Development of a Regional Groundwater Flow Model for the U.S. Department of Energy Oak Ridge Reservation: EarthVision® Conceptual Site Model-17367

Robert L. Gelinas***, Samantha R. Pack**, Lynn M. Sims**, Holly M. Clancy**, Charles S. Haase**, Richard H. Ketelle**, Dennis Mayton*, and Alauddin Khan***

*U.S. Department of Energy, Oak Ridge Environmental Management
**URS | CH2M Oak Ridge LLC/Restoration Services, Inc.
***Leidos, Inc.

ABSTRACT

A regional scale groundwater flow model (GFM) has been developed for the U.S. Department of Energy (DOE) Oak Ridge Reservation (ORR). Development of the model implements a key recommendation of the ORR Groundwater Strategy. The model will be used as the calibrated flow model for the ORR and as the framework for future, smaller scale, modeling efforts to support cleanup actions and decisions under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA).

The Oak Ridge site is located in a geologically complex region and encompasses three large government facilities, including the Y-12 National Security Complex (Y-12), Oak Ridge National Laboratory (ORNL), and the East Tennessee Technology Park (ETTP). An interagency approach for addressing legacy groundwater contamination from past operations at these facilities has been developed, resulting in an ORR Groundwater Strategy that was agreed to by DOE, the U.S. Environmental Protection Agency (EPA), and Tennessee Department of Environment and Conservation (TDEC) in fiscal year (FY) 2014. The ORR Groundwater Strategy provides a comprehensive approach to addressing and prioritizing groundwater issues across the DOE reservation. Implementation of key recommendations from the strategy began in FY 2014, including the recommendation to "develop and maintain an ORR-wide regional groundwater flow model to ensure a single, regional, calibrated model to support groundwater characterization, decision-making, and remediation."

As part of the cleanup plans for the Oak Ridge site under CERCLA and the Federal Facility Agreement (FFA), there are six final watershed-scale groundwater Records of Decision (RODs) currently planned. In preparation for future projects, the regional GFM has been constructed to serve as the single, calibrated regional flow model to be used as the hydrologic base for the groundwater plume-specific modeling developed for the RODs.

INTRODUCTION

This paper presents information about the development of a regional scale 40 x 16 km (25 mile x 10 mile) groundwater flow model (GFM) for the U.S. Department of Energy (DOE) Oak Ridge Reservation (ORR). Specifically, the up-front conceptual site model (CSM) development is addressed in this paper; details of the associated numerical model are presented in a separate presentation. The modeling objectives, approach, and development process are described, along with Technical Advisory Group (TAG) recommendations that guided the effort. Development of the model implements a key recommendation of the ORR Groundwater Strategy (DOE/OR/01-2628/V1&V2/D2).

Site Description and Regulatory Background

The Oak Ridge site is located in a geologically complex region and encompasses three large government facilities - the Y-12 National Security Complex [Y-12], the Oak Ridge National Laboratory (ORNL), and the East Tennessee Technology Park (ETTP) [Fig. 1 and Fig. 2]. The mission and operations at each of the three ORR facilities have resulted in unique hazardous and radioactive wastes and waste management areas in each of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) decision areas. An interagency approach for addressing legacy groundwater contamination from past operations at these facilities has been developed, resulting in an ORR Groundwater Strategy (DOE/OR/01-2628/V1&V2&D2) that was agreed to by DOE, EPA, and TDEC in fiscal year (FY) 2014. The ORR Groundwater Strategy contains detailed information about contaminants of concern, groundwater plumes, site geology, and hydrology on the ORR, and provides a comprehensive approach to addressing and prioritizing groundwater issues across the DOE reservation. Implementation of key recommendations from the strategy began in FY 2014, including the recommendation to “develop and maintain an ORR-wide regional groundwater flow model to ensure a single, regional, calibrated model to support groundwater characterization, decision-making, and remediation.”

As part of the cleanup plans for the Oak Ridge site under CERCLA and the Federal Facility Agreement (FFA; DOE/OR-1014), there are six final watershed-scale groundwater Records of Decision (RODs) currently planned. In preparation for these future projects, the regional GFM has been constructed to serve as the single, calibrated regional flow model to be used as the hydrologic base for the groundwater plume-specific modeling developed for the RODs.

MODELING OBJECTIVES

The two main objectives of the regional GFM are to: (1) provide a single, calibrated flow model for establishing flow boundary conditions, and (2) provide the framework to support future smaller scale models and groundwater characterization, monitoring, actions, and decisions. The GFM, in conjunction with smaller scale modeling, may play a role in the following:

- Analysis of regional flow systems and simulation of changes,
- Additional characterization and placement of monitoring wells to delineate the extent of plumes, including optimization of the long-term monitoring network,
- Visualization of extent and movement of groundwater and contaminants,

