMWMF site so that the boundary conditions would not be greatly affected by topographic alterations associated with disposal cell development.

To best represent the surface water-groundwater interaction, all the surface-water features in Bear Creek Valley are incorporated into the model including Bear Creek and its tributaries. All the current site features (natural, such as ditches and channels; and man-made, such as cut and filled areas) were also represented in the model. The surface drainage features are represented in the model as drain cells. Actual stream elevations were assigned in the model.

Precipitation is the sole source of groundwater recharge for the site and in Bear Creek Valley. Groundwater recharge is a function of precipitation, runoff, and evapotranspiration. The net recharge to groundwater thus is function of geologic media, surface slope, and vegetation. Different recharge rates were assigned in the model for the area.

Hydraulic Conductivity Field

Regionally, six distinct hydraulic conductivity zones were used in the 2003 Model to represent the eight geologic units that exist in Bear Creek Valley (1. Knox Dolomite, 2. Maynardville Limestone, 3.
Nolichucky Shale, 4. Maryville(Dismal Gap)-Rogersville-Rutledge(Friendship) shale, 5. Pumpkin Valley shale, and 6. Rome shale/sandstone). Anisotropy ratios [Ky vs. Kx (Kz)] of five to one and ten to one were used to represent the preferred fracture/bedding orientation of the natural units. Ky represents the conductivity along strike and Kx and Kz represent the conductivities across strike in horizontal and vertical direction, respectively.

Extensive modifications were made to represent current site conditions and site-specific features associated with cell construction. The features include channel backfill, berms, an underdrain, geologic buffer material, low permeability clay liner, and geomembrane. All the engineered and reworked materials were modeled as isotropic units.

Figure 3 shows the hydraulic conductivities in model layer 1. The hydraulic conductivity field in a vertical south-north cross section is also shown in the figure.

Model Calibration and Result

Calibration of a groundwater flow model refers to the process of adjusting model input parameters (e.g., hydraulic conductivity) and boundary conditions (e.g., precipitation recharge, stream and seep conductances, etc.) to obtain a reasonable match between observed (actual groundwater levels from monitoring wells) and simulated hydrogeologic conditions. In practice, this usually involves an iterative process of adjusting hydraulic properties and/or boundary conditions assigned in the model. Because of the extensive modifications made to develop the 2003 Model, detailed calibration was conducted. At all stages of the model calibration process, parameter values and boundary conditions were constrained by hydrogeologic data collected in the field and engineering design values.

March 2003 water level measurements were used as calibration targets. Since September 2002 precipitation at the EMWMF has been about 30 percent above normal. To reflect the seasonal and high precipitation phenomenon, an elevated recharge ratio (1.3 X normal recharge) was applied to the whole model domain. MODFLOW-96 version was used to conduct all the simulations.

The water table map, as predicted by the 2003 model, matched the field measurement very well. The difference (residual) between modeled results and measured levels are mostly within three feet. The residual mean is 0.38 feet (0.11 m). Considering the great elevation difference across the model domain (approximately 300 feet (91 m)) and complexity of the site conditions, the model calibrates quite well and is suitable for the engineering design analysis.

In addition to water-level measurements, stream discharge data were used to constrain the model. The model predicted groundwater discharge to surface drainage for the area is 0.63 cfs (0.018 m^3/s), which is less than 9% less than the field measured data of 0.69 cfs (0.019 m^3/s) by USGS (Robinson and Johnson 1995). The slightly lower predicted value may reflect the reduced groundwater discharge due to disposal cell construction.

Since the location and elevation of the EMWMF had been supported by previous groundwater modeling efforts, the state and EPA were a little skeptical of the project team’s ability to produce refined and more accurate modeling results as part of the remedy process. The ability of this modeling effort to match the existing site conditions enabled the project team to win support for the selected remedy from both senior management and the regulators. At times during the development process, representatives from all stakeholders were able to interactively participate in changing and refining the inputs to the model. This hands-on involvement greatly increased the confidence and ownership of the stakeholders in the conclusions of the modeling effort.

