Two- and Three-Dimensional Depiction of Subsurface Geology Using Commercial Software for Support of Groundwater Contaminant Fate and Transport Analysis – 13345

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ABSTRACT

Groundwater contamination by hexavalent chromium and other nuclear reactor operation-related contaminants has resulted in the need for groundwater remedial actions within the Hanford Site reactor areas (the Hanford Site 100 Area). The large geographic extent of the resultant contaminant plumes requires an extensive level of understanding of the aquifer structure, characteristics, and configuration to support assessment and design of remedial alternatives within the former 100-D, 100-H, and 100-K reactor areas. The authors have prepared two- and three-dimensional depictions of the key subsurface geologic structures at two Hanford Site reactor operable units (100-K and 100-D/H). These depictions, prepared using commercial-off-the-shelf (COTS) visualization software, provide a basis for expanding the understanding of groundwater contaminant migration pathways, including identification of geologically-defined preferential groundwater flow pathways. These identified preferential flow pathways support the conceptual site model and help explain both historical and current contaminant distribution and transport.

INTRODUCTION

Hanford Site nuclear reactors required a continuous supply of high-quality cooling water during operations. Cooling water consumption ranged from about 40,000 to 100,000 gallons per minute per reactor, depending on specific operating conditions (DOE/RL-2008-46, ADD1 and ADD2). The cooling water source was the Columbia River. Water from the Columbia River was filtered and treated chemically prior to use as cooling water, including addition of sodium dichromate as a corrosion inhibitor. The addition of sodium dichromate included both dry and liquid highly concentrated liquid stock solution.

Spills and leaks of water treatment chemicals, including sodium dichromate solution, particularly in the 100-D, 100-H, and 100-K areas, occurred in the water treatment and chemical storage areas of the reactors and from cooling water conveyance. The treated cooling water passed through the reactors in a single pass, and was released directly to the environment during operations. Large quantity discharges to the environment included contaminated cooling water releases to retention basins, cribs, and trenches. During upset conditions, such as fuel element failures, the cooling water was diverted from the regularly used retention basins to other disposal areas such as ditches or other engineered structures and allowed to infiltrate directly into the soil column. These practices resulted in extensive groundwater recharge mounds consisting primarily of contaminated cooling water and resulted in the wide distribution of contamination in the unconfined aquifer (HW-77170, BNWL-CC-1352). The current plume configurations result from both the behavior of the historic recharge mounds as well as groundwater movement since the cessation of cooling water discharges.

GEOLOGIC AND HYDROLOGIC SETTING

The primary stratigraphic units controlling groundwater flow in the unconfined aquifer in the 100-D, 100-H, and 100-K areas are, from shallowest to deepest:

- Hanford formation - a gravel-dominated deposit encountered at the ground surface and extending down to the vicinity of the current water table at 100-H,
- Ringold Formation unit E - a sand and gravel-dominated deposit that exhibits variable cementation and is the primary aquifer at 100-D and 100-K, and
- Ringold Formation upper mud (RUM) - a fine-textured silt-dominated deposit exhibiting very low hydraulic conductivity and effectively defining the bottom of the unconfined aquifer

On the west side of the study area, at 100-D and 100-K (Figure 1), the unconfined aquifer is primarily within the Ringold unit E, overlain by the Hanford formation. During historical reactor operations, the cooling water recharge mounds raised the water table above the top of the Ringold unit E and into the more hydraulically conductive Hanford formation, allowing rapid, widespread distribution of contamination. Across the Horn, the Hanford formation becomes the primary aquifer, with only pockets of Ringold unit E present. Along the east side of the study area at 100-H, Ringold unit E is absent and the unconfined aquifer is only present within Hanford formation (WHC-SD-EN-TI-132, WHC-SD-EN-TI-155, WHC-SD-ER-TI-003).

