State of Utah

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Department of
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DIVISION OF WASTE MANAGEMENT
AND RADIATION CONTROL
Ty L. Howard
Director

July 25, 2019

Vern C. Rogers, Director of Regulatory Affairs
EnergySolutions, LLC
299 Main Street, Suite 1700
Salt Lake City, UT 84111

RE: Depleted Uranium Performance Assessment (DUPA)
Clive Facility
Model Version 1.4 Amended Interrogatories
Radioactive Materials License #2300249

Dear Mr. Rogers:

The Division of Waste Management and Radiation Control has completed amended interrogatories of open issues regarding version 1.4 of the DUPA model for the Energy*Solutions*, Clive LLRW Disposal Facility, Utah LLRW Disposal license - Condition 35 (RML UT 2300249), pertaining to: EnergySolutions' response of April 3, 2018.

The interrogatories are enclosed. Based on Energy*Solutions* response to these interrogatories, the Division intends to move forward with a second version of the Safety Evaluation Report (SER).

If you have any questions, please call Helge Gabert or Don Verbica at (801) 536-0200.

Sincerely,

Helge Gabert, DU Project Manager
Division of Waste Management and Radiation Control

(Over)

DRC-2019-005281

HG/HG/ar

Enclosure: Status of Interrogatories; Clive DU PA Modeling Report Version 1.4 (DRC-2019-007029)

c: Jeff Coombs, EHS, Health Officer, Tooele County Health Department
Bryan Slade, Environmental Health Director, Tooele County Health Department

UTAH DEPARTMENT OF ENVIRONMENTAL QUALITY
ENERGY*SOLUTIONS* CLIVE LLRW DISPOSAL FACILITY
RML #UT 2300249

STATUS OF INTERROGATORIES

July 2019

Utah Department of Environmental Quality
195 North 1950 West
Salt Lake City, UT 84116

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1.0 INTRODUCTION

In April 2015, the Utah Department of Environmental Quality (DEQ)/SC&A issued a Safety Evaluation Report (SER) based on review of the Energy*Solutions* (ES) Clive depleted uranium performance assessment (DU PA) (DEQ 2015, hereafter the “2015 SER”). The safety analysis was based on versions 1.0 and 1.2 of the DU PA prepared by Energy*Solutions*/Neptune and Company (Neptune 2011, 2014a). Appendix C to the 2015 SER described the status of the 194 interrogatories (Rounds 1, 2, and 3) that had been provided to Energy*Solutions* for comment in 2013 and 2014. Appendix B to the 2015 SER contained 11 supplemental interrogatories related to the evapotranspiration (ET) cover design proposed by Energy*Solutions* for the Federal Cell at Clive. (In the initial DU PA, Energy*Solutions* had proposed a rock armor cover.) On November 25, 2015, Energy*Solutions* submitted Version 1.4 of the DU PA (ES 2015b; Neptune 2015a, hereafter “DU PA v1.4”). The revised performance assessment was designed to address concerns raised in the interrogatories cited above. On May 11, 2017, DEQ provided Energy*Solutions* with amended and new inquires related to DU PA v1.4 (DEQ 2017). The DEQ submittal also included additional comments on then-open prior interrogatories. Subsequently, on April 2, 2018, Energy*Solutions* submitted responses to DEQ interrogatories raised regarding Version 1.4 of the DU PA (ES 2018b).

Section 2 of this report discusses interrogatories (from the group 1–194) that were included in the April 2015 SER (DEQ 2015) and that remained unresolved as of May 2017.[1] Section 3 discusses interrogatories (195–205) that were made on DU PA v1.4 (DEQ 2017). Two additional interrogatories (206 and 207) related to temporal uncertainty and geotechnical issues have been added to Section 3 in this update. Section 4 discusses the status of the supplemental interrogatories related to the ET cover performance.

To issue a license, the Director must find that there is reasonable assurance that the DU PA demonstrates that performance objectives will be met if Energy*Solutions* disposes of the proposed volume and concentration of DU at the Clive facility. The ensuing interrogatories and related discussion are all based on the extent to which the DU PA provides reasonable assurance that the performance objectives will be met.

Table 1 summarizes the current status of interrogatories as of July 2019. The column “Status – May 2017” refers to the review provided in DEQ 2017. The column “Neptune Report” refers to analyses provided by Energy*Solutions*/Neptune in Energy*Solutions* 2018a.

[1] Interrogatories 8 and 51 were closed by May 2017 but are included in this report to add supplemental information to the analyses (see Sections 2.2.1 and 2.2.2).

Table 1. Status of Interrogatories

Interrogatory	Status – May 2017	Description	Neptune Report	Current Status – July 2019	Comments
5	Open	Radon Barrier	NAC-0106_R0	Open	—
8	Closed	Groundwater Concentration Endpoints	NAC-0103_R0	Closed	—
10	Open	Effect of Biologicals on Radionuclide Transport	NAC-0106_R0	Open; see comments	Same topics are covered in Interrogatory 28/3 and Supp. Int. 2 and 3, which remain open.
18	Open	Sediment Accumulation	NAC-0105_R0	Open	
20	Open	Groundwater Concentrations	NAC-0106_R0	Open	—
21	Open	Infiltration Rates	NAC-0106_R0	Open	—
28	Open	Bioturbation Effects and Consequences	NAC-0106_R0	Open; see comments	Same topics are covered in Interrogatories 20/2 & 71/1 and Supp. Int. 2, which remain open.
51	Closed	Nature of Contamination	NAC-0103_R0	Closed	—
59	Open	Bathtub Effect	NAC-0106_R0	Closed	Closed based on comparison of percolation rates versus the permeability of rate of flow through the clay liner.
60	Open	Modeled Radon Barriers	—	Open; see comments	Same topics are covered in Interrogatories 5/2 and 21/2 and Supp. Int. 2, which remain open.
70	Open	Gully Screening Model	—	Closed	—
71	Open	Biotic Processes in Gully Formation	NAC-0108_R0	Open	—
81	Open	Comparison of Disposal Cell Designs	NAC-0101_R0	Open	—
84	Open	Below-Grade Disposal of DU	NAC-0101_R0	Closed	A license condition will ensure that this objective is achieved.
90	Open	Calibration of Infiltration Rates	NAC-0106_R0	Open; see comments	Same topics are covered in Interrogatory 5/2 and Supp. Int. 2, which remain open.

Interrogatory	Status – May 2017	Description	Neptune Report	Current Status – July 2019	Comments
100	Open	Groundwater Recharge from Precipitation	—	Open; see comments	Same topics are covered in Supp. Int. 2 and 5, which remain open.
108	Open	Biointrusion	—	Open; see comments	Same topics are covered in Supp. In. 2, which remains open.
112	Open	Hydraulic Conductivity	—	Open; see comments	Same topics are covered in Supp. Int. 1–3, 5, and 7–9, which remain open.
132	Open	Sedimentation Model	—	Open; see comments	Same topics are covered in Interrogatory 18, which remains open.
150	Open	Plant Growth and Cover Performance	NAC-0106_R0	Open; see comments	Same topics are covered in Supp. Int. 2, which remains open.
153	Open	Impact of Pedogenic Process on the Radon Barrier	NAC-0106_R0	Open; see comments	Same topics are covered in Supp. Int. 2, which remains open.
160	Open	Comparison of Class A West and Federal Cell Designs	NAC-0101_R0	Open; see comments	Same topics are covered in Interrogatory 81, which remains open.
162	Open	Disposal Cell Stability	NAC-0101_R0	Open; see comments	Same issues are raised in Interrogatories 25 and 81, which remain open
175	Open	Infiltration Rates for the Federal Cell Versus the Class A West Cell	NAC-0106_R0	Open; see comments	Same topics are covered in Interrogatory 05/2 and Supp. Int. 1–3, 5, and 7–9, which remain open.
176	Open	Representative Hydraulic Conductivity Rates	NAC-0106_R0	Open	—
189	Open	Modeling Impacts of Changes in Federal Cell Cover-System Soil Hydraulic Conductivity and Alpha Values	NAC-0106_R0	Open; see comments	Same topics are covered in Interrogatory 05/2, which remains open.
191	Open	Effect of Gully Erosion	NAC-0108_R0	Open	—

Interrogatory	Status – May 2017	Description	Neptune Report	Current Status – July 2019	Comments
192	Open	Implications of Great Salt Lake Freezing on Federal Cell Performance	NAC-0106_R0	Open; see comments	Same topics are covered in Interrogatory 05/2, which remains open.
195	Open	Aquifer Characterization	NAC-0104_R0	Open	—
196	Open	Non-DU Waste Characteristics	NAC-0102_R0	Open	—
197	Open	Properties of Embankment Side Slope Materials	NAC-0108_R0	Open	—
198	Open	Gravel Content of Embankment Materials	NAC-0108_R0	Open	—
199	Open	Uncertainties in Erosion Modeling	NAC-0108_R0	Open	—
200	Open	Use of RHEM to Develop Parameters for SIBERIA	NAC-0108_R0	Open	—
201	Open	Estimating Rainfall Intensity	NAC-0108_R0	Open	—
202	Open	Use of SIBERIA to Model Federal Cell Erosion	NAC-0108_R0	Open	—
203	Open	Inclusion of Other Wastes in PA	NAC-0102_R0	Closed	—
204	Open	Exposure to Groundwater	NAC-0104_R0	Closed	ES/N provided a GWPL calculation to 10,000 years.
205	Open	Erosion Analysis	NAC-0108_R0	Closed	DEQ/SC&A determined the reason for FractionGully's behavior.
206	New	Temporal Uncertainty in Performance Assessment	None	Open	—
207	New	Stability of Disposal Site	None	Open	—
Sup Int. 1	Open	Adequate Characterization of Parameter Uncertainty	NAC-0106_R0	Open	—
Sup Int. 2	Open	Bounding of Parameter Distributions	NAC-0106_R0	Open	—
Sup Int. 3	Open	Insensitivity to K_{sat} and Lack of Water Balance Information	NAC-0106_R0	Open	—
Sup Int. 4	Open	Justification for Rosetta Database	NAC-0106_R0	Open; see comments	Same topics are covered in Supp. Int. 2, which remains open.
Sup Int. 5	Open	Surface Boundary Conditions and Applicability of Linear Model	NAC-0106_R0	Open	—
Sup Int. 6	Open	HYDRUS Infiltration Results	NAC-0106_R0	Open	—
Sup Int. 7	Open	HYDRUS and GoldSim Infiltration Rate Output	NAC-0106_R0	Open	—
Sup Int. 8	Open	Underrepresentation of the Tails of the Distributions and Daily Water Balance Graphs	NAC-0106_R0	Open	—
Sup Int. 9	Open	Volumetric Water Content	NAC-0106_R0	Open	—

Interrogatory	Status – May 2017	Description	Neptune Report	Current Status – July 2019	Comments
Sup Int. 11	Open	Use of Naturalized Parameters	NAC-0106_R0	Open; see comments	Similar concerns raised in Supp. Int. 2 and 8, which remain open.

For those 28 of the original 194 interrogatories listed as "open" in Appendix C of the 2015 SER, the discussion format used here is generally as follows:

- DEQ Conclusion from 2015 SER Appendix C (DEQ 2015, Volume 2)
- DEQ Critique of DU PA v1.4, Appendix (x) (DEQ 2017)
- DEQ Critique of DU PA v.14, Appendix 21 (DEQ 2017)
- DEQ Discussion of NAC-01xx_R0 – July 2019

For the original interrogatories, the first three sections listed above present the historical evolution of DEQ's position on the interrogatory as given in DEQ 2015 and DEQ 2017, based on inputs from Energy*Solutions*/Neptune at that time. The fourth bullet summarizes DEQ's current position in this report, based on Energy*Solutions*/Neptune's 2018 analyses (ES 2018a). The historical information is shown in a grayed font to distinguish it from the current DEQ position on an interrogatory.

In some cases, the format may vary depending on the information available.

For the DU PA v1.4 interrogatories (195–205 plus 206 and 207), the discussion format is as follows:

- Preliminary Finding
- Interrogatory Statement
- Basis for Interrogatory.
- DEQ Discussion of NAC-01xx_R0 – July 2019

It is important to note that some interrogatories listed as "closed" might need to be reopened, depending on resolution of currently open interrogatories. For example, if infiltration rate questions are resolved in a manner that results in higher infiltration rates, then groundwater exposure modeling would need to be redone. Also, DEQ expects that the resolution of some of the interrogatories will necessitate the revision of the DU PA model, a re-running of GoldSim, and a revision of the Clive DU PA Model Final Report and its appendices. For example, DEQ has identified logic bugs in the Deep Time GoldSim model (Interrogatory 18), and changes to the ET cover modeling could affect infiltration and the groundwater protection level (GWPL) calculations (multiple interrogatories, including Supplemental Interrogatory Comment 2). Finally, in order to take credit for some of the Energy*Solutions*/Neptune interrogatory responses that appear in DU PA v1.4, Appendix 21, those responses would need to be incorporated into the main portion of the DU PA. If Energy*Solutions*/Neptune desires to include alternative analyses that are not responsive to the interrogatories, they should be placed in an appendix.