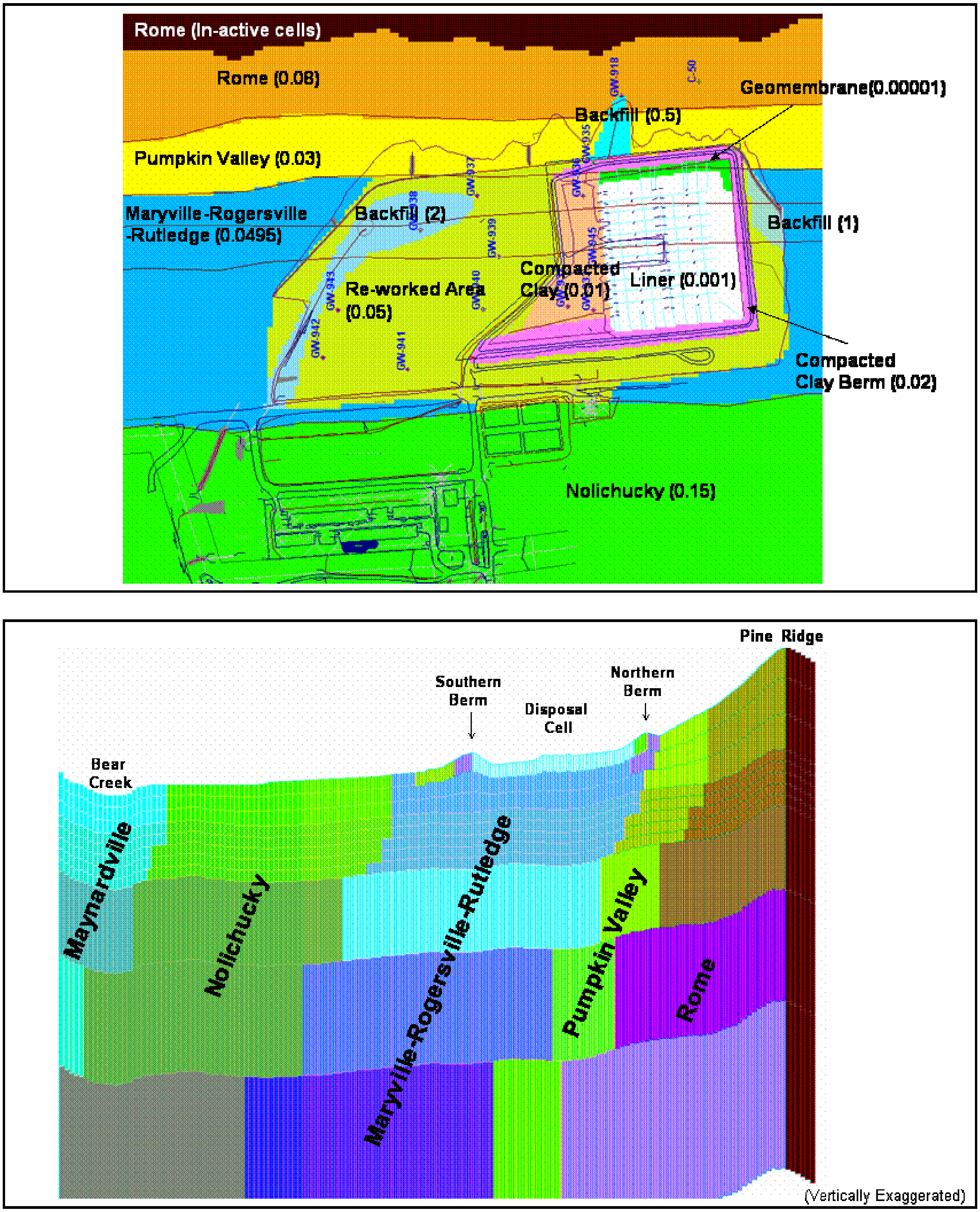

Fig. 3. Hydraulic Conductivity (in ft/day) Representation of the EMWMF Site.

Sensitivity Analysis

The response of the calibrated 2003 EMWMF model to changes in hydraulic conductivity, anisotropy ratio, channel backfill distribution, recharge rate, and drain conductance was evaluated through sensitivity analysis. One parameter at a time was varied while all other parameters were held constant. Each parameter was, in turn, multiplied by various factors, and the residual sum of squares and the percent deviation from the calibration run was recorded. The percent deviation is a good indicator of the overall sensitivity of the water levels to a change in parameter value. A high percent deviation indicates that the model is sensitive to changes in that particular parameter. In general, the model is most sensitive to recharge, anisotropy ratio of the geologic units, and hydraulic conductivity of underlying units. Other factors have little effect on the overall model calibration.