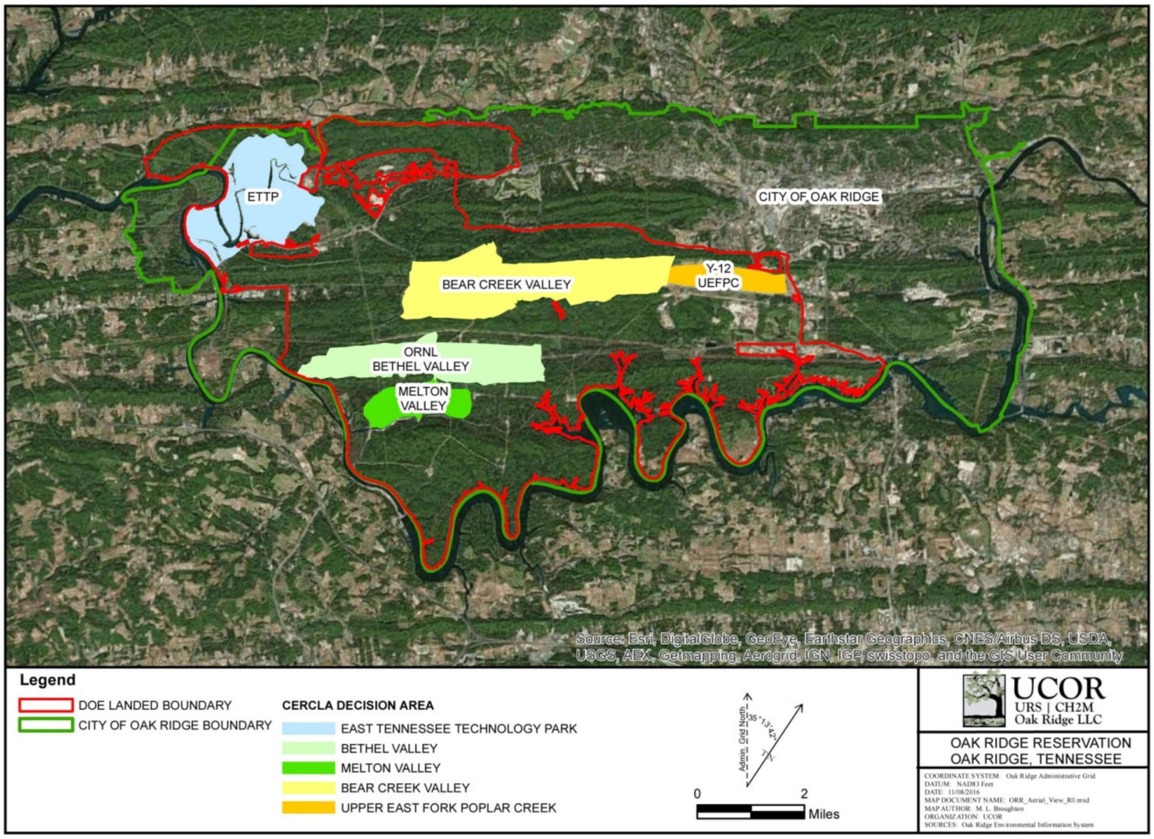

Fig. 1. Aerial view of the ORR and surrounding areas.

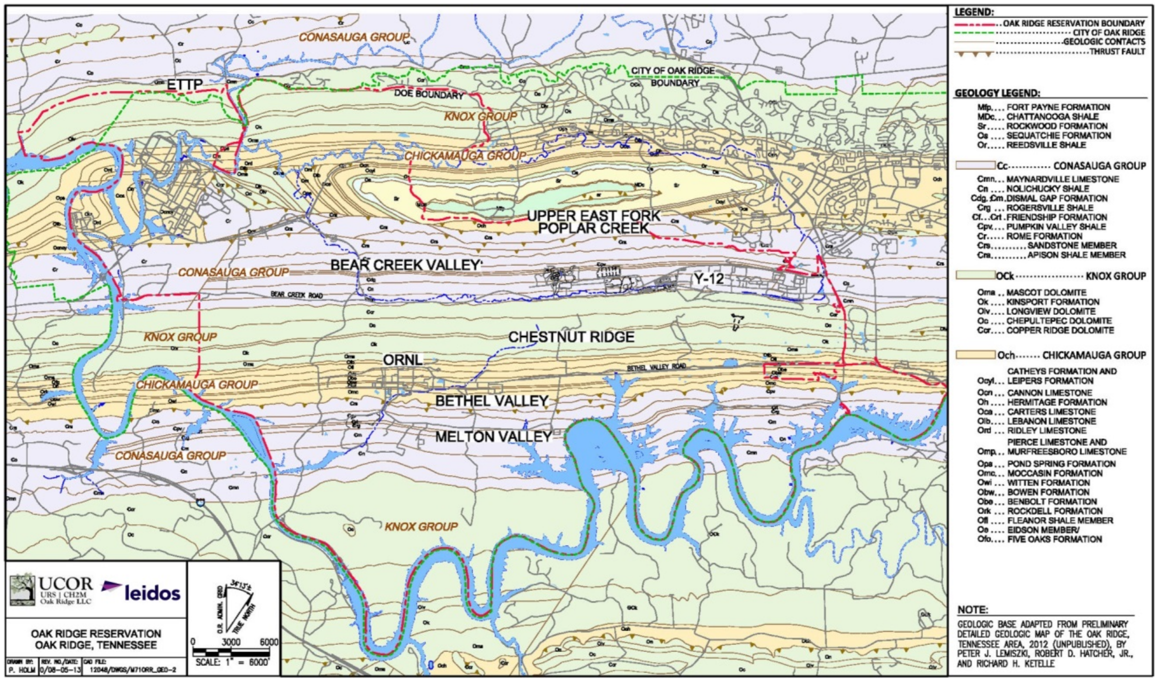

Fig. 2. Geologic formations in the ORR.

- Conducting ”what-if” testing to evaluate potential on-site and off-site migration flow paths,
- Engineering studies to identify remediation alternatives, as well as the follow-on engineering design work,
- Assessment of potential short- and long-term risks, and
- Final watershed groundwater decisions that may include monitored natural attenuation or Technical Impracticability waivers

This paper and the associated FY 2014 and FY 2015 Model Progress Reports (UCOR-4634 and UCOR-4753, respectively) present information about development of a three-dimensional (3-D) representation of the conceptual site model (CSM) using EarthVision® (EV) software. This hydrogeologic framework has been used as input to the numerical groundwater model. The numerical model, developed using USGS MODFLOW-USG software, is the first version of a completed, calibrated regional GFM based on available data. Updates of the model based on improved data are anticipated.