2.0 PREVIOUS OPEN INTERROGATORIES

During the review of the versions 1.0 and 1.2 of the DU PA, 194 interrogatories were developed. Appendix C to the 2015 SER indicated that 165 of those interrogatories were considered to be closed. Relevant information regarding each of the 29 open interrogatories that was provided in Appendix C to the 2015 SER is included in this section of the report. Interrogatories 08 and 51 have been included in this list because their closure is contingent upon a license condition that, under certain eventualities, disposal of recycled uranium is not allowed in the DU waste. For each interrogatory, the discussion below includes DEQ's conclusion based on the information presented in the 2015 SER and DU PA v1.2 (headed "DEQ Conclusion from April 2015 SER, Appendix C"), plus updates to that discussion based on DU PA v1.4 (headed "DEQ Critique of DU PA v1.4") and/or Appendix 21 to DU PA v1.4 (headed "DEQ Critique of DU PA v1.4, Appendix 21"). Subsequently, Energy*Solutions*/Neptune provided additional input on open interrogatories in *RML UT2300249 – Condition 35.B: Responses to Interrogatories Raised with Version 1.4 of the Depleted Uranium Performance Assessment* (ES 2018a, which includes NAC-0101 through NAC-0108 (Neptune 2018a–2018g)). DEQ's July 2019 analysis and discussion of these responses are included for each interrogatory under the heading "*DEQ Discussion of NAC-0101* [or similar headings] – *July 2019*."

Discussion of the supplemental interrogatories pertaining to the ET cover is included in Section 4.

2.1 Open Interrogatories as of July 2019

2.1.1 Interrogatory CR R313-25-7(2)-05/2: Radon Barrier

DEQ Conclusion from April 2015 SER, Appendix C

Based on several unresolved issues related to the ET cover, DEQ indicated in the 2015 DU PA SER that the cover design was deficient. Therefore, this interrogatory remains open. The unresolved issues are as follows:

Evapotranspiration Cover – There are still a number of unresolved issues with respect to the selection of parameter ranges, distributions, and correlations, as well as the modeling approach and predicted sensitivities. These concerns are detailed in Appendix B.[2] Further, because the model-predicted infiltration rates will be sensitive to the hydraulic properties assigned to each ET layer, DEQ recommends that Energy*Solutions* develop hydraulic properties for the cover system based on the approach outlined by Dr. Craig H. Benson in Appendix F to the 2015 SER. Issues related to this portion of the performance assessment cannot be closed until these concerns have been resolved.

Clay Liner – As with the ET cover, there is still an unresolved concern that saturated hydraulic conductivity (K_{sat}) values will increase greatly over time, and that the van Genuchten's alpha (α) and K_{sat} values assumed for modeling flow through the liner must either be correlated or a sensitivity analysis be conducted to demonstrate that the lack of correlation assumed does not adversely affect the modeling results. In addition, there are problems with assumed liner hydraulic conductivity values. Furthermore, DU PA v1.2 does not account for liner degradation

[2] All references in prior interrogatories to Appendices of "the SER" refer to the April 2015 SER (DEQ 2015).

over time. These issues must be resolved before DEQ can determine the adequacy of this portion of the DU PA.

Infiltration – Before the adequacy of the DU PA can be determined, additional modeling of the ET cover infiltration rates must be conducted based on in-service hydraulic properties and correlated log(α) and log(K_{sat}) values as described in Appendix E to the 2015 SER. Without this information, DEQ is unable to conclude if the infiltration rates predicted by the DU GoldSim model are reliable or representative of future conditions (i.e., ≥ 10,000 years).

Erosion of Cover – Before the adequacy of the DU PA can be determined, Energy*Solutions* needs to clarify certain issues relating to Appendix 10 to the DU PA Model v1.2 (June 5, 2014; Neptune 2014c) as described in Section 4.4.2 of the 2015 SER. The Division of Waste Management and Radiation Control (DWMRC) is currently reviewing a proposed ET cover test request as part of a Stipulation and Consent Agreement to use a cover of similar design to that proposed for the Federal Cell in the DU PA. Any recommendations and conclusions from that review will need to be applied to the proposed Federal Cell as well.

Effect of Biologicals on Radionuclide Transport – Energy*Solutions* has not shown that the cover system is sufficiently thick or designed with adequate materials to protect the cover system or the underlying bulk waste in the embankments against deep rooting by indigenous greasewood (a species known to penetrate soils at other sites down to 60 feet) or other plants, or against biointrusion by indigenous ants or mammals (e.g., with maximum documented burrowing depths greater than the proposed cover thickness). Higher rates of infiltration are typically associated with higher contaminant transport rates. Under Utah rules, infiltration should be minimized (see Utah Administrative Code (UAC) Rule R313-25-25(3) and (4)). DEQ cannot determine the adequacy of the DU PA until Energy*Solutions* accounts for greater infiltration through the cover system at the proposed Federal Cell embankment due to biointrusion by plant roots and by animals.

Frost Damage – With the current proposed Federal Cell design, Energy*Solutions* should account in modeling for substantial disruption of near-surface layers above and within the radon barriers by frost, with accompanying decreases in ET and increases for initially low-permeability soil in both hydraulic conductivity and correlated α values, which could affect modeled infiltration rates and radon release rates. UAC R313-25-25(3) and (4) require a licensee to minimize infiltration; therefore, Energy*Solutions* must calculate frost depths and model infiltration under realistic long-term assumed site conditions before DEQ can determine that this requirement has been met.

DEQ Critique of DU PA v1.4, Appendix 5 and Appendix 21

Evapotranspiration Cover – See Interrogatories 21, 175, 176, 189 for discussion of assumed ET properties affecting predicted infiltration rates.

Clay Liner – Modeling conducted for the clay liner beneath the waste should employ hydraulic parameters representative of a compacted clay liner. Typical α, *n*, and Θ_s for compacted clays can be found in Tinjum et al. (1997). Typical saturated hydraulic conductivities for clay liners can be found in Benson et al. (1994).

Infiltration – See Interrogatories 21, 175, 176, and 189 for discussion of the relationship between infiltration and the in-service hydraulic properties.

Erosion of Cover – See Interrogatories 20, 28, 160, and 191 for discussion of cover erosion.

Effect of Biologicals on Radionuclide Transport – See Interrogatories 10, 20, 28, and 71 for discussion of enhanced transport due to biological processes.

Frost Damage – See Interrogatory 192 for discussion of depth of potential frost impacts.

DEQ Discussion of NAC-0106_R0 – July 2019

Evapotranspiration Cover – As discussed in greater detail in Supplementary Interrogatory Comment 2, Energy*Solutions*/Neptune predicted the infiltration through the cover with the computer code HYDRUS utilizing two conceptual models. One conceptual model assumes that the ET cover consists of five layers with distinct properties and functions (i.e., surface layer, evaporative layer, frost protection layer, and two radon barrier layers). The parameter ranges assigned to each of these layers, however, do not fall within the ranges of naturalized parameters recommended in NUREG/CR-7028 (Benson et al. 2011). In the second conceptualization, all five of the ET cover layers are combined into a single model layer. The ranges of the hydraulic properties for this single layer model are within the ranges recommended in NUREG/CR-7028. In our interrogatory discussions, these conceptual models are referred to as the non-naturalized and naturalized models, respectively.

In their responses to interrogatories (NAC-0106_R0, Neptune 2018f), Energy*Solutions*/Neptune do not provide the HYDRUS abstraction into GoldSim, nor do they present a comparison of the HYDRUS predictions against GoldSim results for the naturalized model.

Most of the issues addressed in the responses to Interrogatory 05/2 are associated with the efficacy of the method used to predict percolation from the base of the cover. These concerns fall into three categories:

1. Energy*Solutions*/Neptune assert that the Clive, Utah site is unique relative to all other sites in the region without sufficient justification, and therefore ignore the relevance of the evolution of soil structure and hydraulic properties in the cover profile.
2. Inadequate justification for the soil hydraulic parameters used in the non-naturalized HYDRUS model, including relevance to site-specific conditions and the absence of appropriate temporal and spatial scaling to account for evolution of the soil properties and spatial variability. Similarly, justification has not been provided regarding use of a series of 10 sequential back-to-back runs of the same 100-year record to represent a 1,000-year meteorological record.
3. Inadequate demonstration that either of the HYDRUS models, as employed in this performance assessment, provides a reasonable representation of the hydrology of the cover system without documentation consistent with standards of care associated with hydrological modeling of water balance covers.

Each of these concerns is described in greater detail in the discussions of Energy*Solutions*/Neptune's responses to the interrogatories listed above in NAC-0106_R0, and this report's discussion of this interrogatories in subsection "DEQ Critique of DUPA v1.4, Appendix 5 and Appendix 21."

The primary issue with Energy*Solutions*/Neptune's position regarding naturalization is that they have not characterized the soil properties from near-surface layers that have undergone weathering and pedogenesis. They have excavated test pits and examined profiles but for their non-naturalized HYDRUS modeling rely heavily on (1) old data from Bingham Environmental for the radon barrier and (2) Rosetta properties for overlying layers, neither of which is relevant to designing and evaluating an engineered cover because studies show that hydraulic soil properties change over time.

Energy*Solutions*/Neptune were in the field doing characterization ca. 2014 (per Neptune 2015k) but elected not to collect appropriate-size undisturbed samples for evaluating field-scale naturalized hydraulic properties. They also did not conduct a geomorphological study to characterize structure in the soil profile. There are standard practices for geotechnical and geomorphological techniques to conduct such investigations and evaluations, and yet they have chosen not to use them. Dr. Benson (SC&A) is currently using these techniques, many of which have been developed over the past two decades under the support of the U.S. Nuclear Regulatory Commission (NRC) and U.S. Department of Energy (DOE), for a study for the NRC evaluating the in-service hydraulic properties of radon barriers. This study is showing consistently that the hydraulic properties of all radon barriers evolve over time in response to pedogenesis, and that the hydraulic properties in the field are consistent with those recommended in NUREG/CR-7028. The NRC study has included analog evaluations to evaluate probable long-term scenarios. These analogs have consistently shown clearly pedogenic development in *all* environments, and the hydraulic properties of analogs are consistent (and at the upper end) of the ranges recommended in NUREG CR-7028 (Benson et al. 2011). Dr. Benson is currently working on a NUREG document summarizing some of the current data from this NRC project that was presented at an NRC workshop on radon barriers and at the DOE-Legacy Management (LM) Long-Term Stewardship conference in Summer 2018. A full NUREG on the current NRC study is expected to be available at the end of 2019 or early 2020.

Despite the NRC studies, Energy*Solutions*/Neptune strongly contend that the data from the obsolete Bingham Environmental report (1991) and Rosetta database are representative. Strong statements are made that no substantive change in methodologies to characterize and measure hydraulic properties have occurred since the Bingham Environmental study in 1991 (e.g., "there has been little change to the standard methods used to determine saturated hydraulic conductivity, volumetric water content, and water retention relations," NAC-0106_R0, p. 52, Neptune 2018f). The ASTM International standard methods used for these techniques, however, have undergone extensive revisions since 1991 (ASTM D5084, D7015) or were developed after 1991 (D6836). The data for the water retention curves in the Bingham Environmental study also exhibit the class attributes of inattention to equilibrium states (Gee et al. 2002), knowledge that was developed from vadose zone research conducted for DOE to support cover assessments. The dewpoint methodology to characterize the dry end of the water retention curve (Method D, ASTM D6836) has been developed since 1991 based on research published by Jones et al. (1990), as has appropriate parameterization of the pore interaction term in the van Genuchten-Mualem expression to characterize unsaturated hydraulic conductivity (Schaap and Leij 2000). The issues of scale have also received extensive attention in the literature since 1991 (e.g., Benson et al. 1994; Benson et al. 1999) and are clearly described in Section 6 of NUREG/CR-7028. Therefore the obsolete nature of the data contained in the Bingham Environmental report has clearly been stated, and continued utilization of these data is affecting DEQ/SC&A's ability to establish a defensible technical basis for relevant Federal Cell design where supporting technical analyses have relied on Bingham Environmental data.

There is no scientific rationale to indicate that the geological and depositional environments at Clive are so unique that the cover at this site is immune to pedogenic development and evolution of hydraulic properties that have been observed in all geological and climatological environments in North America, including sites in proximity to Clive (Grand Junction, Colorado; Monticello, Utah; Blanding, Utah) where eolian processes are significant. Energy*Solutions*/Neptune's apparent lack of understanding of the evolution of technological change in vadose zone hydrology, particularly for cover design and assessment, leads to significant shortcomings in confidence regarding the broader assessment of hydrological processes in the performance assessment.

Clay Liner – The methods that Energy*Solutions*/Neptune have used to evaluate this issue are sufficient. The liners would be below ground in a humid and high-stress environment, in which ideal conditions to maintain barrier integrity exist. The National Research Council study conducted about a decade ago on waste containment systems is consistent with this position and indicates that liners that are properly constructed continue to function well (National Research Council 2007). Furthermore, over the long term, the cover properties would control the flux through the system and the properties of the liner would become inconsequential. This is a well-established principle in waste containment systems.