Based on the insight gained from the sensitivity analysis, the more sensitive parameters, including recharge, anisotropy ratio of the geologic unit, and hydraulic conductivity of underlying units, were varied for the selected engineering alternative base runs to see the effect on the predicting results. The changes of the input parameters within the sensitivity range did not change the effectiveness of the engineering alternatives.

MODEL ANALYSES OF ENGINEERING ALTERNATIVES

The evaluation of the engineering alternatives consisted of quantitative and qualitative assessments of specific alternatives applying the following evaluation criteria:

- Predicted effectiveness—a modeled prediction of the ability of an alternative to permanently lower groundwater levels beneath the EMWMF;
- Risk—a measurement of the confidence that the alternative will perform as predicted;
- Difficulty of implementation—the level of difficulty of construction or installation of the alternative (including future maintenance);
- Predicted effect on EMWMF performance/waste acceptance criteria (WAC)—a modeled prediction of the impact of an alternative on the future performance of the EMWMF;
- Effect on EMWMF capacity—a prediction of the effects of an alternative on site topography that would impact the available footprint and airspace for future expansion of EMWMF;
- Cost—a rough-order-of-magnitude estimate of the cost of implementing an alternative.

The 2003 Model was used as quantitative tool of the evaluation. Compared with earlier site models, the 2003 Model has many significant improvements that make it more suitable for conducting engineering analyses. The improvements are necessary considering the changes in site conditions and new groundwater data.

Current site surface conditions, ranging from topography to surface drainage features, were incorporated.

Recharge to groundwater is more precisely represented based on current and possible future conditions.

All engineered features, such as backfill, berm, and liner, were incorporated.

Smaller grid size allows detailed and distinct presentation of hydrogeologic and engineered features.

Newly available groundwater monitoring data allows better model calibration.

A natural groundwater boundary (top of the Pine Ridge) was used as model boundary.

The calibrated 2003 Model was used to simulate site conditions as of March 2003 when the study commenced and average (annual steady state) groundwater levels at the EMWMF site. Expected groundwater levels following the closure and capping of the EMWMF were also modeled.

Engineering alternatives considered for lowering the water table beneath the EMWMF were also evaluated by entering parameters representing the alternative into the 2003 Model. Modeling to evaluate the effectiveness of the engineering alternatives at lowering the water table was performed using the March 2003 (wet season) recharge rate. Modeling to evaluate the effect of the engineering alternative on the future performance of the EMWMF was performed using the average precipitation/recharge condition and assumed that the 1.2M CY (917,466 m^3) configuration of the EMWMF was capped.

To evaluate the effects of the engineering alternatives on the risk performance of the EMWMF, MT3D (Zheng, 1990), a fate-transport model code, was used to predict the future contaminant movement and resulting concentration in the area. The risk scenario where a hypothetical domestic groundwater supply well is placed hydraulically downgradient from the EMWMF location was analyzed. The well is designed as a typical domestic water supply well in the same location as was used in the previous model to set the facility’s waste acceptance criteria. A conservative constant leaching source from the facility to groundwater across the entire facility footprint was used in the model. Because of the nature of the contaminants (long-life radionuclides) considered, only the advection process was considered. No retardation processes were considered. Method-of-characteristics solution was used for all the simulations to minimize the potential error from numerical dispersion.

The groundwater flow parameters, including groundwater flow path, travel time, and groundwater velocity, were obtained by using the USGS particle tracking code, MODPATH (Pollock 1989).

Detailed Alternatives Modeling Analysis

Following alternatives were considered during the alternative analysis. The starting condition for the model used the site-specific operational condition at 2003. Cells 1 and 2 had been constructed but waste was only being disposed in Cell 1. NT-4 had been backfilled in preparation of construction of Cells 3 and 4. Addition of Cells 3 and 4 would bring the capacity up to its full design capacity.

Construct Deep Upgradient Trench

Under this alternative, a deep groundwater collection trench would be constructed along an east-west alignment in the vicinity of the existing northern fence line, north of the EMWMF. The trench would be excavated, backfilled with fine-to-medium sand and capped with about three feet of clay. The sand would act as a filter against piping of the natural soils yet would offer a much higher hydraulic conductivity. The trench would extend to a depth such that the bottom of the geologic buffer would remain dry–expected to be as deep as 52 feet (15.8 m) deep. The trench would be gravity-drained to existing surface features (NT-3 and NT-5). This alternative was identified to permanently lower groundwater levels beneath the EMWMF.