MODELING APPROACH AND PROGRAM SELECTION

Prior to development of an initial Y-12 centered Test Cast Model and build out of the full regional scale model, a selection process for the CSM and numeric model program (code) was performed primarily by the Technical Committee of the TAG. The goal was to select programs that would be consistent with the modeling objectives and be applicable to the ORR site-wide scale, and meeting as many of the desirable attributes as possible including representation of the stratified heterogeneous aquifer system with dipping beds, conduit flow, etc., that are present at the ORR. The software also needed to have the ability to model sufficient details (i.e., finer grids to include all the features including dipping beds, faults, rivers, creeks and tributaries, etc.) and stay within memory limitation of the computer platform chosen for simulations.

The steps followed for selecting the numerical code included identification of a set of code attributes, development of a preliminary list of potentially viable codes, evaluation of a short list of codes that incorporate key code attributes, and finally testing of the candidate codes. This process is described in the FY 2014 Model Progress Report (UCOR-4634). Based on this evaluation, MODFLOW-USG was selected for testing via a test case. The primary features to address in the test case application were: (1) ORR representative lithologic and structural features, including groundwater flow in stratified heterogeneous aquifer system with dipping beds; and (2) conduit flow. Based on review of the capabilities of modeling codes and supporting programs, the following primary programs were selected for model development:

- MODFLOW-USG (Panday et al. 2013)
- mod-PATH3DU by S.S. Papadopulos & Associates
- Parameter Estimation (PEST) software by Doherty (2004; 2013)
- Groundwater Vistas (GV) model design system with graphical interface
- EarthVision® (EV) 3-D CSM software (Dynamic Graphics, Inc., 2009)

GENERAL CSM AND NUMERIC MODEL CODE ASSUMPTIONS

A CSM and numerical groundwater model is the quantitative transformation of a physical system representing complex hydrogeologic conditions of a site. Therefore, it represents a modeler's understanding of the subsurface flow system, which may deviate from the actual system. For example, the GFM assumes no-flow boundary conditions along all the sides of the boundaries as well as the inclined layer configuration for the subsurface geology with by valley average dip angles, although the geologic formations on the ORR dip at angles ranging from 0 to 1.57 radians (90 degrees). Also, uniform hydraulic conductivity is assigned in each layer that may not be representative of the actual groundwater system within that layer. It is understood that this simplification of the subsurface geology represents a limitation in the model. In spite of these limitations, the GFM will be verified to reasonably capture regional flow patterns, and the model will be considered applicable for the study and meeting the desired purposes of this modeling study.

CSM DATA NEEDS

This section describes the CSM data and information compiled for input into development of the regional GFM. These data comprise the information necessary to develop the CSM for input into the numerical groundwater model. CSMs are essential elements of the systematic planning process and present the current understanding of the site, help to identify data gaps, and help to focus the data collection efforts. The CSM can be updated as new information is collected. The CSM is used to support scientific and technical decisions for the site, and can assist in the effective communication of critical issues and/or processes identified at the site and support the remedial decision-making process. The EV-rendered CSM hydrogeologic framework has been used as input to the numerical groundwater model developed using the U.S. Geological Survey (USGS) MODFLOW USG software (a modular finite-difference flow model using un-structured grids). The numerical GFM (MODFLOW-USG) is used to simulate groundwater flow under either constant or transient conditions to assess aquifer responses to various potential future condition scenarios.

There have been numerous studies of the geology and hydrology of the ORR, and many of these that provide some of the best geologic and hydrologic information were completed 20 to 30 years ago. Much of the information used for input into the ORR Regional GFM has been derived from these older investigations. The hydrogeologic data necessary for the CSM are housed in numerous different sources. With the large number of sources of information to research and the differences in the types of information available (e.g., electronic vs. hardcopy), a process had to be implemented for data compilation.

Process for Implementation

The process for implementation of the ORR Regional GFM began with identification of the data needs for development of the model. After identification of the data needs, the sources for these data had to be identified. Once these sources were identified, collection of the data was initiated. The necessary data were in a variety of forms including electronic spreadsheets and text files, electronic information stored in the Oak Ridge Environmental Information System (OREIS), electronic data available from the USGS, electronic data available from the Tennessee Valley Authority (TVA), published geologic maps available from the Tennessee Division of Geology, an unpublished geologic map of the ORR, published USGS reports, numerous published and unpublished DOE ORR documents, and electronic files from previous groundwater modeling efforts on the ORR. The data sets and sources identified [see Appendix C of the FY 2014 Model Progress Report (UCOR-4634)] for incorporation in the GFM included:

1. Well construction information and boring logs generated from the drilling for the installation of wells and any other investigative subsurface logs.
2. Topographic surface for the model domain.
3. Surface water bodies including rivers and local streams.
4. Surface geology of the area covered by the model, including regolith and the outcrop pattern and description of bedrock formations.
5. Groundwater levels from wells within the model boundary.
6. River stage levels for rivers and streams within the model boundary.
7. Hydraulic properties of the subsurface materials including the regolith, the weathered bedrock zone, and the competent bedrock zone.