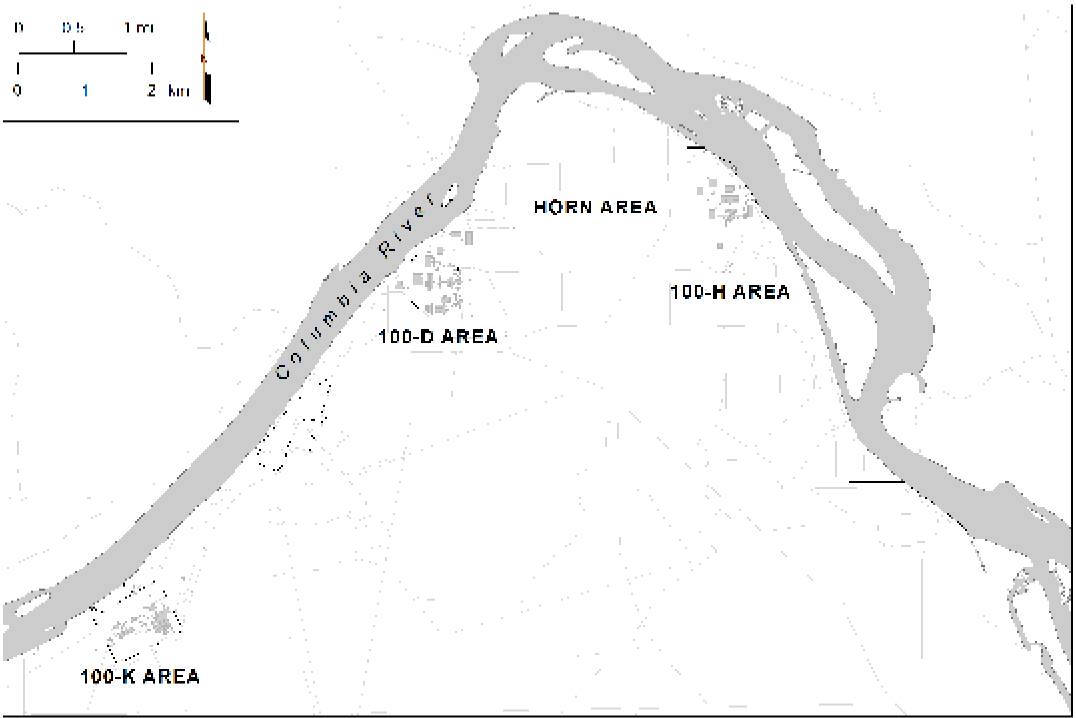

Figure 1: 100-K, 100-D, Horn and 100-H Areas

Interim steps taken to remediate the ground water contamination at 100-D/H and 100-K include the use of pump-and-treat technology, primarily due to the extent of hexavalent chromium in the aquifer. Groundwater monitoring wells and limited capacity pump-and-treat systems were installed. Initial well placement was based on the historical knowledge of the plume configuration, with the interim goal of protecting the Columbia River.

INVESTIGATION AND METHODS

Over the years, several hundred wells were installed in the vicinity of the Hanford reactor areas to define and monitor contaminant plumes (Table 1), as well as to provide groundwater extraction and injection points for installation and expansion of remedial systems. Many of the wells and boreholes were drilled to the RUM surface or just a few feet below the aquifer/RUM contact to define the thickness of the shallow unconfined aquifer unit, and both soil and water samples were collected during drilling, providing extensive information on the unconfined aquifer. Fewer wells have been drilled into the RUM to define the characteristics of the aquitard. Data collected from these wells was combined with existing information to develop a descriptive data set of geologic unit elevations and conditions.

Table 1 – Wells and Boreholes Drilled to the RUM by Time Period

Year	Wells Drilled to RUM
1943-1949	15
1950-1959	20
1960-1969	25
1970-1979	12
1980-1989	23
1990-1999	95
2000-2010	269

Utilizing the combined information collected over more than sixty years of subsurface investigation, the authors prepared a series of subsurface visualizations to describe the site conditions in support of the remedial action decision process. The first step in the process was a review of descriptive geologic logs for wells and boreholes completed across the Hanford Site River Corridor. Results of sieve analysis, geochemistry, and hydraulic property testing of the aquifer were evaluated along with changes in stratigraphy. A dataset of the geologic contact elevations between the key stratigraphic features was then compiled. The structure of the dataset was such that it could be used in a variety of COTS software for analysis and evaluation. The advantage of using COTS software lies in the ability to rapidly produce visualizations of subsurface conditions that can be used as interim and final interpretive work products to help define the nature and extent of contamination and select appropriate remedial actions where needed.