Infiltration – Two concerns regarding infiltration were raised in this interrogatory, including the appropriate evolutionary assumptions for cover properties and the selection of soil hydraulic properties. Both of these aspects of infiltration are discussed below:

Appropriate Evolutionary Assumptions for Cover Properties. Energy*Solutions*/Neptune have not adequately modeled site-specific soil parameters because they have not accounted for any long-term changes in soil properties over time, including during the compliance period. Energy*Solutions*/Neptune contend that the soil properties at the Clive site will not evolve as has been observed at sites around the nation and globally and attribute this resistance to evolution to a unique eolian depositional environment at the Clive site. No direct scientific evidence is provided to support these assumptions. Energy*Solutions*/Neptune indicate that scientific documentation in this regard is included in the *Safety Evaluation Report Response* (Neptune 2015j, NAC-0053_R0). However, the documentation is inconsistent with the standard of care associated with documenting structural development and evolution of soil properties.

The documentation in the *Safety Evaluation Report Response* (Neptune 2015j, NAC-0053_R0) consists of a photograph of a wall of a test pit in the near-surface soils at the site assumed to represent the long-term condition. The surface used for documentation appears to have been exposed using an excavator bucket. A photograph of the surface is provided as documentation. No surface preparation appears to have been conducted, no geomorphological measurements were reported, and no representative undisturbed samples were collected for analysis of hydrologic properties. The photograph was taken at a distance too far from the face of the pit to provide any clear documentation of soil structure. No conclusions regarding changes in soil properties may be derived without geomorphological measurements that meet acceptable industry standard methods.

The NRC and DOE have commissioned a study to evaluate the development of soil structure and the evolution of soil properties in covers over low-level radioactive waste (LLRW) and uranium-tailings disposal facilities, with particular emphasis on understanding the evolution of radon barriers (e.g., Benson et al. 2017). Four covers over uranium tailings in service for approximately 20–30 years have been exhumed and their structure studied in detail. Detailed measurements of hydrologic properties and radon fluxes are being made at each site. Data from these projects have been presented at two recent forums: the NRC "Radon Barriers Workshop" held in Washington, DC on July 25–26, 2018 (NRC n.d.), and the DOE "Long-Term Stewardship Conference" held in Grand Junction, Colorado on August 20–23, 2018 (DOE 2018). At both of these meetings, presentations were made regarding how structure develops in final covers, and how the hydraulic properties evolve as the structure develops. The presentations illustrated how geomorphological techniques are used to map and quantify the structure and how geotechnical procedures are used to collect appropriate-size undisturbed samples for hydrological analysis. Geomorphological evaluations and geotechnical sampling were conducted at natural analogs near each site to provide an estimate of the anticipated long-term condition for each cover.

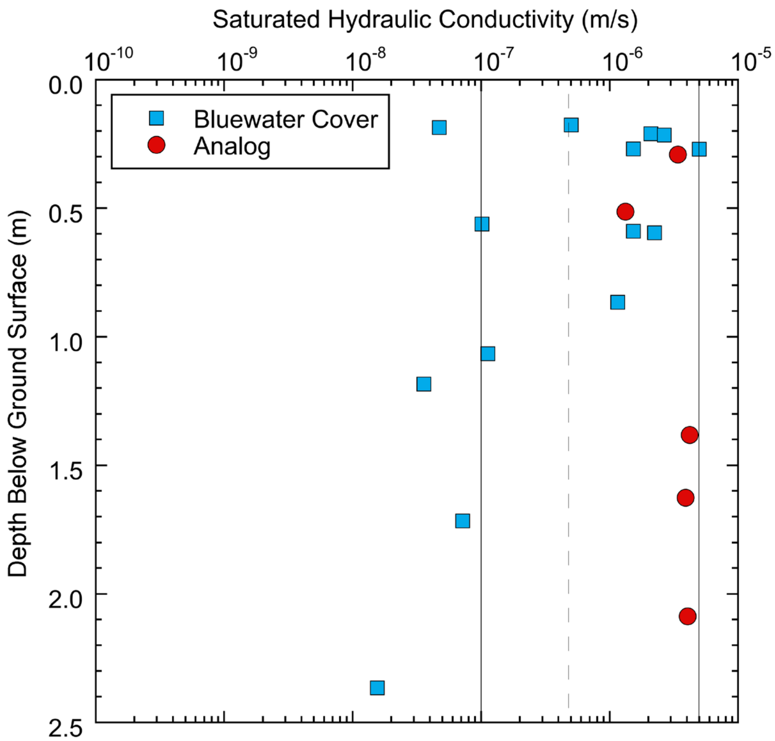
Extensive structural development was documented in each cover that was exhumed. The structure resembled that observed in adjacent analog sites assumed to represent the long-term state. These changes in structure are attributed to volume change in the cover soils induced by changes in stress incurred as the soil underwent wetting and drying, and in some cases underwent freezing and thawing. Structural evolution was also attributed to intrusion of biota. Geochemical and biotic processes with the larger pore networks formed by structural development have exacerbated the changes to the soil structure. Hydrologic properties of the cover soils at each site have evolved concomitantly with the structural development and are on trajectory to be similar to the hydraulic properties observed at the analog sites. The changes in hydraulic properties have been related directly to structural features in the cover profile. The hydraulic properties of the cover soils have been found to be consistent with the recommendations in NUREG/CR-7028 (Benson et al. 2011). For the analog sites, the hydraulic properties have been near the upper bound of the range recommended in NUREG/CR-7028.

The graph in Figure 1 provides an example of the hydraulic properties in the final cover at the Bluewater, New Mexico disposal site examined in the NRC-DOE study (NRC n.d.). Of the sites in the study, Bluewater is physically closest to the Clive site. Most of the samples collected from the cover profile have saturated hydraulic conductivity within the range recommended in NUREG/CR-7028, and the saturated hydraulic conductivity of samples from the analog site is at the upper end of the recommended range.

The techniques used in the NUREG/CR-7028 and in the more recent NRC-DOE study are ASTM International standard methods employed by industry to characterize the hydraulic properties of soils used as input to hydrological models employed to predict the hydrology of water balance covers. Many of these same principles and methods were used in the modeling and performance assessment for the water balance cover at the White Mesa mill in White Mesa, Utah, approximately 380 miles south east of Clive.

Industry-standardized techniques like these should be employed by Energy*Solutions*/Neptune to characterize the hydraulic properties for the modeling. They are much more appropriate than hydraulic properties extracted from a historic database populated with data that have little relevance to the Clive site, many of which were measured with techniques known to be problematic. They are also more appropriate than hydraulic properties reported 28 years ago based on tests conducted on small samples collected and measured using antiquated techniques.

Although the naturalized HYDRUS modeling uses the parameter ranges recommended in NUREG/CR-7028, the lumping of all 5 ET layers into a single model layer has not been adequately justified. Therefore, this aspect of the interrogatory remains open. (See also Section 4.1.2).



Source: NRC n.d.

Figure 1. Saturated hydraulic conductivity vs. depth for the final cover over the uranium mill tailings disposal area near Bluewater, New Mexico and for the adjacent analog site.

Soil Hydrologic Properties. When selecting the input parameters for the unsaturated flow model (HYDRUS), the relevant question to address is: "Does the distribution used for each input parameter represent plausible and realistic values and distributions so that the percolation rate predicted by the flow model represents the range of plausible percolation rates into the waste with appropriate probabilities of occurrence?"

Energy*Solutions*/Neptune have proffered that this question can be addressed for the non-naturalized HYDRUS model by using data for a specific textural class in the Rosetta database, and the standard error computed from a variance in the data set in the database. Energy*Solutions*/Neptune describe this process as spatial and temporal averaging but do not provide supporting information confirming that this approach provides distribution parameters that are appropriate for the Clive site so that the model provides the range of plausible percolation rates into the waste with appropriate probabilities of occurrence.

Energy*Solutions*/Neptune have also used the data in NUREG/CR-7028 for in-service barriers to characterize the mean and to compute a standard error in a similar manner as the data in Rosetta.

Energy*Solutions*/Neptune have not demonstrated that this method to characterize the mean and standard error is appropriate to characterize the uncertainty in hydraulic properties so that the model output represents the range of plausible percolation rates into the waste with appropriate probabilities of occurrence. Both data sets are from a broad range of sites with different materials and different conditions. There is no justification provided to demonstrate that this method provides an appropriate mean and standard error *for the Clive site*. No documentation has been provided demonstrating that this approach to "temporal" and "spatial" averaging is a generally accepted approach.

Hydrologic properties of the cover soils should be characterized based on data collected using appropriate site characterization techniques on materials likely to be employed for the final cover, combined with appropriate upscaling and spatial averaging to characterize the uncertainty. There are standard field and laboratory methods available to conduct characterization of the materials to achieve this objective. Alternatively, databases can be used, but appropriate documentation is needed to confirm that the parameters selected for the distributions provide an appropriate mean and standard error *for the Clive site* so the flow model represents the range of plausible percolation rates into the waste with appropriate probabilities of occurrence. Stating that other databases have been used many times by others in the past is inconsistent with the standard of care normally associated with appropriate documentation that the parameters are reasonable.

Energy*Solutions*/Neptune also contend that the saturated hydraulic conductivity (K_{sat}) and van Genuchten's α parameter used as input to the model are uncorrelated. That is an unlikely occurrence that is inconsistent with other data sets in the literature and suggests an inconsistency in the data set. However, independent simulations SC&A has conducted have shown that percolation rates predicted with the K_{sat} and α parameter uncorrelated are higher than those predicted with correlation. Thus, ignoring correlation between the K_{sat} and α parameter is acceptable.

These issues are discussed in greater detail under Supplemental Interrogatory Comments 1 and 2, which remain open. (See Section 4.1.)

Erosion of Cover – Energy*Solutions*/Neptune indicate that calculations to evaluate the stability of the design with respect to gully erosion for the ET cover of the Class A West cell were provided in Appendix D to Energy*Solutions* (2015a), and that similar calculations for the Federal Cell are presented in the response to Interrogatory 71/1.

The same issues are raised in Interrogatory CR R313-25-8(4)(a)-71/1: Biotic Processes in Gully Formation, which remains open.

Effect of Biologicals on Radionuclide Transport – Since naturalized parameters incorporate the effects of plants, animals, and insects on infiltration rates, the effect of biologicals are considered under the naturalization issues discussed in Supplementary Interrogatory Comment 2 (see Section 4.1.2).

Frost Damage – Since naturalized parameters incorporate the effects of frost damage, the effect of frost damage is considered under naturalization issues discussed in Supplementary Interrogatory Comment 2 (see Section 4.1.2).

2.1.2 Interrogatory CR R313-22-32(2)-10/3: Effect of Biologicals on Radionuclide Transport

DEQ Conclusion from April 2015 SER, Appendix C

As discussed in the April 2015 SER (Section 4.4.3), Energy*Solutions* has not shown that the cover system is sufficiently thick or designed with adequate materials to protect the cover system or the underlying bulk waste in the embankments against deep rooting by indigenous greasewood (a species known to penetrate soils at other sites down to 60 feet) or other plants, or against biointrusion by indigenous ants or mammals (e.g., with maximum documented burrowing depths greater than the proposed cover thickness). Higher rates of infiltration are typically associated with higher contaminant transport rates. Under Utah rules, infiltration should be minimized (see UAC Rule R313-25-25(3) and (4)). DEQ cannot determine the adequacy of the DU PA until Energy*Solutions* accounts for greater infiltration through the cover system at the Federal Cell embankment due to biointrusion by plant roots and by animals. Therefore, this interrogatory remains open.

DEQ Critique of DU PA v1.4, Appendix 5

Energy*Solutions*/Neptune retain the same assumptions with respect to biointrusion depths and potential impact on infiltration in v1.4 as were provided in v1.2 of the DU PA.

In DU PA v1.4, Appendix 5, *Unsaturated Zone Modeling for the Clive DU PA, Clive DU PA Model v1.4* (Neptune 2015e, p. 33), Energy*Solutions* indicates that root water uptake was modeled assuming the roots extended to the bottom of the evaporative zone layer and that rooting density decreased with depth. This text seems to contradict the statement in v1.4, Appendix 5 (p. 33), that root distribution was modeled as extending into the Frost Protection Layer with a maximum depth of 31 inches (80 centimeters (cm)). The base of the evaporative zone would be at 18 inches. Figure 1 of Appendix 5 indicates that the roots cease within the Frost Protection Layer. The impact of the rooting depth in v1.4 is to remove water from the system and thereby reduce the infiltration rates. The concern raised by the interrogatory is related to the roots creating preferential pathways and thereby increasing the infiltration.

DEQ Critique of DU PA v1.4, Appendix 21

Energy*Solutions*/Neptune state (Neptune 2015j, p. 15):

> *It is important to recognize how the range of rooting depths discussed in the comment actually relates to what was used as a maximum rooting depth in GoldSim Models v1.2 and v1.4. A maximum root depth of 5.7 meters (18.7 ft) (Robertson 1983) is used in the Model, so the Model already assumes that roots extend beyond the radon barrier. In addition, v1.4 of the GoldSim Model assumes increased permeability, correlation between saturated hydraulic conductivity and the hydraulic function alpha parameter, and homogenization of the cover materials, with no physical barriers to either plant roots or infiltration.*

It is unclear how the specification of the rooting depth in GoldSim is particularly relevant to the concern expressed in the comment pertaining to potential increased infiltration rates due to biointrusion of plants and animals. The rooting depth in GoldSim is related to the depth of contaminant uptake, redistribution of contamination, and assimilation of contaminants once the plant dies rather than changes to the hydraulic properties that would allow greater infiltration.