A variation of this alternative consists of installing a single trench, draining to NT-3, along the northeast corner of the EMWMF to assist another alternative, such as the undercell drain, in lowering the groundwater primarily beneath the northeast portion of EMWMF.

Install Undercell Drain

This alternative consists of an underdrain, installed along the eastern edge of Cell 3. This drain would consist of a core zone of cobbles surrounded by zones of gravel and sand designed to meet filter criteria for assured long-term performance (i.e., non-clogging). The underdrain would serve to lower the groundwater beneath future Cells to the west in a manner similar to the original NT-4 drainage. The base elevation of the underdrain would be determined by modeling analysis. The underdrain would gravity flow to the south, beneath the southern berm and discharge to either the ground surface or to an exfiltration gallery (i.e., leach field). Monitoring of the discharge was added to the site environmental monitoring scope since the presence of contaminants in the discharge would indicate a liner system failure. This alternative was identified to permanently lower groundwater levels beneath the EMWMF.

Construct Additional Geologic Buffer Under EMWMF

Additional geologic buffer would be added to the existing geologic buffer in Cell 2 to achieve the required ten feet of geologic buffer above the water table. The existing liner system (geosynthetic materials and compacted clay liner material) in Cell 2 would be removed and additional buffer material would be added to the existing buffer. The low permeability clay would be replaced and the geosynthetic liner system reconstructed. The thickness of additional geologic buffer would be determined by modeling current and future groundwater conditions in the Cell 2 area. This alternative was identified to increase the separation between the waste and the groundwater levels beneath the EMWMF.

Install Horizontal Undercell Drainage Wells

Under this alternative, several horizontal boreholes would be drilled under the geologic buffer beneath Cells 1 and 2 to lower groundwater levels. The boreholes would be installed from the southern end of the cells and would slope upward. At the northern end of the cells, the borings would slope up more steeply, eventually surfacing in the berm north of Cells 1 and 2. A well screen with a pre-packed sand filter would then be installed through the boreholes. The completed wells would gravity-drain to the south, where the collected water would be monitored and discharged as required. Three to five wells, each about 1200 feet (366 m) long, were envisioned.

Although this alternative was identified to lower groundwater levels beneath the EMWMF, it was not considered to be a viable permanent alternative due to concern of the long-term integrity of the wells.

Install Impermeable Layer over Northern Recharge Area

As originally envisioned, this alternative involved the placement or construction of a layer of impermeable material (for example, concrete or a geosynthetic material) over the southern slope of Pine Ridge from the top crest of the ridge to approximately the northern berm of the EMWMF. Following the field visit to the site, it was determined that a less aggressive approach to reducing recharge north of the EMWMF would likely be as effective, more implementable, and less expensive.

This less aggressive alternative consists of making improvements to the drainage ditches to minimize infiltration of the surface water in the area north of the cells. This would include regrading ditches to provide steeper slopes, lining the ditches with impermeable membrane or concrete, and making other improvements to maximize runoff and reduce the retention of water flowing over the affected area. This portion of the alternative is intended to lower groundwater during operations. To control groundwater levels after the EMWMF operations cease, the final facility cover would be extended over these same areas.

Install Northern Dewatering System

This alternative involves installation and pumping of vertical dewatering wells (or well points) located along the northern edge of Cells 1 and 2 in order to lower the groundwater just upgradient of the cells. The depth of the wells would be about 60 feet in order to provide groundwater control essentially equivalent to the upgradient trench. The wells, however, would require constant pumping to maintain the lowered groundwater condition.

This alternative was not considered feasible for the long-term because it required an active system to remove groundwater. It was considered feasible for a localized short-term groundwater remedy. For this reason, this alternative was considered in combination with other alternatives.

Restore Natural Surface Drainage in Former NT-4

Under this alternative, the existing Cells 1 and 2 would remain, but the original NT-4 would be reconstructed west of these cells. A western berm would be constructed adjacent to Cell 2 (probably within the existing cell footprint) and a final cover would be placed over Cells 1 and 2 once they reached their revised capacity. A surface water drainage channel would be constructed approximating the former NT-4 location from the northern end of the facility to the ditch just south of EMWMF. Any future expansion of the EMWMF would require construction of a separate waste containment structure in the area west of this drainage feature, essentially eliminating waste disposal in the area currently designated as Cell 3. This alternative was identified to permanently lower groundwater levels beneath the EMWMF.