The evolution of understanding of subsurface conditions in the Hanford River Corridor with the increasing number of observations and descriptions of the site stratigraphy can be presented in the context of the level of detail that was possible only ten years ago versus the level achieved recently. As shown in Table 1, the basis of knowledge regarding the location of the RUM surface and other geologic characteristics, such as the presence of the Ringold unit E, was greatly expanded from 2000 through 2010.

An example of an early description of the potential for preferential groundwater flow pathways was developed in 2001 using the stratigraphic information available at the time. This information is summarized in the inferred surface contour map of the top of the RUM unit (Figure 2). The illustration was prepared in 2000 and 2001 and reflected the first identification of a preferential flow pathway associated with a paleochannel in the RUM surface that appeared to affect migration of the hexavalent chromium plume at 100-D. A depression in the RUM surface was identified that appeared to influence seasonal transients in groundwater flow vectors.

Figure 2 – Inferred Surface of the RUM at 100-D and Observed Azimuth Range of Groundwater Flow Vectors

An analysis of seasonal changes in groundwater flow vectors in the shallow unconfined aquifer at 100-D indicated that the groundwater flow exhibited substantially more variability inland (i.e., in the vicinity of the inferred channel in the RUM surface) than near the river shore.

A greatly-increased body of stratigraphic information has been developed over the intervening decade and the current body of information provides a technical basis for a much more extensive graphical analysis of the key subsurface features and inference of the effects of subsurface conditions on historical and current groundwater contaminant migration (Figure 3).

Figure 3 – Inferred Surface of the RUM at 100-D using Data Available Through 2010

Mapping, analysis, and display of the geology in the Hanford River Corridor and overlaying the contaminant plumes was performed using Surfer™ software (Golden Software) and ArcGIS™ (Environmental Systems Research Institute, Inc. [ESRI]) software. Two key geologic features were evaluated, the Ringold Unit E (the aquifer within the 100-K and 100-D areas), and the RUM surface which forms the base of the unconfined aquifer in the 100-D, 100-H, and 100-K Areas. To evaluate the Ringold unit E surface, groundwater contours were developed for the 100-K area using the geologic contacts dataset and standard contouring algorithms available in Surfer. A similar process was used to generate a surface of the RUM in the River Corridor since it was previously know the RUM surface is continuous within most of the River Corridor areas. In addition, three-dimensional surfaces of the RUM were generated using the ArcGIS 3D Analyst (ESRI) extension software, and displayed using ArcScene (ESRI).

Since it was previously known that the Ringold unit E is discontinuous within the 100-D, Horn, and 100-H Areas, the data was first plotted as a "dot-plot" using ArcGIS™ software which simply displayed locations where the Ringold Formation Unit E was present of absent. After these initial evaluations revealed that further analysis was needed to define the extent of the presence of the Ringold Formation Unit E, Surfer™ software was used. The generation of the presence/absence areas was an interactive process using Surfer.

The first step in the process was to remove wells within the dataset that were not drilled deep enough to encounter the Ringold unit E and/or the RUM surface in areas where the Ringold unit E is not present. Secondly, the Ringold unit E surface was contoured using standard Surfer contouring algorithms. However, given the nature of the data (presence and absence of an elevation over short distances), the results were unsatisfactory. In order to refine the analysis, the wells with a known Ringold unit E elevation were assigned a value of 1, and the borehole locations where the Ringold unit E was known to be absent were assigned a value of 0. The data were re-contoured and a value of 0.5 from the contour results was used to infer the boundary between the presence and absence of the Ringold unit E unit.

RESULTS

Until very recently, and based on available data, it was thought that the Ringold unit E truncated entirely just northeast of the 100-D Area. However, current analysis using the COTS software with the addition of recent geologic data collected in support of drilling of additional boreholes for expansion of interim remedial actions and CERCLA remedial investigations, revealed relatively large areas of Ringold unit E northwest of the 100-D area, within the Horn, and relatively small pockets in the 100-H area (SGW-48612). This new understanding of the area geology is directly and immediately relevant in optimization of the pump-and-treat remediation systems, by placing extraction and injection wells where existing preferential pathways for contaminant movement.