Plant roots will almost certainly extend downward and into the radon barrier. These roots will then penetrate into the underlying waste if water is available in the waste. As described Benson et al. (2008), roots were observed in the radon barrier in the caisson lysimeters exhumed at Monticello in 2008. These were at depths of 1.6–1.9 meters below ground surface (mbgs) (see Figure 2 below). The roots desiccated the radon barrier, causing large cracks and an increase in K_{sat}.

Furthermore, Energy*Solutions* has used a homogeneous cover profile in the most recent simulations. This was not the intent of the previous comments and approach outlined in Appendix E to the April 2015 SER and was misconstrued from the parameter recommendations provided in Appendix E. The cover profile should retain a layered structure representative of the materials planned for each layer, but with the hydraulic properties of each layer adjusted to reflect pedogenesis. The parameters in the 2015 recommendations were presented as a guide for reasonable ranges consistent with the recommendations in NUREG/CR-7028 (Benson et al. 2011).

Figure 2. Section of radon barrier in caisson lysimeter at Monticello Uranium Mill Tailings Disposal Facility. Roots and cracks in the barrier are evident at a depth of 1.6–1.9 m. (Source: Benson et al. 2008)

DEQ Discussion of NAC-0106_R0 – July 2019

In their response in NAC-0106_R0, *ET Cover Design Responses for the Clive DU PA Model* (Neptune 2018f), Energy*Solutions*/Neptune describe the literature reviews and field data collected by SWCA (2013). Energy*Solutions*/Neptune contend that increased infiltration due to biotic activity would be minute, based on the same conclusion reached by SWCA (2013). It was not apparent, however, that SWCA (2013) based this conclusion on any quantitative data (e.g., lysimeters) from the immediate vicinity of the Clive site. However, SWCA (2013) did raise the issue of high-precipitation events and snowmelt leading to the greatest infiltration rates.

Since naturalized parameters incorporate the effects of biologicals, their effects are considered under naturalization issues discussed in Supplementary Interrogatory Comment 2 (see Section 4.1.2).

The issues related to the variability of infiltration rates during high-precipitation events and snowmelt are discussed in Round 3 Interrogatory CR R313-25-8(4)(A)-28/3: Bioturbation Effects and Consequences (ES 2014c) and in Supplemental Interrogatory Comment 3 in Appendix B of 2015 SER. Interrogatory 28/3 and Supplemental Interrogatory Comments 2 and 3 remain open. See also Section 4.1 in this document.

2.1.3 Interrogatory CR R313-25-8(5)(A)-18/3: Sediment Accumulation

DEQ Conclusion from April 2015 SER, Appendix C

In its Round 3 response, Energy*Solutions* stated that "discussions of aeolian sedimentation rates have been revised. For example, reference to a rate of 0.1 to 3 mm/year has been removed. Note that sedimentation rates for aeolian deposition were not used in the model" (ES 2014c, p. 15). However, the Energy*Solutions* Round 3 response to Interrogatory 05 states (ES 2014c, p. 9):

> *Aeolian deposition will probably cover the existing sediments (rather than mixing with them completely as is currently modeled). This will result in considerably smaller concentrations in deep time than currently presented in the PA model, with the potential to be as low as, or even lower than, background concentrations. Note the in recent correspondence with Dr. Charles (Jack) Oviatt, the pit wall has been re-interpreted. Originally Dr. Oviatt interpreted the top 70 cm as reworked Gilbert Lake materials but now does not believe that the Gilbert Lake reached Clive, and, consequently, that the top 70 cm are probably aeolian deposits (…). If this is the case, then aeolian deposition can play a more important role in site stability and site protection, including providing a layer of protection against radon transport.*

Energy*Solutions* provided a Deep Time Supplemental Analysis (DTSA) (Neptune 2014f, 2015l), which effectively made moot the DU PA Model v1.2 deep time analysis. The April 2015 SER, Section 5.1.1, presented DEQ's evaluation of the DTSA. As stated in the April 2015 SER, Section 5.1.1, Neptune (2014f and 2015l) used a mean Intermediate Lake sedimentation amount of 2.82 meters, which, when coupled with the mean Intermediate Lake duration of 500 years, gives a sedimentation rate of 5.64 millimeters per year (mm/yr). DEQ's consultant, Dr. Paul Jewell, provided information indicating that Great Basin Lake sedimentation rates ranged from 0.12 to 0.83 mm/yr. The DEQ analysis provided in the April 2015 SER, Section 5.1.1, utilized a range of Intermediate Lake sedimentation rates, based on data provided by Neptune (2014f, 2015l) and Jewell (2014).

For aeolian deposition, Neptune (2015k) based its radon flux calculation on the information obtained during a December 2014 field investigation (Neptune 2015k). DEQ (and its consultant, Dr. Jewell) have reviewed the results of the field investigation and agree with its results regarding the depth of aeolian deposition in the Clive area and the length of time over which that deposition accumulated.

DEQ continues to disagree with Energy*Solutions* on the Intermediate Lake sedimentation rate and concludes that additional study of this issue is necessary. Thus, this interrogatory remains open.

DEQ Critique of DU PA v1.4, Appendix 13

Energy*Solutions*/Neptune continues to use the combination of a 500-year Intermediate Lake duration (Neptune 2015g, Section 7.3) coupled with an Intermediate Lake total sedimentation of 2.82 meters (Section 7.4). As stated previously, this combination results in an Intermediate Lake sedimentation rate of 5.64 mm/yr. Such a large sedimentation rate is unsupported by any of the reviewed literature (see the April 2015 SER, Table 5-2). Energy*Solutions*/Neptune needs to either (1) provide independent documentation that a sedimentation rate of 5.64 mm/yr is plausible or (2) define a plausible, defensible Intermediate Lake sedimentation rate and redo the deep time analysis.

Energy*Solutions*/Neptune justifies use of the standard error (i.e., the standard deviation of the mean) rather than the standard deviation of the data because the raw data represent points in time and space. DEQ/SC&A does not agree with this interpretation. The raw data that were collected in December 2014 are the total thicknesses of the aeolian deposition. Thus, rather than a "point in time," the raw data represent the accumulated aeolian deposition over thousands of years. As such, the raw data include year-to-year fluctuations in the deposition rates. The following discussion assumes that the aeolian deposition can vary over the surface of the disposal embankment, but that it remains constant over the duration of the analysis.

If the disposal embankment is divided into two subareas, and the mean and standard deviation of the 11 measured aeolian deposition thickness are applied independently to each, then the total embankment average deposition would differ from a single deposition calculated from the same mean and standard deviation. This is because in the two-subarea case, every time an extreme deposition is calculated for one subarea, the other subarea will have a less extreme deposition, so that the embankment average would always be less extreme than the single mean and standard deviation extreme. When this is repeated a large number of times, it results in a deposition distribution for the two subarea case that is narrower than the distribution for the single embankment area case. This is shown in Figure 3 below.

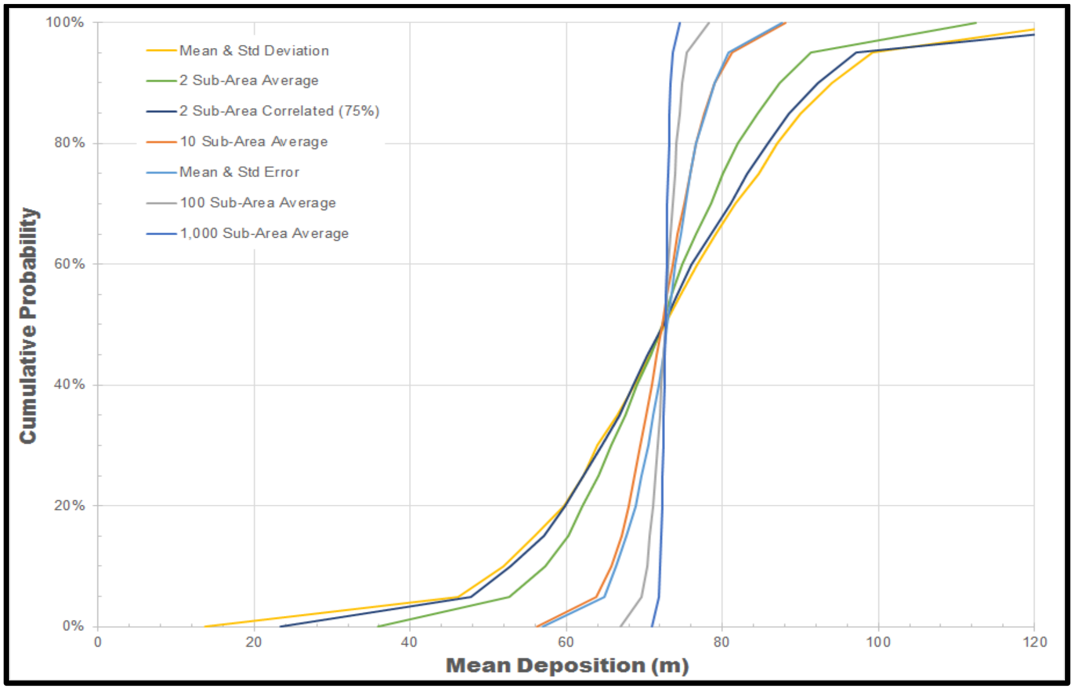


Figure 3. Deposition distributions.

As the embankment is divided into ever more subareas, the resulting deposition distribution will become ever more narrow, until it reaches its limit at the mean. This is true even though the same mean and standard deviation have been independently applied to each of the subareas. Again, Figure 3 above shows this for 10, 100, and 1,000 subareas.

When Energy*Solutions*/Neptune applied the standard error instead of the standard deviation to their calculation of the average embankment deposition, they were essentially dividing the embankment into 11 subareas, also shown on the above figure, which agrees well with the 10-subarea case.

There are at least four concerns with this subarea approach. First, how does one select the number of subareas in which to divide the embankment? As stated above, Energy*Solutions*/Neptune essentially divided the embankment into 11 subareas, based on the number of samples that were obtained. Although DEQ/SC&A believes this to be a practical approach, we also believe that a more defensible approach would be to first determine the appropriate number of subareas and then collect a representative sample for each. Presently, the only justification Energy*Solutions*/Neptune provides is that the resulting three standard error (99.7^{th} percentile) deposition range results in a “reasonable simulation range,” which is very subjective. However, we do note that 11 subareas/samples are sufficiently large that adding or removing one or two would not have a significant impact on the results; for example, to impact the results by a factor of two would require four times as many samples. Nonetheless, Energy*Solutions*/Neptune should provide the rationale for selecting their approach.

Second, until now, the mean and standard deviation have been applied independently in each subarea. It seems reasonable to assume that neighboring subareas would behave similarly; e.g., if one subarea’s deposition is smaller than the mean, its neighboring subareas would have depositions that are also smaller than the mean. In other words, the subarea depositions should be correlated, not independent. Clearly, correlation is necessary to prevent the physically unrealistic case where one subarea has an extremely low deposition while its neighbor has an extremely high deposition. To test the impact of correlated subareas, the two-subarea case was reanalyzed with the two subareas being 75 percent correlated. Figure 3 above shows that when the two subareas are 75 percent correlated, the deposition distribution is much closer to the single mean and standard deviation case than to the two-independent-subareas case. However, it remains to be determined what is the appropriate degree of correlation—75 percent or some other value. This is very important, because any deposition distribution between the single embankment (i.e., 100 percent correlation) and the two-subarea case (i.e., 0 percent correlation) can be obtained by tailoring the degree of correlation. Also, the effect of correlation on cases with more than two subareas has not been investigated (e.g., the Energy*Solutions*/Neptune 11-subarea case), but it can safely be assumed that they would result in wider deposition distributions than the corresponding independent subarea cases.

Third, use of the average embankment deposition based on multiple subareas (as was done in the Energy*Solutions*/Neptune model) results in the implicit assumption that the dose receptor spends an equal amount of time in each of the subareas. The alternative conservative assumption would be to have the dose receptor spend all of their time in the subarea with the smallest amount of deposition.

Finally, the impact of the aeolian deposition model on the acceptability of the DU PA model must be taken into consideration. If a DU PA acceptability determination is to be made based on the 50th percentile of the results, then the selection of the deposition model has virtually no impact, as shown in Table 2 below. However, if a DU PA acceptability determination is to be made based on the 95th percentile of the results (i.e., 5th percentile of the deposition), then the mean and standard deviation model results are about 29 percent smaller (more conservative) than with the Energy*Solutions*/Neptune mean and standard error model. When considering the concerns expressed above, this difference is not great and can be factored into a DU PA acceptability determination even if the Energy*Solutions*/Neptune aeolian deposition model remains unchanged.