The 3-D geologic CSM represents an area approximately 39,624 m long by 16,611 m wide (130,000 ft long by 54,500 ft wide), and retains the lower cut-off at sea-level. The unified ORR model was constructed in chunks, with the sequence [see Appendix B of the FY 2015 Model Progress Report (UCOR-4753)] being:

- The Test Case Model area, including Bear Creek Valley (BCV) and the Y-12 Plant site in the headwaters of Upper East Fork Poplar Creek (UEFPC)
- East Fork Ridge Syncline to Pilot Knob,
- Area North of ETTP, then ETTP Proper,
- South of Melton Valley (MV), Melton Valley, Bethel Valley (BV), and finally
- BCV extension to east and west, and adjustments to some surface geologic contacts in the Test Case Model area (completed last)

The primary data sources used to develop the regional CSM included:

- 2012 Preliminary Detailed Surface Geology Map of the Oak Ridge, Tennessee area (Lemiszki et al. [unpublished], see Fig. 2).
- Other geology maps: Cave Creek and Lovell TDEC quad maps (Lemiszki 2001; Lemiszki 2013); USGS Geologic Map of TN (2015).
- USGS Digital Elevation Model for surface topography; National Hydrography Dataset for streams and water bodies.
- Geologic cross-sections from various historical sources, and
- Historical well pick data from ORNL and ETTP.

Process for Generating the 3-D Geologic Model

The geologic model constructed in EV provides the geologic framework for the numerical GFM constructed in MODFLOW-USG. The GUI, GV, is being utilized as the front-end/post-processing software for the 3-D groundwater flow modeling, calibration, and optimization using the MODFLOW suite of codes (Panday et al. 2013). Thus, the surfaces used to construct the EV 3-D geologic model must be exported to GV/MODFLOW-USG. These surfaces include the EV 2grds (referred to as “2 grids”) that define the top of the inclined bedrock units, plus the three 2grds (top of competent bedrock, top of weathered bedrock, and topography) that are laid on top of the inclined grids.

Major processing steps to prepare the CSM in EV included operations related to the following data sets:

- Development of topographic surface
- Assembly and gridding of regolith and weathered bedrock data
- Assembly and gridding of well pick data
- Incorporation of surficial formation contacts from various geologic maps
- Processing USGS National Hydrography dataset for stream/water bodies

Each of these steps is described in the following sections.

Development of the Topographic Surface

The first step for generating the topographic surface in the model space was to download appropriate USGS NED tiles from the National Map Viewer. Two tiles are required to cover the model area (grdn36w085_13 and grdn37w085_13, both in ESRI GRD format). These tiles were opened in ArcGIS, and projected/clipped to the ORR regional model space. These projected, clipped NED datasets were then converted from ESRI GRD format to ASCII txt files and brought into EV and through a series of steps migrated to a native *.2grd file format.

As identified during previous work on the Y12 Test Case Model, the USGS DEM deviates from available surveyed ground surface elevation data for wells in the project model sets (typically within a meter, but up to nearly 15 m (50 ft) in the worst case). Consequently, the correction gridding routine in EV was used to warp the imported USGS topography to honor available surveyed ground surface elevation data. The final corrected topographic surface was used in the EV WorkFlow Manager for generation of the 3-D geologic model, and included tasks such as back interpolation of XY data for surface contacts from geologic maps to obtain the Z (elevation component), use as a truncation surface within EV to clip off the solid model above the topographic surface, and to produce the weathered and fresh bedrock surfaces via grid subtraction.

Process for Creating Regolith and Weathered Bedrock Data Set

An Excel spreadsheet containing depth to weathered bedrock and depth to competent bedrock for all wells in the model area was prepared. These two attributes correspond to the thickness of the Regolith (sediment/soil) and weathered bedrock, respectively. Initial attempts to generate layers for these two units included variations on direct gridding of well-based elevation surfaces for top of weathered bedrock and top of competent bedrock, combining gridding of the well-based elevation surfaces with assumed weathered and fresh bedrock depths along stream traces, and introduction of average based depth control points with these two approaches. Gridding attempts to create these surfaces via the methods described above provided poor results, with significant amounts of "islanding" and areas where the regolith and weathered bedrock units were truncated. Upon closer review, it was found that this inconsistency was partly attributable to deviations of the USGS NEDs from available surveyed ground surface elevations in the well data set. The NEDs are not a perfect representation of the topographic surface and some error is to be expected; however, differences of ±1.5 m (5 ft) were common, and some surveyed ground surface elevations deviated between 6 and 15.2 m (20 and 50 ft) from the NEDs. Consequently, the USGS NEDs were corrected to honor available surveyed ground surface elevation data at select wells. Due to the imperfections of the topographic surface representation a simplified approach was utilized wherein average depths to weathered bedrock and competent bedrock were developed by simply subtracting 5.5 m (18.3 ft) and 10.6 m (34.8 ft) from the corrected topographic surface.

Process for Assembly and Gridding of Well Pick Data

An Excel spreadsheet containing subsurface logged information for all wells in the model area was assembled. Although there are several thousand wells of various types that have been drilled on the DOE ORR, many are shallow and did not cross geologic formation contacts so significantly fewer borings provided useful control with depth. Pick information from drill locations off of the DOE ORR was very limited, making incorporation of assumed dips key in expanding the CSM in these areas. Since EV does not read Excel files, the well dataset was exported to ASCII text file format for import into EV. Data for respective geologic units were placed into separate ASCII text files that were created specific to the top of each respective geologic unit. Some wells were noted for having inconsistencies with the surface geologic mapping and/or the assumed formation top dips relative to pick elevations. Picks which were considered to be suspect or uncertain were commented out and not used in the ORR regional model. Assumed dips for formation top control points were modified to account for a gradual shallowing of dip angles from the northern to southern portion of the model.

Process for Incorporating Geologic Maps of the Oak Ridge Area

A key resource in developing both the Y-12 Test Case Model and subsequent ORR regional model was the Preliminary Geologic Map of the Oak Ridge Area (Lemiszki et al. 2012). This map covers roughly 80 to 90% of the regional ORR model space and includes detailed surface geology. Additional detailed geologic maps obtained that helped to define the surface geology contacts included the Cave Creek Geologic Map (Lemiszki 2001) and the Lovell Geologic Map (Lemiszki 2013). For reference, the general locations of these maps and their relationship to the model areas are provided on Fig. 3.