Within the 100-K and 100-D areas, the contact between the Hanford formation and the underlying Ringold unit E, generally resides within the vadose zone, and influences the vertical migration of contaminants. Between the 100-D and 100-H areas, within an area locally known as the Horn Area (Figure 1)of the Hanford Site, the aquifer transitions from the generally less permeable and more cemented Ringold unit E to the more permeable Hanford formation. One particular area of note is the absence of the Ringold unit E between two relatively large areas of remnant Ringold unit E within the Horn area just northeast of the 100-D Area (Figure 4), which is inferred to be a former Columbia River channel. Review and analysis of pre-Hanford aerial photographs, as well as light detection and ranging (LIDAR) data collected in 2008 (Figure 5) also indicated the potential presence of river channel in this vicinity. This channel area is of particular note because it is a preferential flow path for groundwater flow and contaminant transport within the unconfined aquifer from the 100-D Area across the Horn and into the 100-H Area. Figure 3 shows the presence and absence of Ringold unit E across the Horn, and the apparent effect on the contaminant migration in that area.

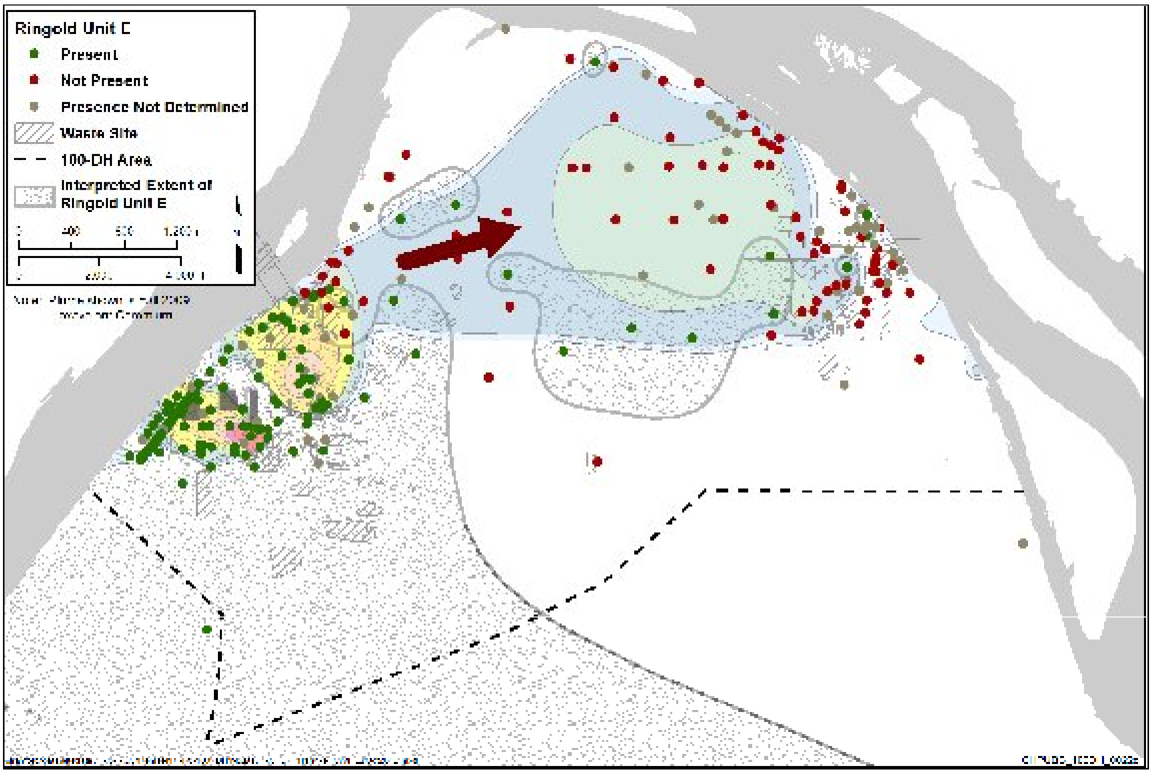

Figure 3 - Presence and Absence of the Ringold Unit E and the Relationship to Inferred Groundwater Contaminant Plumes