Selected Final Alternative

Based on the evaluation of the engineering alternatives discussed above, consensus opinion among BJC, DOE, and the regulators was that the alternative “Install Undercell Drain” was the best means of permanently lowering groundwater levels beneath the facility.

Modeling predicted that this alternative would be effective at permanently lowering the current water table to levels below the EMWMF geologic buffer. Figure 4 shows the resulting groundwater table under the EMWMF cells as simulated by the model. The associated risk was determined to be low. This determination is supported by the anticipated conservative design of the drain. Additional modeling indicated there would be no significant increase in performance of the undercell drain if it were to be extended under the north berm of the EMWMF into the northern reaches of the former NT-4 channel. Also, the drain is predicted to be effective at intercepting and lowering groundwater being driven by the upward hydraulic gradients beneath the former NT-4 channel. The difficulty of implementation was judged to be moderate.

POST CONSTRUCTION MONITORING RESULTS

The undercell drain was successfully constructed in early 2004. The constructed drain is nominally 1,050 ft (320 m) long, 12 ft (3.6 m) wide, and 25 ft (7.6 m) below the original land surface.

Following the completion of the undercell drain at the EMWMF, the model was used to help develop a groundwater-monitoring plan to identify monitoring locations to assist in evaluating groundwater supperssion. Eight new piezometers were installed to join an existing monitoring network. The new monitoring network consists of 42 locations, including 2 regional monitoring wells, 3 existing piezometers, 12 EMWMF performance-monitoring wells, 20 BJC performance monitoring piezometers, and 5 pore pressure transducers.