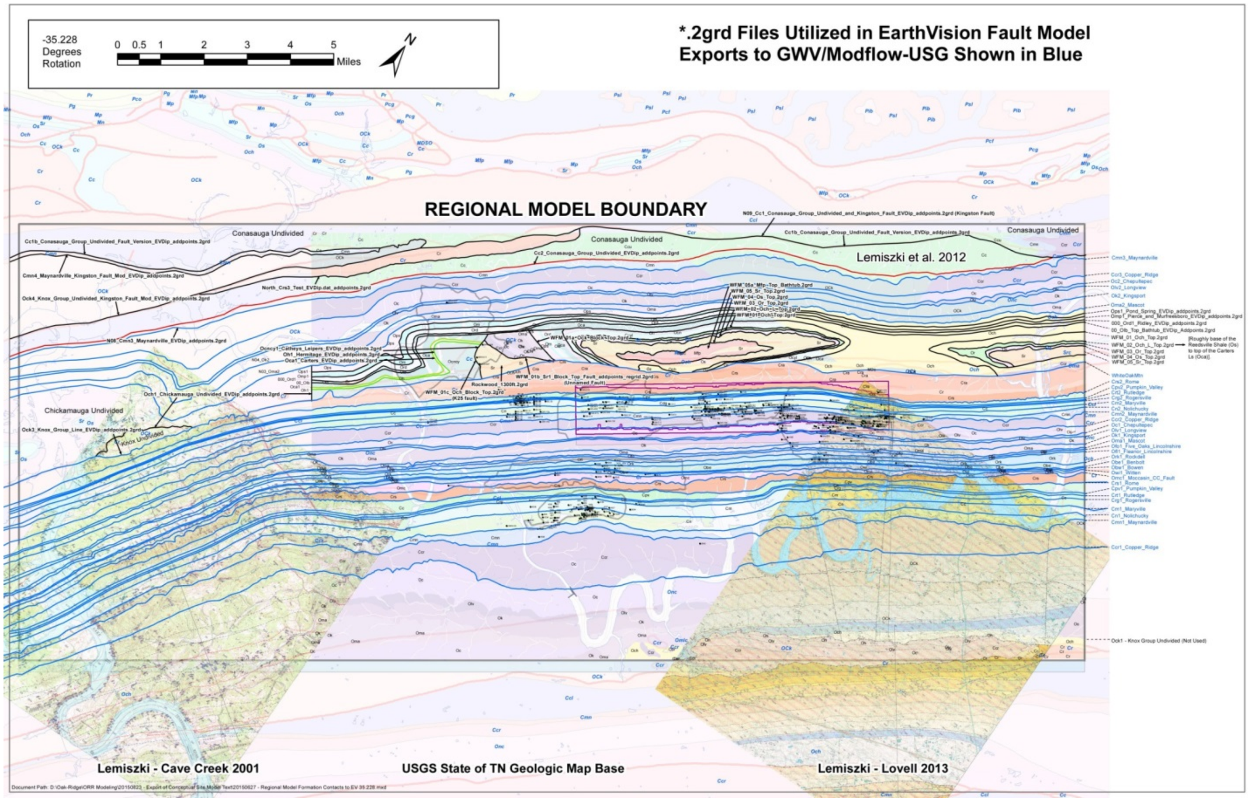

Fig. 3. Primary geologic base maps from Lemiszki 2001; Lemiszki 2013; Lemiszki et al. 2012 [unpublished], and USGS (2015).

The Lemiszki et al. (2012) map was provided to the project team in ArcGIS package format. The map data were re-projected, geologic contact segments joined, and interpretations made in areas not mapped. The surface contacts were clipped to the model space and exported as shapefiles. Since EV does not natively handle shapefiles, these were converted in EV to annotation file type and back-interpolation used to assign ground surface elevations to each vertex. Control points were utilized in the EV input files to help extend/project the geologic surfaces in down-dip and up-dip directions, and variable dip angles were used according to relative location within the model space. Introduction of control points was a critical item in maintaining coherency to the descending formation "slabs" and to prevent wander of the formation tops in an unexpected manner. Control points were minimized in areas where well data were sufficient to establish formation surfaces, but played a significant role in much of the model space where no subsurface data exist.

Process for UGSG National Hydrography Dataset for Water Bodies

The workflow/steps involved in processing the USGS NHD stream/water bodies for display in EV included downloading the USGS High- Resolution National Hydrography Dataset (1:24,000 scale) for Stream/Water Bodies. These were re-projected to the desired coordinate system (TN State Plane) and the linework for various coverages joined and then clipped to the model space and exported. Within EV the shape files were converted to annotation format and elevations were assigned to stream/river/water body traces using the back interpolation function.

Generating the 3-D Geologic Model in EV

After the steps described above were completed, the 3-D model was constructed in EV using the WorkFlow Manager. The key files used for input include the topographic surface, weathered bedrock surface, fresh bedrock surface, geologic pick x,y,z data files (including the limited number of well picks, geologic contacts at the surface, and control points) and fault surfaces. The original attempt at construction of the EV model was undertaken trying to utilize only depositional processes to fill in the stratigraphic sequence. However, the way EV fills the model broke down in the fault block area east of ETTP, where the dip changes on the Unnamed fault (which is inclined toward the south), and the sequence in the East Fork Syncline was filled prior to the fault blocks (which did not work). The model had to be reconstructed using fault trees and assignment of units to each fault block, which added a lot of complexity. In utilizing the fault-based model, two separate *.wfm (WorkFlow Manager) files were maintained: (1) one that is associated with building up the stratigraphic sequence (it generates the 3-D gridded surfaces of the formation tops from the associated ASCII *.dat files that contain the geologic picks, surface contacts, and control points); and (2) a fault-based file that utilizes the *.2grd files created in the previous step and requires assignments of strata to the respective fault blocks. After refinements to the CSM were completed and checks for formational integrity were made, the CSM run was rendered in EV and is provided on Fig. 4 and Fig. 5.