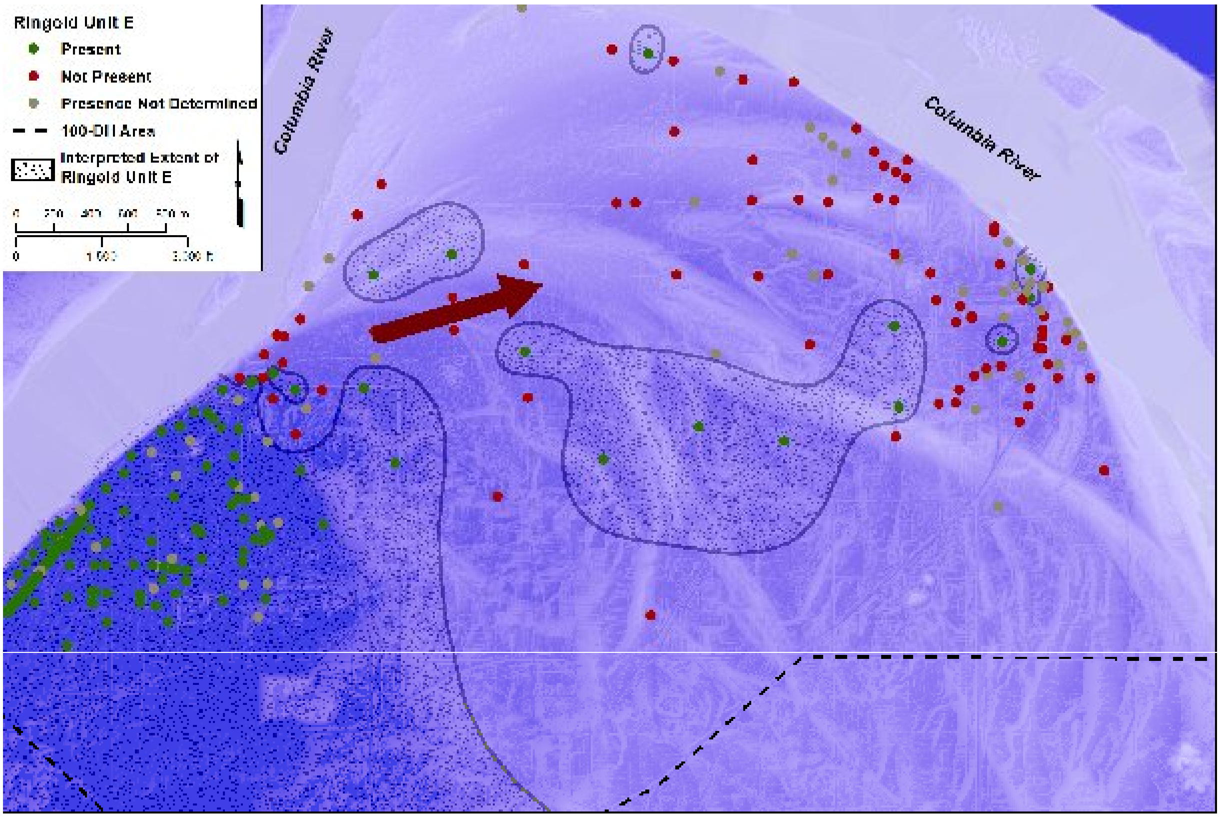

Figure 4 – Presence and Absence of the Ringold Unit E and the Relationship to Inferred Groundwater Contaminant Plumes overlain by 2008 Ground Return Lidar

The second primary geologic feature that influences groundwater flow and contaminant transport in the 100-D, 100-H, and 100-K areas is the RUM. The RUM forms the base of the unconfined aquifer, and differences in the RUM surface affect aquifer thickness and groundwater velocity. Key features identified during evaluation included localized undulation of the surface of the RUM (including likely historical river channels associated with the Columbia river). Low elevation areas of the RUM generally coincide with remnant or high concentration plume areas, or identify channels (preferential flow paths) for contaminant movement.