Table 2. Deposition Models

Deposition Model	**Deposition (cm)**	
	50th	**5th**
Mean & Standard Deviation	72.6	46.1
2 Subarea Average	72.3	52.6
2 Subarea Correlated (75%)	72.5	47.7
10 Subarea Average	72.3	63.8
Mean & Standard Error	73.0	64.9
100 Subarea Average	72.7	69.7
1,000 Subarea Average	72.7	71.8

In conclusion, the above discussion presented four concerns that DEQ/SC&A has identified with the Energy*Solutions*/Neptune aeolian deposition model. In order of perceived importance, these are:

1) Deposition in the subareas of the embankment is likely correlated, rather than independent. A correlated model would produce results that are more conservative than the current Energy*Solutions*/Neptune model. However, the degree of correlation is presently unknown (and perhaps unknowable).

2) The sample results do not represent a "point in time," as Energy*Solutions*/Neptune indicated in their previous response. Rather, the samples are an accumulation over 13,000 to 15,000 years (Appendix 13, p. 38; Neptune 2015g). Thus, the sample results can be thought of as being time averages.

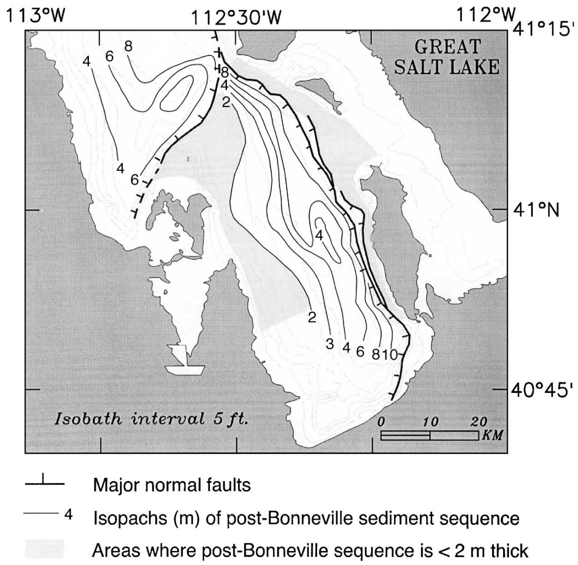
3) Using the Energy*Solutions*/Neptune model results in a dose calculation means that the dose receptor spends an equal amount of time in each embankment subarea. The more conservative assumption is that the dose receptor spends all of his time in the subarea with the least amount of deposition. Alternatively, the subarea in which the dose receptor spends his time could be randomly selected.

4) Dividing the embankment into 11 subareas based on the number of samples, as was done for the Energy*Solutions*/Neptune model, appears reasonable. However, Energy*Solutions*/Neptune should provide the rationale for selecting this approach.

For these reasons, DEQ/SC&A continues to believe that for nuclear licensing purposes the mean and standard deviation aeolian deposition model should be used.

DEQ Critique of DU PA v1.4, Appendix 21

Energy*Solutions*/Neptune indicate that the April 2015 SER requested that the deep time analysis be redone using an Intermediate Lake sedimentation rate that is 10 times the Large Lake sedimentation rate (Neptune 2015g, p. 21). This is incorrect. While the 2015 SER makes clear that the Intermediate Lake sedimentation rate of 5.64 mm/yr used in the Energy*Solutions*/Neptune analysis is unrealistic, it made no recommendation as to what an appropriate Intermediate Lake sedimentation rate should be. Specifically, regarding the 10 times the Large Lake sedimentation rate, the 2015 SER, Section 5.1.2.3 states, "it can be concluded that a sedimentation rate of 1.2 mm/yr for intermediate lakes is likely too large." 2015 SER Table 5-2 includes several published sedimentation rates from eastern Great Basin, Utah, lakes ranging from 0.12 to 0.83 mm/yr, which could be used to develop an Intermediate Lake sedimentation rate distribution for the deep time analysis (see 2015 SER Table 5-3 and Figure 5-5 for examples). In the opinion of Dr. Paul Jewell, Professor of Geology & Geophysics, University of Utah, "the dominant factor [in determining sedimentation rates] is proximity to an active fault [as seen in Figure 4 below]. The Clive site is approximately 12 km from the range-bounding fault of the Cedar Mountains meaning sedimentation is probably on the mid to low end of the 0.12 – 0.83 mm/yr scale" (Jewell 2017). Dr. Jewell also points out that the "sense by Neptune that the deep portions of shallow/intermediate lakes are dominated by clastic sedimentation and those of large lakes are dominated by carbonate sedimentation (…) is true only in a general sense. The carbonate/clastic ratio is much more dependent on the amount of local fluvial input to a lake, not lake size or depth. For instance, the shallow portion of cores taken from 20-50 m water depths in Bear Lake (a lake with minor river input) are 60-80% carbonate (Dean, 2009)" (Jewell 2017).



Source: Colman, et al., 2002, Figure 12, as provided by Jewell 2017

Figure 4. Sedimentation in the eastern Great Basin.

For all of these reasons, Energy*Solutions*/Neptune needs to either (1) provide independent documentation that a sedimentation rate of 1.2 mm/yr is plausible or (2) define a plausible, defensible Intermediate Lake sedimentation rate and redo the deep time analysis.

DEQ Discussion of NAC-0105_R0 – July 2019

Due to the evolving nature of the deep time analysis, Interrogatory CR R313-25-8(5)(A)-18/3: Sediment Accumulation has also evolved somewhat since it was first created in Round 1. In its current form, it consists of two concerns: aeolian deposition and Intermediate Lake sedimentation rate. Both of these processes result in material overlaying the DU once the embankment has been "washed away" by the first returning lake.

Interrogatory CR R313-25-8(5)(A)-18/3: Part One – Aeolian Deposition

Based on samples collected on site, Energy*Solutions*/Neptune have developed an aeolian deposition distribution with a mean, standard distribution, and standard error. To account for spatial and temporal effects, Energy*Solutions*/Neptune propose to substitute the standard error for the standard deviation when the aeolian deposition distribution is entered into the GoldSim v1.4 model. While DEQ/SC&A agree with the concept of adjusting for spatial and temporal effects, we believe that for the purposes of nuclear facility licensing, a more rigorous and defendable approach to its implementation is required.

As we demonstrated in our previous response, using the standard error, rather than the standard deviation, is mathematically equivalent to dividing the embankment into 11 subareas. As Energy*Solutions*/Neptune state in their NAC-0105_R0 responses to concerns 1 through 3 (Neptune 2018e), we agree that the site was not divided into 11 subareas. Thus, their use of the standard error seems to contradict their responses to concerns 1 to 3. Energy*Solution*s/Neptune provide no basis for using the standard error in their response to concern 4, other than to state that the "technically established statistic for upscaling is the mean thickness of the field measurement and the standard error of the mean to represent the variance of the averaged measurement data" (Neptune 2018e, p. 5).

We have reviewed the three references provided earlier in the response by Energy*Solutions*/Neptune (i.e., Blöschl and Sivapalan (1995); Neuman and Wierenga (2003); Zhang et al. (2004)), and, while the references describe the need for upscaling, they do not "technically establish" the use of the standard error in this manner. Zhang et al. (2004) do state that "scaling should only be applied over a limited range of scales and in specific situations," while Neuman and Wierenga (2003) state that "One approach has been to postulate **more-or-less ad hoc rules for upscaling** based on numerically determined criteria of equivalence" (emphasis added).

DEQ remains concerned that (1) the proposed embankment is not a specific situation that allows for upscaling and (2) the approach taken by Energy*Solutions*/Neptune is "an ad hoc rule" rather than a "technically established" approach. Although it is recognized that the impacts of this interrogatory are limited and understood, it is important that all nuclear facility licensing assumptions that result in less conservative results be well understood and documented, rather than based on "ad hoc rules." Therefore, until Energy*Solutions*/Neptune provide either a technical basis that is sufficiently detailed and defendable for a nuclear licensing application for using the standard error or revert to using the standard deviation, this portion of the interrogatory remains open.

Interrogatory CR R313-25-8(5)(A)-18/3: Part Two – Intermediate Lake Sedimentation Rate

Energy*Solutions*/Neptune have developed an Intermediate Lake sediment deposition model for input to the GoldSim v1.4 model (Neptune 2015l, Section 7.4). It is DEQ/SC&A's opinion that the Energy*Solutions*/Neptune-developed Intermediate Lake sediment deposition model overpredicts the amount of sediment that would be present once the lake recedes and thus underpredicts the radon flux on the surface of the sediment.

DEQ/SC&A made a 100-realization run of the GoldSim Deep Time v1.4 model to study the calculated cover thickness due to aeolian deposition and lake deposition. Figure 5 plots the GoldSim-calculated radon flux versus the embankment total cover thickness (i.e., aeolian deposition plus lake sedimentation).[3] A trendline was fitted to the results, and, as expected, the radon flux is strongly related to the cover depth. This means that it is imperative that the cover depth be calculated correctly, conservatively, and in a technically defendable manner.

[3] Data used to generate Figure 5 and all of the other figures presented in this discussion are provided in the table at the end of the discussion.

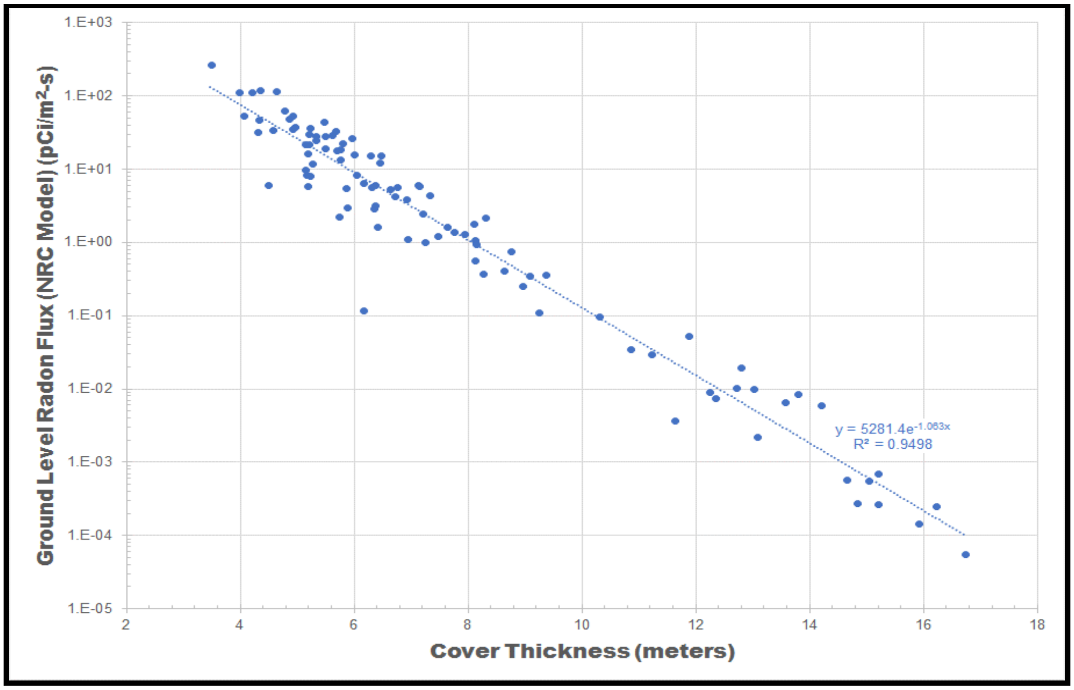


Figure 5. GoldSim model calculated radon flux versus cover thickness

Regulatory compliance is to be demonstrated at the point when the receding lake (Intermediate or Deep) exposes the destroyed embankment, not at 100,000 years or any other fixed time.

Regarding Intermediate Lake sedimentation, Energy*Solutions*/Neptune state:

> *Sedimentation is assumed to occur during these intermediate lake events at greater annual rates than is assumed to occur for the open-water phase of deep lakes. This is based on the pre-Bonneville lacustrine cycles that are documented in the Deep Time Appendix to version 1.2 of the Modeling Report* [Neptune 2014d]. *The intermediate lake is assumed to recede after some period of time, at which point a shallow lake relative to the Clive facility will occupy Bonneville Basin until the next intermediate or deep lake cycle. Modeling of radon flux focuses on this point in time.* [Neptune 2015l, page 10, a similar statement appears in Neptune 2015g, page 20]

A review of the GoldSim v1.4 file found that the following statement by Energy*Solutions*/Neptune is not the way Intermediate Lake sedimentation was actually implemented in the GoldSim v1.4 model:

> *the depth of lake and eolian sediments removed at the Clive location due to wave action, and the residual material from the destroyed embankment are expected to be approximately equal, and their effects essentially cancel. Therefore,* ***the thickness of residual embankment material and sediment overlying the disposed DU waste at the time when the first intermediate lake recedes will be effectively equivalent to the thickness of eolian sediments deposited up until that point in time****, represented by the rising elevation of the surrounding grade.* [Neptune 2015g, page 28; emphasis added]

Using mean data from Neptune 2015g, Table 1 for the eolian deposition (72.2 cm), the age of the eolian deposition (13,614 years), the duration of the Intermediate Lake (500 years), and the Intermediate Lake sedimentation (2.82 meters), it can be shown that the above statement is incorrect. That is, 72.2 cm divided by 13,614 years times 500 years is 0.0265 meters, which is two orders of magnitude less than 2.82 meters.