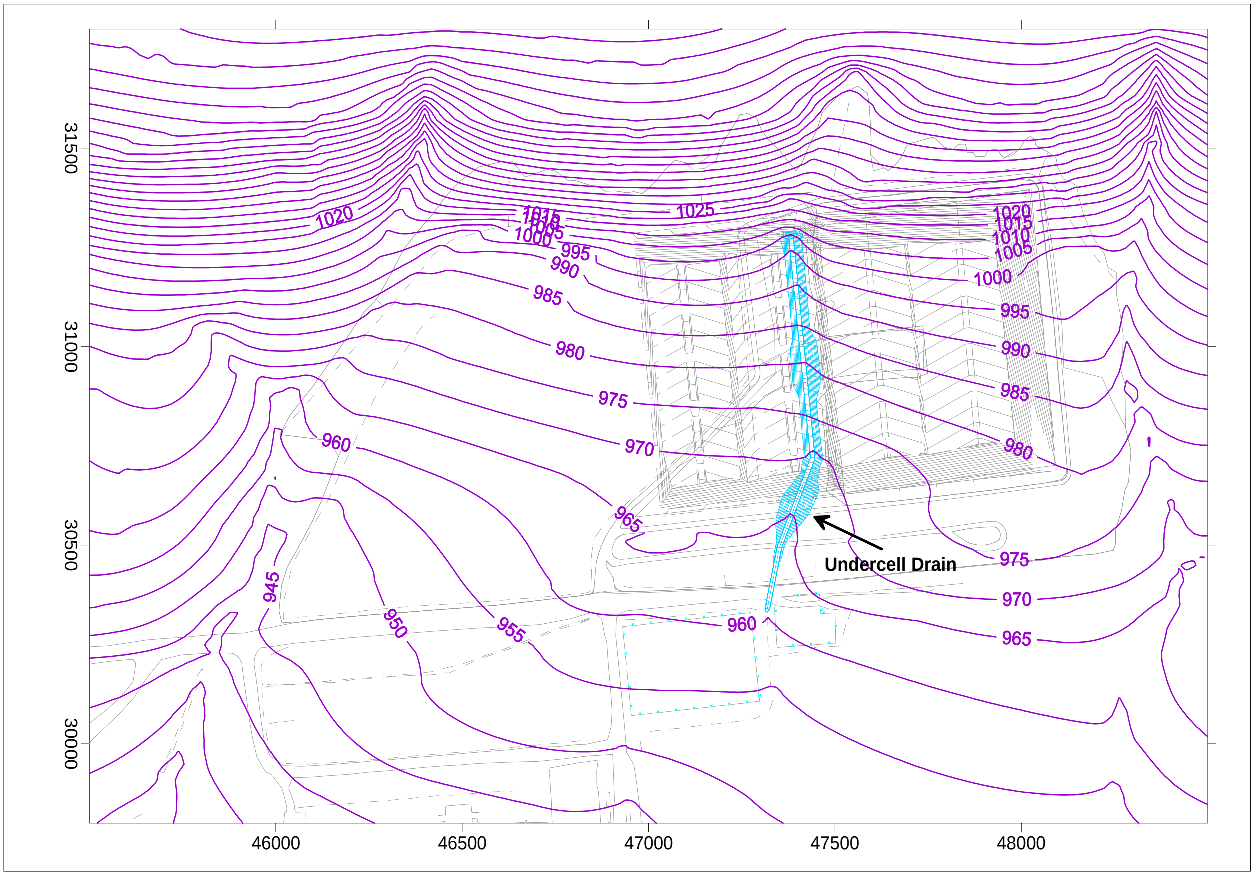

Fig. 4. Model predicted Groundwater Levels (in ft-msl) for the Undercell Drain Alternative.

The model was also used to conduct the transient modeling analysis on the groundwater level change over time in response to the installation of the undercell drain. As the site consists of mostly lower permeability formations, the drawdown will develop over a period of years, in similar fashion to the observed slow water rise due to construction backfill at the site. The predicted rate of drawdown provided guidelines for post-construction water level data analysis.

Since seasonal variability is relatively high in the area, the absolute elevation measured at the monitoring locations must be normalized to derive the effect from the underdrain in some of the locations. The current monitoring data suggest that the implemented alternative has the desired effect on the groundwater levels at the site as predicted by the model. The groundwater levels show net decreasing trends over the area.

The outflow measurements from the underdrain have been about 8 gpm (1.8 m^3/hour). The model had predicted the same rate based on construction configuration. The ability of the model to forecast the system design and the response of the remedy over time provides additional confidence in the model.

The ability of the model to convincingly forecast the response to the remedy over time enabled DOE to gain permission from oversight agencies to proceed with the addition of Cells 3 and 4 to increase the facility capacity to 1.2M cy (917,466 m^3).

CONCLUSIONS

A three-dimensional groundwater flow model was developed for use on the EMWMF at DOE's Oak Ridge Reservation to select and evaluate engineering alternatives for lowering the groundwater level under the EMWMF and to help the performance analyses and monitoring activities. This detailed site-specific flow model was constructed by (1) revising model input to reflect the local geology based on field reconnaissance and information gained during site development and construction of Phase I of the EMWMF, (2) incorporating the current site topography and engineering features, (3) adding properties to represent the as-built EMWMF, and (4) utilizing latest groundwater monitoring data in and around the EMWMF. The refined model, consisting of 1.3 million cells with a grid spacing of 10 × 10 ft (3 m x 3 m) and finer vertical layers (11 layers), was able to represent more precisely the construction/engineering design features and other site-specific conditions at the EMWMF which the earlier models were unable to do.

Rigorous model calibration was conducted for the model to match with measured groundwater levels at the site, groundwater flow directions, and stream discharge data. Detailed sensitivity analyses were performed to evaluate the response of the calibrated groundwater model to changes in soil/rock hydraulic conductivity, anisotropy ratio, channel backfill distribution, recharge rate, and drain conductance.

The ability of this modeling effort to match the existing site conditions enabled the project team to win support for the selected remedy from both senior company management and the regulators. At times during the development process, representatives from all stakeholders were able to interactively participate in changing and refining the inputs to the model. This hands-on involvement greatly increased the confidence and ownership of the stakeholders in the conclusions of the modeling effort.

The undercell drain was successfully constructed in early 2004. Following the completion of the undercell drain at the EMWMF, the model was also used in developing the groundwater-monitoring plan to identify monitoring locations and evaluating the design basis for future cell expansion. Transient modeling analysis provided information on the groundwater level change in response to the installation of the undercell drain. The current monitoring data suggest that the implemented alternative has the desired effect on the groundwater levels at the site.

The ability of the model to convincingly forecast the response to the remedy over time enabled DOE to gain permission from oversight agencies to utilize the remaining portions of the cell capacity and continue planning for the future construction of cells 3 and 4.

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