At 100-D, the RUM surface dips to the south, which is consistent with the inferred surface from 2001 (Figure 2). Recent information indicates that the surface curves to the south and then towards the Columbia River, moving the contaminant plume in that direction (Figure 4). Near the river at 100-H, contamination is most prevalent within the first water-bearing unit of the RUM. This zone coincides with depressions in the RUM surface (Figure 5).

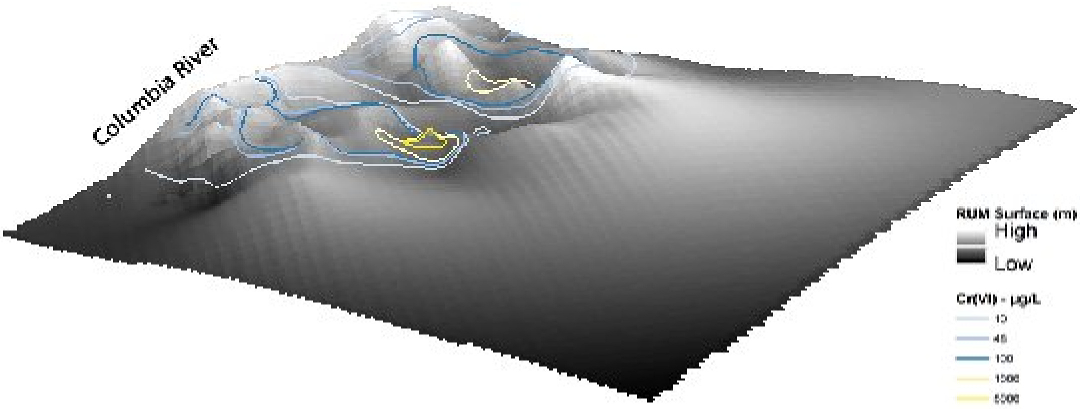

Figure 4 – Three Dimensional Depiction of the RUM Surface at 100-D with Hexavalent Chromium Plume

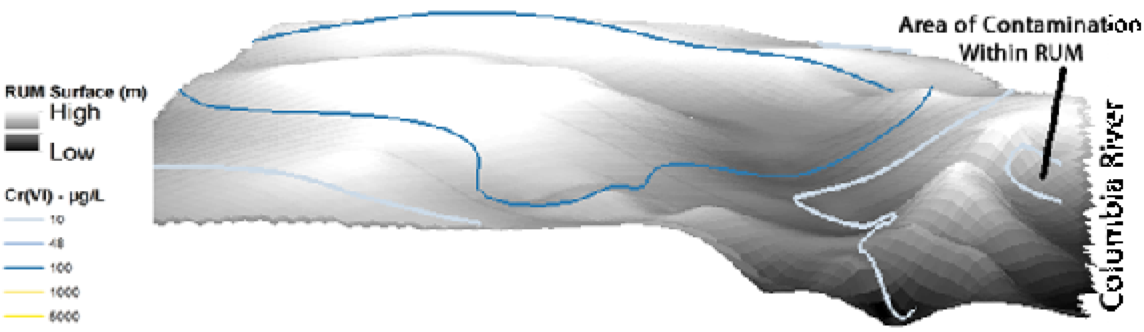

Figure 5 – Three Dimensional Depiction of the RUM Surface at 100-D with Hexavalent Chromium Plume

Using Surfer™ software, a wire frame diagram was used to evaluate how the ground surface, Ringold unit E, and RUM surfaces relate to each other. The inferred surfaces exhibit the effects of prehistoric river channel erosion; these effects evident in the sculpting of the surfaces and the presence of buried paleochannels. As shown in Figure 6 and 7, the RUM surface has considerably more relief than the Ringold unit E. Since groundwater flow across the Horn within the shallow unconfined aquifer is preferential in areas where the RUM surface has a depression and the Ringold unit E is absent, the groundwater (and associated contaminants) flow patterns are affected by the variations in aquifer hydraulic conductivity in those areas. These variations are then considered in remedy development. At 100-D, where the Ringold unit E is present in most areas, the depressions in the RUM surface appear to have more control on the contaminant flow patterns. Future pump-and-treat system refinements will consider these geologic formations carefully during well placement for system optimization.