As described in Neptune 2014d, Section 6.3, the GoldSim model defines the Intermediate Lake sedimentation as "a lognormal distribution with geometric mean 2.82 m and geometric standard deviation 1.71." We confirmed this by examination of the GoldSim parameter: IntermediateLake SedimentAmount. Thus, the following statement made by NAC-0105_R0 is not supported by the GoldSim model itself:

> *the intermediate lake sediment thickness is not an independent parameter in the Deep Time model results. It covaries with both the aeolian sedimentation rate and the deep lake sedimentation rate. The three model parameters are constrained in the Deep Time model by the composite thickness of sediments during the 100-ka glacial cycles (15 to 20 meters thickness"; Neptune (2015*[l]*)).* [Neptune 2018e, p. 10]

Based on our 100-realization run, we could find no relationship between Intermediate Lake sedimentation and the aeolian deposition rate or the Deep Lake sedimentation rate. We also could not locate within the GoldSim v1.4 model where the three parameters were constrained; on the contrary, most of the cover thicknesses that were calculated by our running of the GoldSim v1.4 model were outside of the 15- to 20-meter 100-kilo-annum (ka) thickness range (i.e., 83 percent less than, 3 percent greater than).

The following Energy*Solutions*/Neptune statement from NAC-0105_R0 suggests that, as opposed to being field observations, the 15 to 20 meters per glacial cycle sediment depth is the result of a heuristic model constructed by Energy*Solutions*/Neptune, which has not been submitted to DEQ for review.

> *the composite sediment thickness of intermediate lake events is combined with aeolian and deep lake sedimentation. This composite sediment thickness is constrained in the model by observed sediment thicknesses of 15 to 20 meters per glacial cycle based on core studies at the Knolls and Burmester sites (Neptune (2015*[g]*), Section 7.4).* [Neptune 2018e, p. 7]

Additionally, Neptune 2015l, Section 7.4, indicates that the heuristic model utilized data from the Saltair Boat Harbor monitoring site, rather than the Knolls and Burmester sites.

DEQ agrees with the following statement, which makes the cover depth at the time the First Lake recedes of critical importance and diminishes the importance of the glacial cycle (i.e., 100,000 year) cover depth:

> *Modeling results indicate that sediment accumulation overwhelms the influence of progeny ingrowth. This is revealed by inspection of the results of individual model realizations, where radon flux is always highest at the model time when the first intermediate lake recedes, and then decreases over time to the end of the modeling period. Hence, the time of peak radon flux is equivalent to the time*

> *when the first lake to reach the elevation of Clive (and destroy the embankment by wave action) has just receded…* [Neptune 2015l, p. 14]

Unfortunately, because v1.4 shuts off aeolian deposition once the first Intermediate Lake appears (i.e., FirstIntermediateLakeAppears is set to "true" and there is no trigger to reset it to "false," which is needed to allow aeolian deposition to resume), the GoldSim v1.4 model peak radon flux appears up to 29,500 years after the appearance of the first Intermediate Lake (i.e., the radium-226 continues to build up but the cover thickness remains unchanged).

Because the GoldSim v1.4 model resamples the Intermediate Lake sedimentation after each lake, it is only possible to check those realizations that include a single Intermediate Lake before a Deep Lake. The 100-realization run that SC&A made includes 33 realizations with a single Intermediate Lake before a Deep Lake. Figure 6 shows the cover thickness time histories for three of those 33 realizations: Realization 74 that has the largest Intermediate Lake sedimentation, Realization 73 with the smallest Intermediate Lake sedimentation, and Realization 90 with a middle amount of Intermediate Lake sedimentation. The solid lines in Figure 6 were developed for this study using a combination of GoldSim results and hand calculation. SC&A conducted two hand calculation checks of the GoldSim results: (1) the cover thickness at the time when the First Intermediate Lake recedes and 2) the cover thickness at 100,000 years. The first check confirmed the GoldSim results, while the second check showed that the GoldSim model does not include aeolian deposition after the first Intermediate Lake recedes. The dotted lines in Figure 6 show the GoldSim v1.4 model-calculated thickness, which ignores aeolian deposition after the first Intermediate Lake.

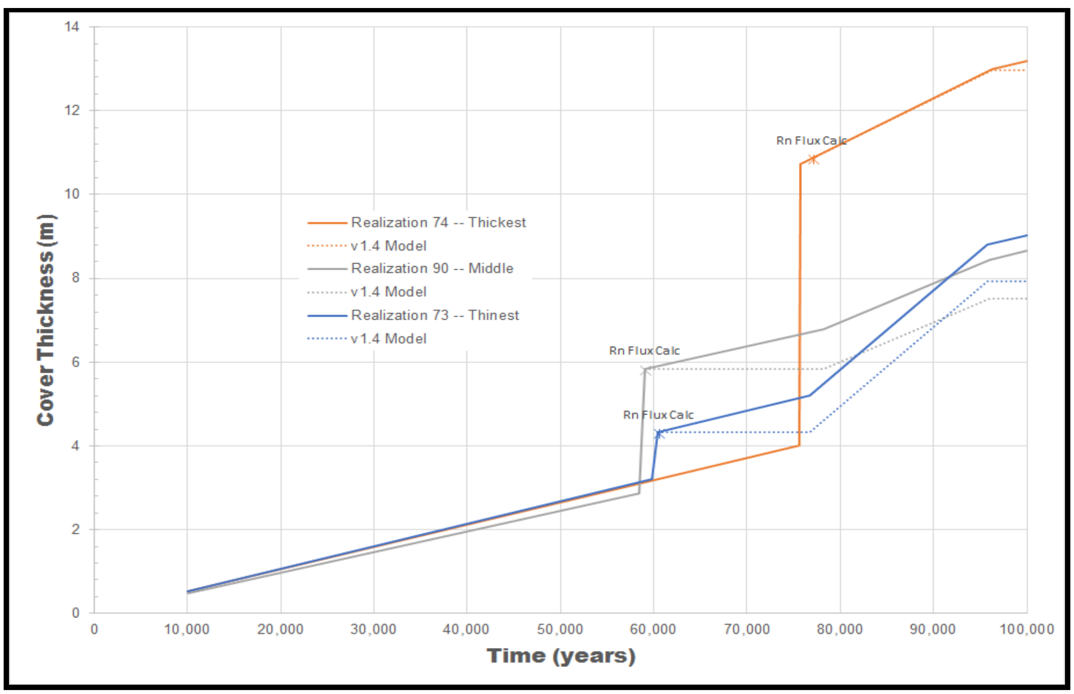


Figure 6. GoldSim model cover thicknesses for three realizations

In Figure 6, notice the essentially "step changes" in cover thicknesses that occurs when the Intermediate Lake is present. We can think of no physical process that could be responsible for these "step changes." The Energy*Solutions*/Neptune arguments seems to be that these non-mechanistic influxes of sediment are needed to generate the "observed" glacial period (i.e., 100,000-year) cover thicknesses (i.e., 15 to 20 meters). There are two problems with that argument. First, the "observed" thicknesses were not observed in the field but rather are the results of an unverified heuristic model constructed by Energy*Solutions*/Neptune. Second, the critical time is not at 100,000 years, but when the First Lake recedes, as indicated in the text from Neptune 2018e reproduced above.

The following information was taken directly from DU PA v1.4, Appendix 13, Section 4.4):

> *Brimhall and Merritt (1981) reviewed previous studies that analyzed sediment cores of Utah Lake, a freshwater remnant of Lake Bonneville that formed at approximately 10 ka. They suggest that up to 8.5 m of sediment has accumulated since the genesis of Utah Lake, implying an average sedimentation rate of 0.85 mm/y or* ***850 mm/ky****. Within the Bonneville Basin as a whole the major lake cycles resulted in substantial accumulations of sediment based on the depth of the cores analyzed (e.g., a 110 m core that corresponds to the past 780 ky, or four deep lake cycles [Oviatt et al., 1999]). This accumulation averages about* ***140 mm/ky****. Einsele and Hinderer (1997) indicate that sediment accumulation in the Bonneville Basin occurred at a rate of* ***120 mm/ky*** *during the past 800 ky. The Knolls Core suggests that there has been 16.8 m sedimentation formed in the last glacial cycle, or nearly* ***170 mm/ky****.*
>
> *Interpretations of the Clive pit wall (C.G. Oviatt, unpublished data) indicate that the sedimentation rate at the Clive site for the Lake Bonneville cycle is on the order of 2.75 m over a 17 to 19 ky time period (****140 to 160 mm/ky****). By contrast, shallow lacustrine cycles that occurred prior to Lake Bonneville (but after the Little Valley cycle) indicate that the amount of sediment deposited during each cycle is approximately 1/3 that of the Bonneville sediment deposited. The timing of these shallow lake cycles is uncertain, however, it can be approximated when comparing the Clive pit wall interpretation to the Knolls Core (C.G. Oviatt, personal communication). The Little Valley lake cycle is exhibited in the Knolls Core at a depth of approximately 17 m, which is roughly 14 m deeper than the beginning of the transgressive phase of the Bonneville lake cycle event noted on the Clive pit wall interpretation. Given the Little Valley event occurred 150 ka, a sedimentation rate can be approximated for the depth between this event and the transgressive phase of the Bonneville cycle of* ***110 mm/ky****.* [Neptune 2015g, Section 4.4, pp. 17–18; emphasis added]

If instead of using the v1.4 Deep Time Intermediate Lake sedimentation model, the Utah Lake "much greater" sedimentation rate of 850 mm/ky is used (i.e., the largest sedimentation rate from Neptune 2015g, Section 4.4), then the cover thicknesses for the three realizations plotted above changes as shown in Figure 7. If any of the smaller sedimentation rates presented in Neptune 2015g were to be used, or if a distribution were to be developed from all the above Neptune 2015g sedimentation rates, then the cover thickness would be less than that shown in Figure 7.

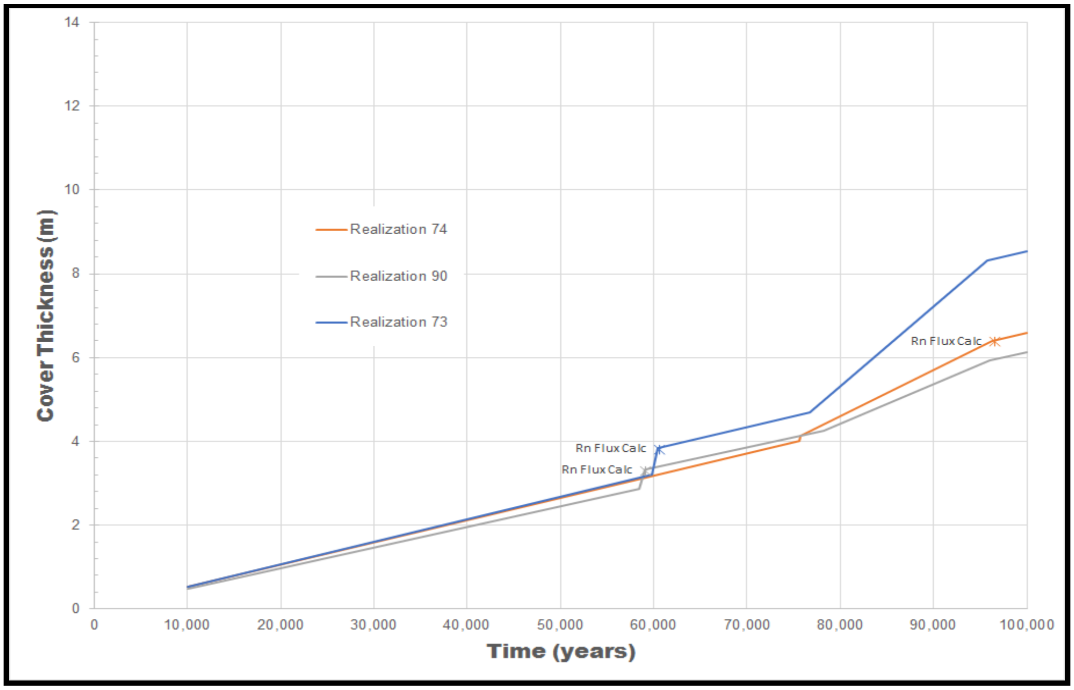


Figure 7. Potential impact of Utah Lake sedimentation rate on cover thickness for three realizations

In Figure 7, notice that there are no "step changes" in the cover thicknesses, and that a greater sedimentation rate is shown when an Intermediate Lake is present. Also, notice that the radon calculation time for Realization 74 has been moved to after the Deep Lake recedes.

The potential impact on the radon flux of using the Utah Lake sedimentation rate for the 33 single Intermediate Lake realizations is presented as in Figure 8. As shown, the median radon flux increases from 7.9 to 91.5 picocuries per square meter per second (pCi/m^2-s), while the 95th percentile flux increases from 82.7 to 313.2 pCi/m^2-s.