Export/Import of the Conceptual Site Model

Export of the EV surfaces to MODFLOW-USG involved nulling (truncating) the surfaces in areas beyond the numerical model domain and then exporting the nulled surfaces to x,y,z ASCII data files. The procedure for nulling the 2grds differed for the inclined surfaces, which extended completely across the regional CSM domain from northeast to southwest, versus those which are discontinuous (i.e., do not completely cross the model). For the former, the continuous inclined 2grds were nulled above the competent bedrock surface (in order to leave space for the overlying weathered bedrock and regolith layers in the numerical model) and also nulled below sea level (the bottom of the numerical model domain). The discontinuous inclined 2grds were also nulled above the competent bedrock surface and nulled below sea level; however, additional manual operations were needed to prepare the discontinuous 2grd surfaces including truncation of lateral extents due to the presence/absence of faults or instances where discrete

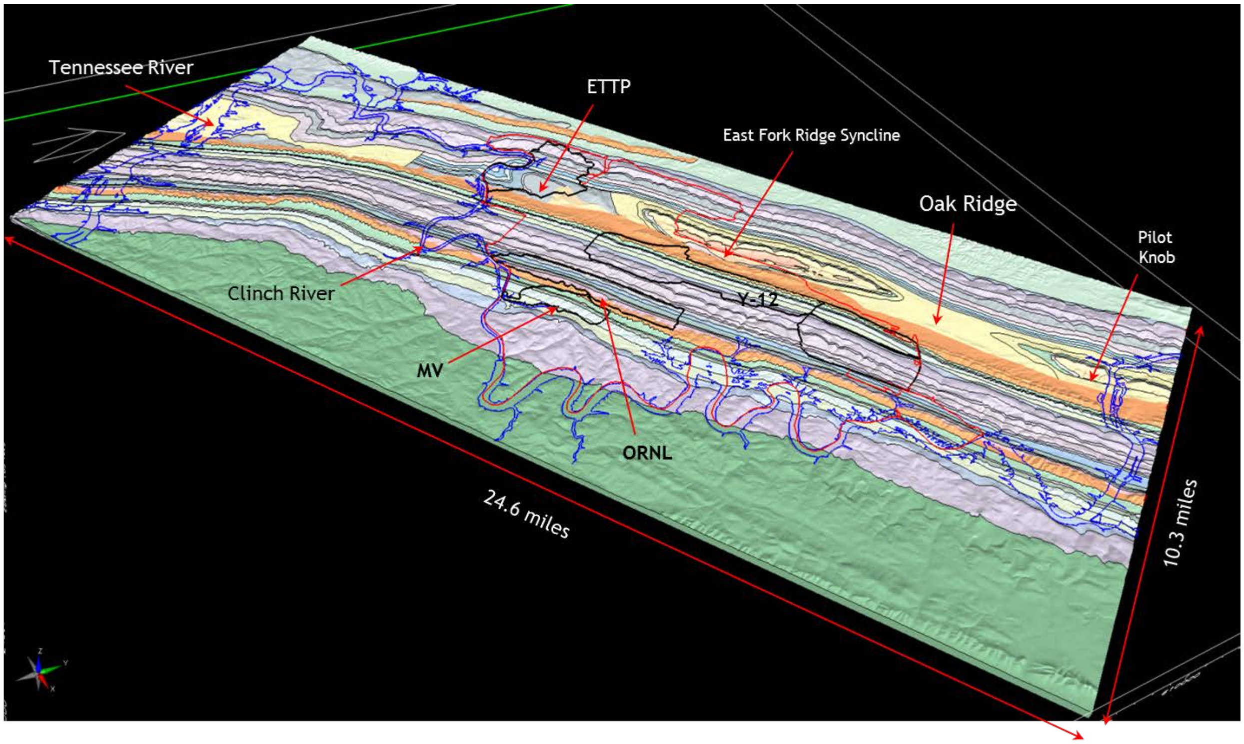

Fig. 4. Regional-scale ORR CSM as rendered in EV.