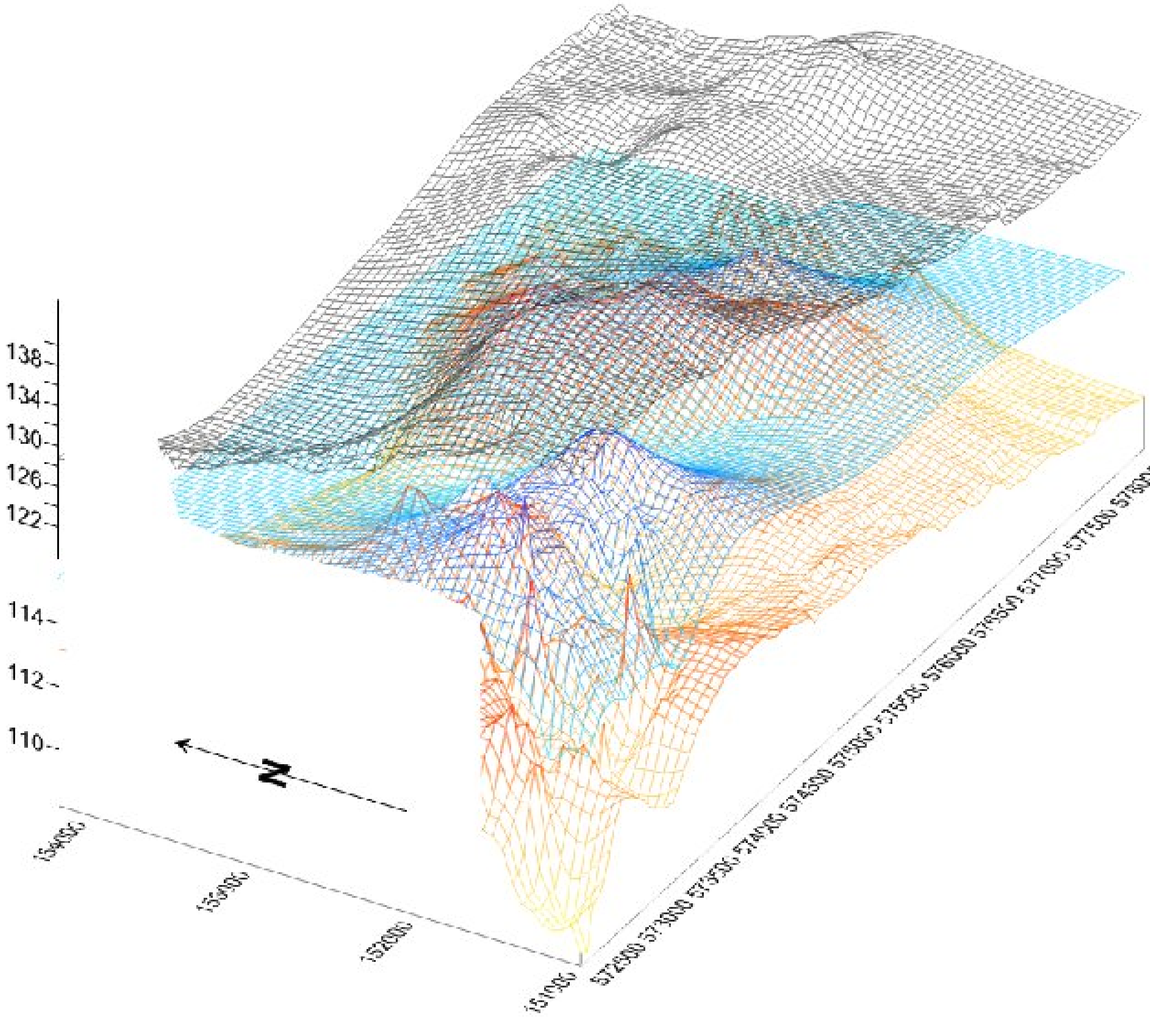

Figure 6 – Wire Frame Depiction of the RUM, Ringold unit E, and Ground Surface in the Vicinity of 100-D and 100-H Areas, Elevation to Scale.