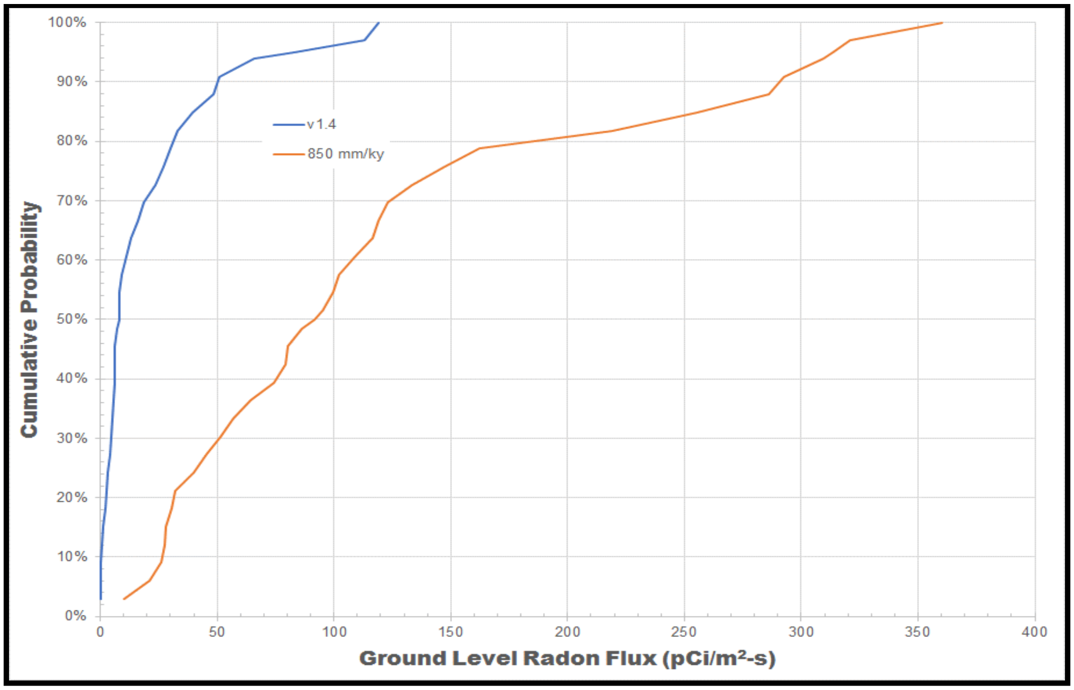


Figure 8. Potential impact of Utah Lake sedimentation rate on the radon flux

As mentioned above, the DEQ/SC&A review of the GoldSim v1.4 Deep Time model identified the following logic bugs:

1. When a Deep Lake appears before an Intermediate Lake (which occurs in about 15 percent to 20 percent of the realizations), the radon flux (and other results) is not calculated when the Deep Lake recedes, but rather the model waits for an Intermediate Lake and calculates the radon flux (and other results) once the Intermediate Lake recedes. For the realizations affected, the potential impact of this bug on the radon flux is shown in Figure 9, which shows at least two (and up to almost four) orders of magnitude increase in the calculated radon flux when this bug is corrected.

2. When a Deep Lake appears before an Intermediate Lake, aeolian deposition continues to accumulate when the Deep Lake is present, overcalculating the cover thickness.

3. When an Intermediate Lake appears first, aeolian deposition remains off after the lake recedes, even before and after the Deep Lake. This does not affect the radon flux calculation, since that occurs when the Intermediate Lake recedes, but it does undercalculate the cover thickness at 100,000 years (see the dotted lines in Figure 6).

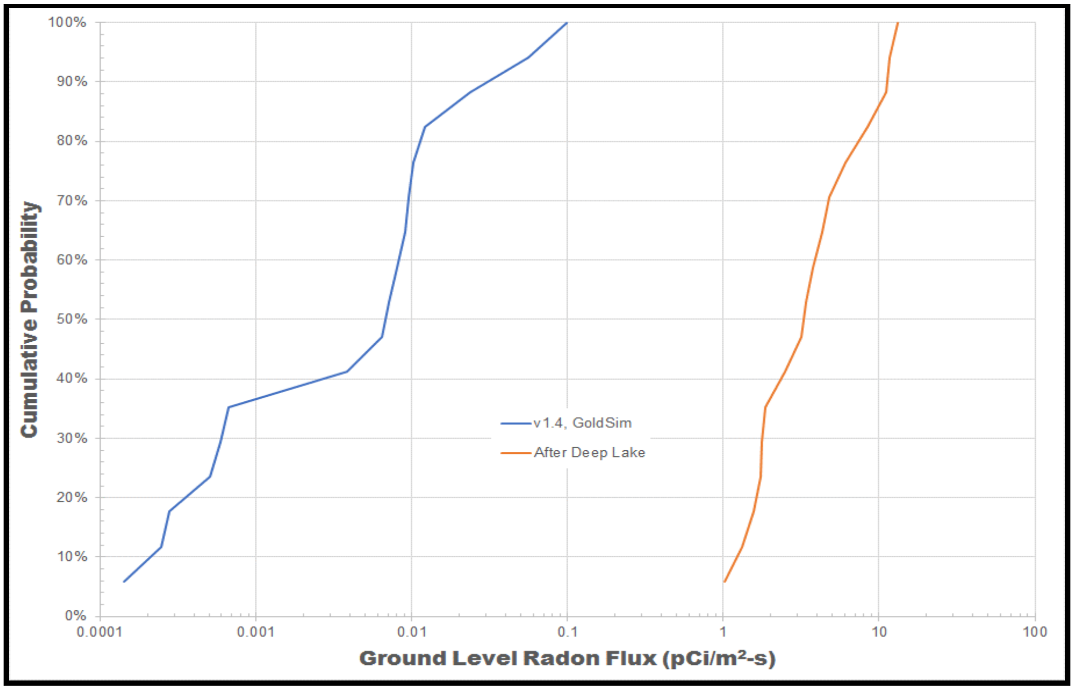


Figure 9. Potential impact on the radon flux

4. In some realizations, the Deep Lake appears before the Intermediate Lake recedes. When this occurs, the model does not wait for the Deep Lake to recede, but rather calculates the radon flux when the Intermediate Lake recedes even though the site is still covered by the Deep Lake. For example, Realization 74, a 420.8-year-duration Intermediate Lake, appears at year 75,597, a Deep Lake appears at year 75,750 and lasts until year 96,250, and the radon flux is calculated at year 77,000.

In conclusion, this interrogatory remains open, and the v1.4 Deep Time GoldSim model is currently unacceptable. Three actions are needed to close this interrogatory: (1) a more realistic Intermediate Lake total sedimentation or sedimentation rate needs to be developed, (2) Appendix 13 of the DU PA needs to be revised to correctly describe the deep time model, and (3) the logic bugs need to be removed from the GoldSim model.

2.1.4 Interrogatory CR R317-6-2.1-20/2: Groundwater Concentrations

DEQ Conclusion from April 2015 SER, Appendix C

Gullies that form on the embankment have the potential to increase the infiltration rate on the embankment, and an increased infiltration rate has the potential to increase the groundwater concentration of radionuclides leached from the DU. The Clive DU PA Model includes a gully formation model; however, the DU PA Model v1.2 (Neptune 2014a, p. 3) states that "No associated effects, such as…local changes in infiltration are considered within the gullies." As indicated in the April 2015 SER, Section 4.4.2, "Erosion of the Cover," Energy*Solutions* explained these omissions as follows in its Interrogatory 20 Round 2 response (ES 2014b, p. 26):

> *While the formation of some of the gullies may actually erode through significant depths of the evapotranspirative cover, the ratio of gully footprint to total evapotranspirative cover surface area remains minimal.*

In its Round 3 response to Interrogatory 70, Energy*Solutions* further stated that “The influence of gully formation on infiltration and radon transport is negligible given the current below grade disposal design” (ES 2014c, p. 43). The reason given is “that only a small fraction of the cover would have gullies extending through the surface and evaporative zone layers to the top of the frost protection layer.”

Nonetheless, the April 2015 SER, Section 4.4.2, concluded the following:

> *Before the DU PA can be determined to be adequate, Energy*Solutions *needs to clarify certain issues relating to Appendix 10 to the DU PA Model v1.2 (…) as described in* [SER] *Section 4.4.2. DRC*[4] *is currently reviewing a license amendment request to use an ET cover of similar design to that proposed for the Federal Cell in the DU PA.*[5] *Any recommendations and conclusions from that review must be applied to the proposed Federal Cell as well.*

DEQ Critique of DU PA v1.4, Appendix 10

See Interrogatory 201 for further discussion.

DEQ Critique of DU PA v1.4, Appendix 21

Energy*Solutions*/Neptune state (Neptune 2015j, p. 16):

> *The conceptual model of cover “naturalization” described in Appendix E of the SER (*[DEQ] *2015) is that plant and animal activity and freeze-thaw cycles result in disturbance and mixing of soil layers in the upper portion of the cover system subject to their influences. The extent of the influence of these processes decreases with depth of roots, animal burrowing, and frost penetration. This conceptual model does not maintain the designed functions of store and release layers and barrier layers to reduce net infiltration. Using this conceptual model, the upper portion of the soil profile subject to naturalization processes is considered to be homogeneous with respect to the hydraulic properties affecting net infiltration. For the Clive Site, the hydraulic properties of the waste below the cover are modeled as Unit 3 material and would be subject to the same naturalization processes as the materials used to construct the cover.*
>
> *With this conceptual model, the depth to the waste would be reduced by erosion but the net infiltration will not vary. The net infiltration is determined by climate and hydraulic properties. If the hydraulic properties are assumed to be homogeneous and determined by climate and biotic activity, loss of material from the surface of the cover will not change the net infiltration.*

Energy*Solutions* has used a homogeneous cover profile in the most recent simulations. This was not the intent of our previous comments and approach outlined in Appendix E to the April 2015 SER and was misconstrued from the parameter recommendations provided in Appendix E. The

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[4] In 2015, the Division of Radiation Control (DRC) and the Division of Solid and Hazardous Waste within DEQ were merged into the Division of Waste Management and Radiation Control (DWMRC). In this document, the term “DRC” is retained only in quoted excerpts from documents published prior to the merger.

[5] Since the SER was published in 2015, Energy*Solutions* has withdrawn its request for approval of an ET cover on the Class A West cell.

cover profile should retain a layered structure representative of the materials planned for each layer, but with the hydraulic properties of each layer adjusted to reflect pedogenesis. The parameters in the 2015 recommendations were presented as a guide for reasonable ranges consistent with the recommendations in NUREG/CR-7028 (Benson et al. 2011).

Energy*Solutions* has conducted a series of analyses to evaluate the impact of erosion on percolation rates from the cover. In one case, the simulation included loss of 1.2 meters of cover soil. Energy*Solutions* reports that percolation rates obtained for the full thickness cover and a cover eroded by 1.2 meters are essentially the same.

This is not logical, given that the soil in the cover is required to store the water during cooler and wetter periods, and then release the water during drier periods. The proposed cover is 1.52 meters thick. If the cover thickness is reduced by 1.2 meters via erosion, then the soil water storage capacity of the cover will be reduced by approximately 80 percent, and the percolation should change accordingly. This result without supporting analysis makes all of the HYDRUS modeling suspect.

Additional quantitative and mechanistic evidence is needed to support the outcomes in this part of the report. Water balance graphs, which depict the temporal variation in water balance quantities (rather than a water balance quantity chart) should be used to illustrate whether the outcomes are reasonable. Water balance graphs typically are created using daily output predicted from a water balance model and show the seasonal variation in each water balance quantity. Examples of water balance graphs are shown in Figure 10. These graphs depict actual water balance data; water balance graphs from a model prediction would be similar. The soil water storage record in the water balance graph would be compared to the soil water storage capacity of the eroded profile.

Significantly higher Tc-99 concentrations were obtained for percolation rates predicted using the hydraulic properties Energy*Solutions* developed with the recommended approach (Appendix E, April 2015 SER) relative to the percolation rates predicted in their previous analyses (Figure 11). The differences are very large, which is difficult to understand given that the percolation rates predicted for the cover are on the order of 1 mm/yr and are consistent with percolation rates measured for covers placed at other sites in the region.

If the impact on groundwater concentrations is this sensitive to percolation rates on the order of 1 mm/yr, then detailed assessment and proof of the cover design should be particularly important. Energy*Solutions* should consider installing a lysimeter to confirm that the cover modeling is reliable.