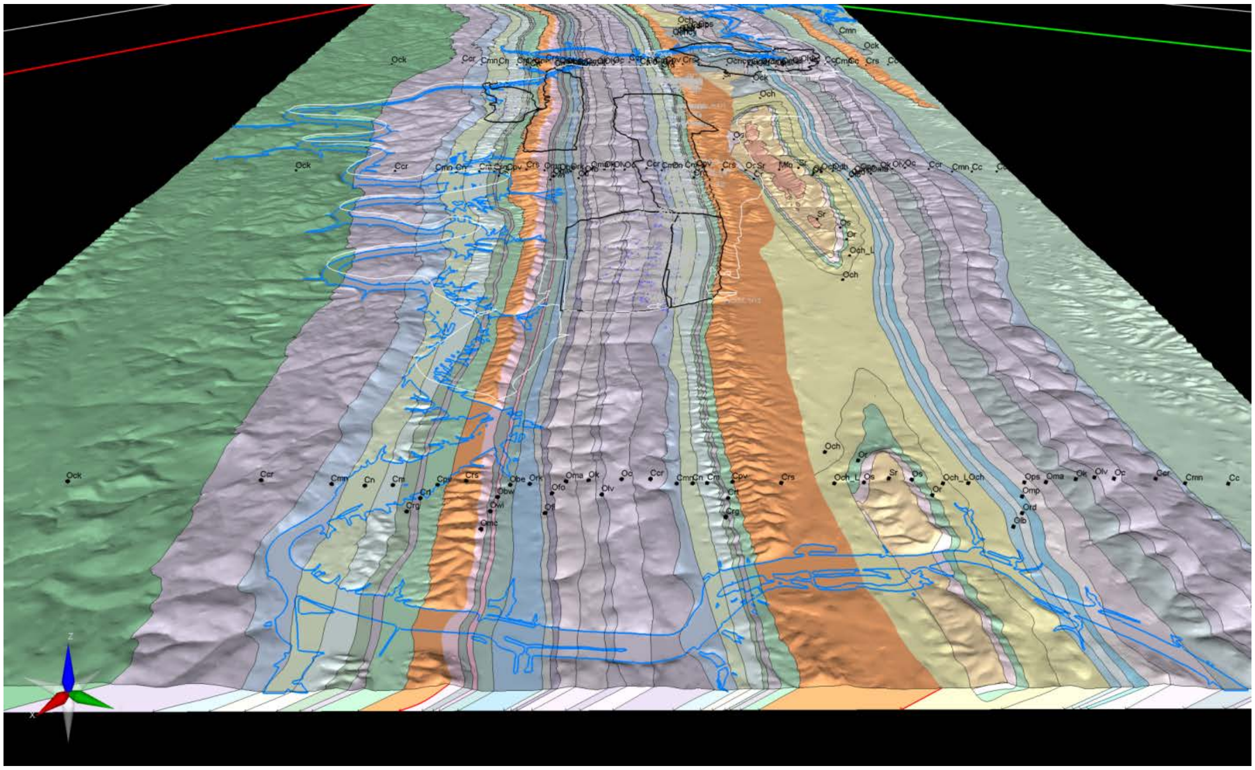

Fig. 5. Down valley view (from NE to SW) of regional-scale ORR CSM.

formations were merged into undifferentiated group level units.

Due to requirements of GV, additional surfaces associated with each formation had to be prepared. GV requires each inclined layer to extend across the full model domain (not just cover the top of the inclined layer that looks like a sideways ribbon). These surfaces include a “hill” component (which represents the top of fresh bedrock north of the inclined geologic slope surface) and a “toe” component south at sea level running south of the inclined geologic surface. The hill and toe surfaces are referred to by the modelers as “pinch-out areas” and the individual x,y,z triplets as “pinch-out nodes.” These surfaces are shown in plan view and 3-D perspective on Fig. 6. The hill and toe portions of each model layer are unpopulated, no-flow nodes and, therefore, do not play a role in the numerical calculations. They only exist as a model construction requirement of GV.

Approach to Export Surfaces

Due to limitations within EV, regridding and faces file manipulation routines, the best approach was determined to be resampling all the raw 2grd files output by EV to the desired 30.48 m × 30.48 m (100 ft × 100 ft) and 152.4 m x 30.48 m (500 ft × 100 ft) spacings *prior* to nulling and/or truncation operations. This approach was opposite of the initial approach in which regridding operations were conducted after nulling/truncation operations. In order to proceed with this approach, a comprehensive shell script was written in EV to perform a series of grid manipulations and quality checks. In total, 34 continuous formations were exported using shell script processing by GV and inclusion in the groundwater model. Several surfaces were manually prepared and not processed with the master shell script described above, including the topographic/fresh bedrock/weathered bedrock surface, and several discontinuous units in the ETTP area and on the north side of the model area. Separate shell scripts/steps were used to process these cases.

Vertical Discretization

Based on the TAG recommendations (UCOR-4634), it was decided to enhance the model construction by dividing the inclined geologic layers in the existing model to additional sub-layers based on the distribution of hydraulic conductivity (K) values, water level elevations, etc., by depth. To maximize resources the subdivision was limited to the two most important formations in Bear Creek Valley (i.e., Maynardville Limestone and Nolichucky Shale) in the Y-12 portion of the model domain. Both units were divided into three horizontal layers based on the hydraulic conductivity distributions. These inclined layer subdivisions were at approximately 0 to 61 m (0 to 200 ft) below average ground surface (bgs), 61 to 122 m (200 to 400 ft) bgs, and 122 m (400 ft) bgs and below. A lesson from this effort is that vertical discretization within the inclined layers is not currently supported by GV. Therefore, the most efficient way to discretize vertically was to create those layers in EV before importing the CSM into GV for construction of the MODFLOW-USG model.