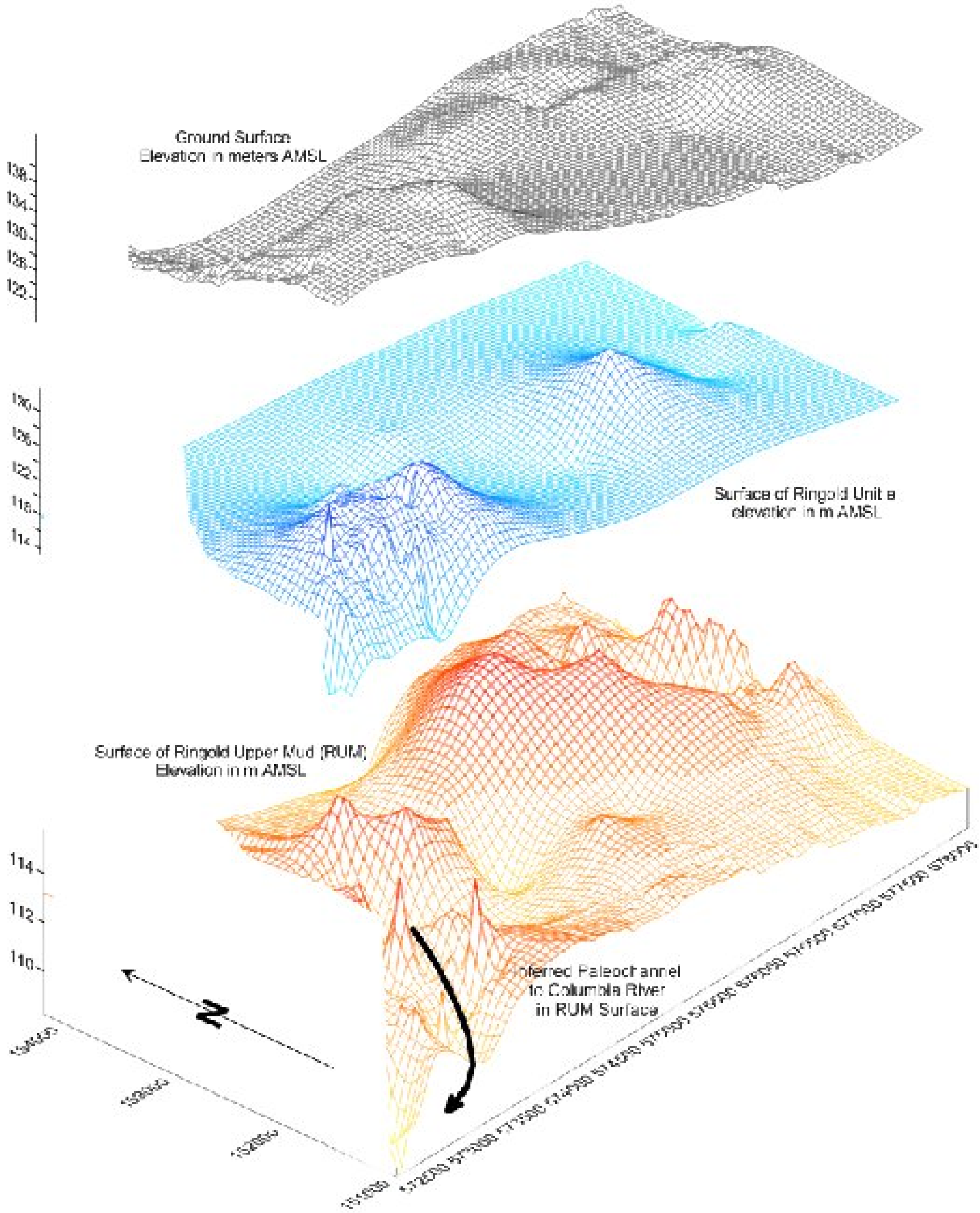

Figure 7 – Wire Frame Depiction of the RUM, Ringold unit E and Ground Surface in the Vicinity of 100-D and 100-H Areas, Elevation Scale Expanded.

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