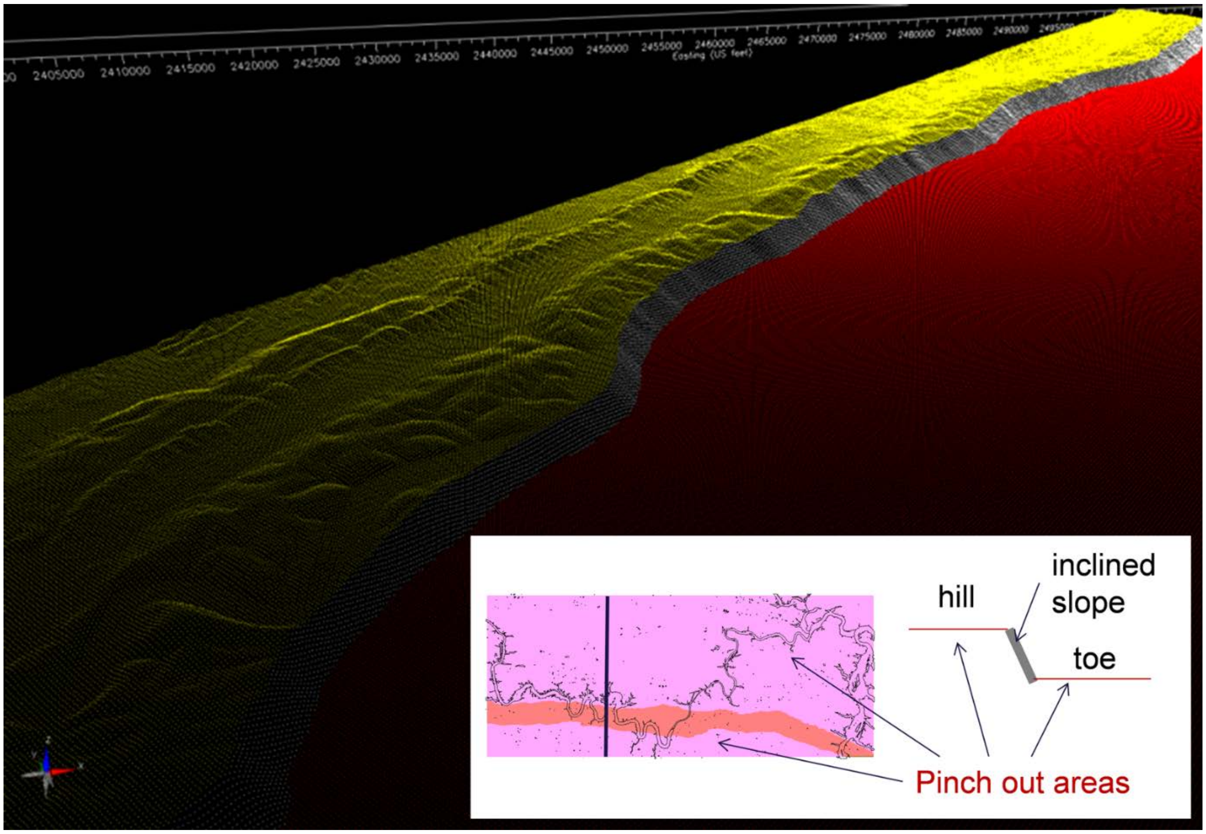

Fig. 6. Relationship of hill, slope, and toe surface in plan view (figure inset) and 3-D perspective.

Status of Construction of Numerical Model in GV/MODFLOW-USG

The surfaces used to construct the EV 3-D geologic model were exported to files that were directly imported into MODFLOW-USG in GV GUI. EarthVision® data were provided in 152.4 m x 30.48 m (500 ft × 100 ft) spacing for all geological formations, including the regolith and the weathered bedrock. Therefore, numerical model grid spacing was also designed at 152.4 m x 30.48 m (500 ft × 100 ft) so that each numerical cell has actual EV data imported and no data interpolation was necessary while developing the numerical geometric grids. The top two horizontal formations (regolith and weathered bedrock), the 34 continuous inclined formations, and 6 discontinuous formation in the vicinity of ETTP were assimilated into the numerical model. Each of the exported geologic grids consisted of 546 rows x 261 columns and was rotated clockwise so the XY axes were oriented in cardinal directions.

CSM ASSUMPTIONS AND DATA GAPS

Although much is understood about the CSM currently, assumptions had to be made to fill in current gaps in available information (see UCOR-4753 for additional discussion of assumptions). The modeling team identified several high-level assumptions for developing the ORR regional EV model which included the following:

- The surface geologic mapping performed by Lemiszki et al. (2012) provides the overall framework for interpreting the structure and configuration of geologic units in the region. This source was supplemented with pick data where available, but outside of the immediate DOE plan areas (ORNL, ETTP, and Y-12 Complex), there was a paucity of drilling information, and surface geologic contacts and dips were the primary resource for generation of the 3 D model. In addition, professional judgment and other map/report resources were employed to fill in/interpret the geology in areas which have not been mapped in detail (i.e., formations were carried along strike as a first recourse to provide a continuous model).
- Inconsistencies were observed between a small number of well picks and the corresponding surface geologic mapping obtained from the Lemiszki et al. (2012) geologic map. In these cases, picks either plotted on the wrong side of the corresponding surface geologic contact or had an elevation significantly inconsistent with the surface contacts and assumed dips associated with control points. Review of these picks indicated that a number of them had a high level of confidence, but others were considered to be suspect. Consequently, the surface geologic mapping may be locally inaccurate and was shifted to honor the geometry of the well picks. In cases where picks had a low level of confidence, those picks were eliminated.
- It was noted that the USGS digital elevation model did not match some of the ground surface elevations in the assembled well databases, primarily due to the resolution of the DEM. The decision was made to correct the DEM by warping the topographic surface to match the ground surface elevations associated with the well set. The topographic resolution of the DEM impacted the approach to development of the layers 1 and 2 in the CSM, which correspond to the regolith (sediment/soil) and weathered bedrock, respectively. The depths/elevations to these surfaces in boreholes often did not line up with the DEM from the standpoint of elevation, with boreholes either above or below the surface of the DEM. The surfaces developed for these two attributes were derived by subtracting 5.6 m (18.3 ft) and 10.6 m (34.8 ft) from the corrected topographic surface (USGS digital elevation model). Although this approach allowed for these two thin units to be generated within the CSM, this assumption caused challenges in meeting well targets during PEST calibration.
- Where well pick data was available control points were minimized and the EV gridding routines were allowed to utilize the well pick data.

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