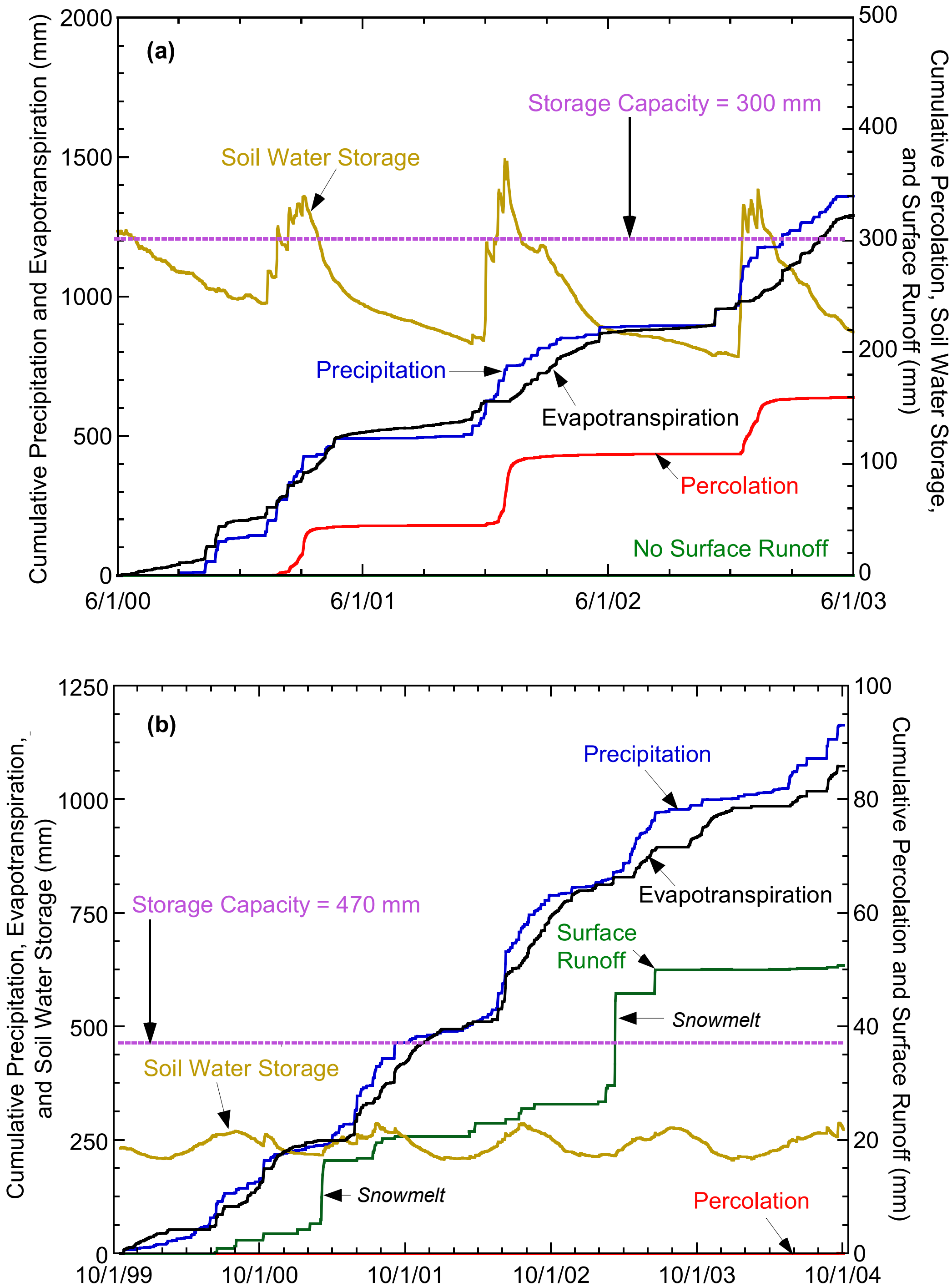


Figure 10. Water balance graphs showing temporal variation in water balance quantities for sites in California (a) and Montana (b). The soil water storage capacity of the cover is shown on each graph.

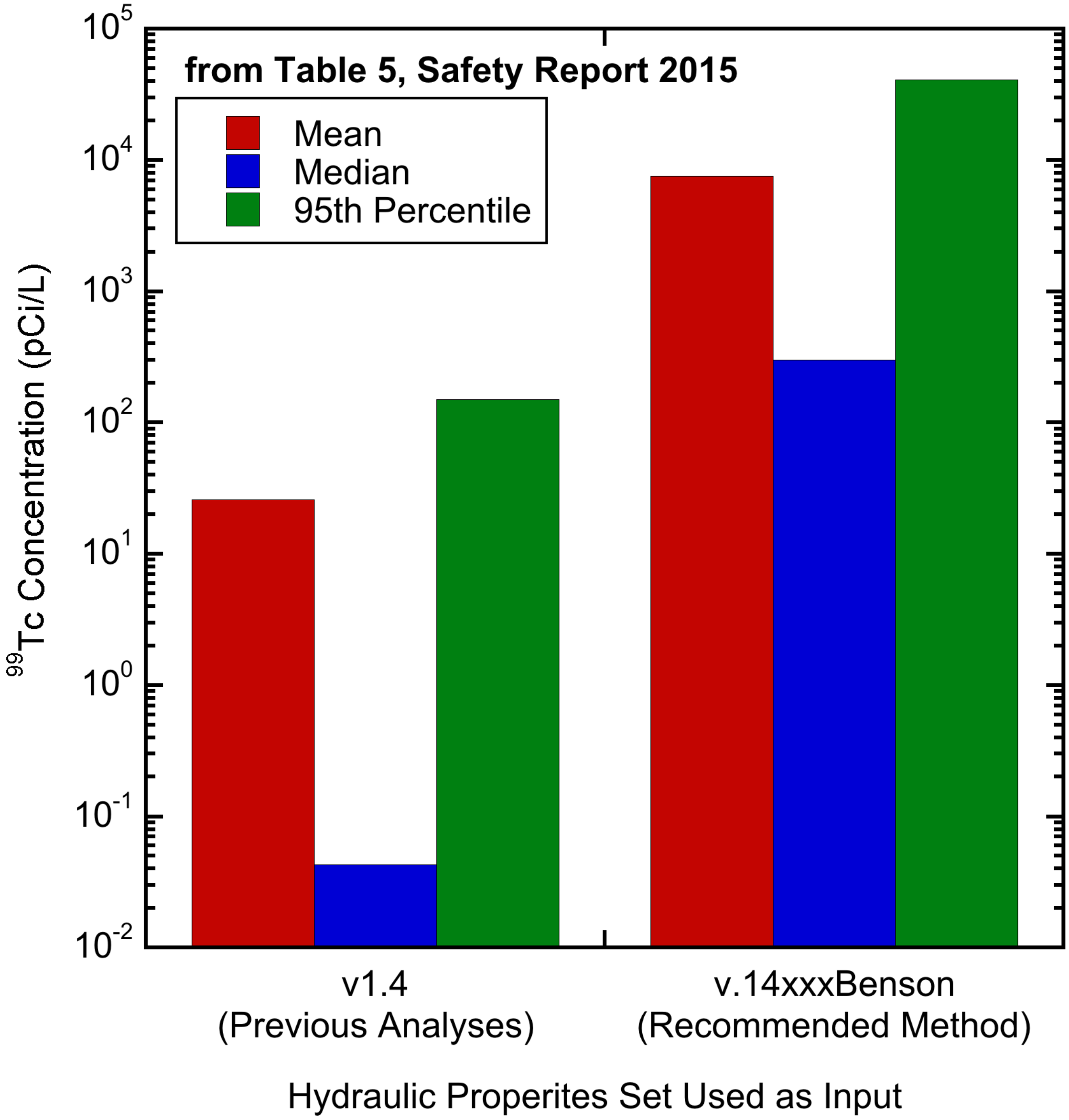


*Figure 11. Tc-99 concentrations in groundwater extracted from DU PA v1.4, Appendix 21, Table 5, and predicted using percolation rates from previous analyses by Energy*Solutions *and from percolation rates derived from using hydraulic properties developed with methods by DEQ/SC&A recommended in Appendix E (April 2015 SER).*

DEQ Discussion of NAC-0106_R0 – July 2019

Energy*Solutions*/Neptune refer to Interrogatory 71/1 for their complete response to concerns related to the formation of gullies on the cover leading to infiltration rates. This interrogatory remains open.

Energy*Solutions*/Neptune note that, although DEQ has requested daily water balance plots of the flow simulation results, they have been provided with annual averages for water balance components of precipitation, runoff, evapotranspiration, storage, and deep drainage and that daily water balance is not the appropriate scale to evaluate a performance assessment model. DEQ/SC&A contend that it is only daily water balance information that will allow an assessment of the reasonableness of the infiltration. For instance, yearly averages of precipitation do not reflect the important role that snowmelt has on infiltration in which the saturations could be sufficiently high to reach K_{sat} values. Yearly averaging may be one of the reasons the HYDRUS results are insensitive to K_{sat}, which is further discussed in Interrogatory 176/1: Representative Hydraulic Conductivity Rates.

With respect to the implementation of the naturalized parameters into HYDRUS, Energy*Solutions*/Neptune state (Neptune 2018f, p. 41):

> *Based on UDEQ's conceptual model of formation of soil structure in cover systems, there is no difference in the in-service properties of what were constructed as storage layers or barrier layers (Benson et al. 2011). Normally, the distinction in properties between depth intervals in the flow model that constitute layers used for the cover simulations are the hydraulic properties of the intervals. The DEQ conceptual model does not maintain the differences in hydraulic properties that provide the designed functions of store and release layers and barrier layers. Thus, the cover can no longer be represented by a layered system.*

DEQ/SC&A disagrees that Energy*Solutions*/Neptune cannot build in layering into the naturalized model and remain consistent with the recommendations in NUREG/CR-7028. For example, a more permeable surface crust (upper 300 mm) could be input that would ensure that the surface boundary (i.e., infiltration) is represented realistically. That is not outside the bounds of the recommendations in NUREG/CR-7028. Lack of detailed (e.g., daily) water balance predictions for any part of the simulation period has confounded an assessment of the realism of this interface. For example, without careful attention to the surface layer properties, runoff can be overpredicted and infiltration underpredicted. Consequently, SC&A is not able to evaluate the efficacy of the surface boundary with information provided and cannot have confidence that infiltration at the surface is represented reasonably.

Energy*Solutions*/Neptune need to provide a daily water balance record for several periods in the time series that would allow an independent assessment of the realism of their predictions.

This interrogatory remains open.

2.1.5 Interrogatory CR R313-25-8(4)(d)-21/2: Infiltration Rates

DEQ Conclusion from April 2015 SER, Appendix C

As discussed in the 2015 DU PA SER (Section 4.1.1.1), there are still a number of unresolved issues with respect to the selection of parameter ranges, distributions, and correlations, as well as the modeling approach and predicted sensitivities. These concerns are detailed in Appendix B to the April 2015 DU PA SER. Before the DU PA can be determined to be adequate, additional modeling of the ET cover infiltration rates will need to be conducted based on in-service hydraulic properties and correlated log(α) and log(K_{sat}) values as described in Appendix E. Without this information, DEQ is unable to conclude if the infiltration rates predicted by the DU

GoldSim model are reliable or representative of future conditions (i.e., ≥ 10,000 years). Therefore, this interrogatory remains open.

DEQ Critique of DU PA v1.4, Appendix 5:

Energy*Solutions*/Neptune describe their approach to parameterizing the radon barriers for v1.4 as follows (Neptune 2015e, pp. 39–40):

> *An expanded assessment of the performance of the radon barriers was made possible by developing a distribution for the saturated hydraulic conductivity (K_s) of the radon barriers to use for the modeling. The K_s values for the radon barriers were sampled from a distribution developed from a minimum value of 4.32×10^{-3} cm/day corresponding to the design specification for the upper radon barrier (Whetstone 2007, Table 8), and 1st, 50th, and 99th percentile values of 0.65 cm/day, 3.8 cm/day, and 52 cm/day, respectively, which are from a range of in-service ("naturalized") clay barrier K_s values described by Benson et al. (2011, Section 6.4, p. 6-12). A shifted lognormal distribution was fit to the 1st, 50th, and 99th percentiles, and the minimum value of 4.32E-3 cm/day was used as a shift. The resulting distribution is:*
>
> *Ks ~ Lognormal geom. mean: 3.37 cm/day, geom. sd: 3.23 cm/day, with a right shift of 0.00432 cm/day*
>
> *For all HYDRUS simulations, the same K_s value was applied to both the upper and lower radon barriers.*
>
> *Correlations between α and n were investigated by analyzing the combinations of α and n for the 12 textural classes in Rosetta (Schaap, 2002), and no correlations were evident. There were also no statistically significant correlations between K_s and α or n.*
>
> *The developed 50 sets of uncertain parameters for α, n, and K_s were then used as hydraulic property inputs to 50, 1000-year simulations using HYDRUS-1D.*

This approach varies from that taken in DU PA v1.2 as described below (Neptune 2014b, Appendix 5, pp. 41–42):

> *An expanded assessment of the performance of the radon barriers was made possible by developing a distribution for the saturated hydraulic conductivity (K_s) of the radon barriers to use for the modeling. The K_s values for the radon barriers were sampled from a distribution developed from a minimum value of 4×10^{-3} cm/day corresponding to the design specification for the upper radon barrier (Whetstone 2007, Table 8), and 50th and 99th percentile values of 0.7 cm/day and 52 cm/day, respectively, which are from a range of in-service ("naturalized") clay barrier Ks values described by Benson et al. (2011, Section 6.4, p. 6-12). A normal distribution was fit to the 50th and 99th percentiles, and the minimum value of 4E-3 cm/day was used as a shift. For all HYDRUS simulations, the same K_s value was applied to both the upper and lower radon barriers.*

> *Correlations between α and n were investigated by analyzing the combinations of α and n for the 12 textural classes in Rosetta (Schaap, 2002), and no correlations were evident. There were also no correlations between K_s and α or n.*
>
> *The developed 20 sets of uncertain parameters for α, n, and K_s were then used as hydraulic property inputs to 20 1000 year simulations using HYDRUS-1D.*

The infiltration results for v1.4 are presented on p. 44 of Appendix 5 (Neptune 2015e):

> *The 50 HYDRUS-1D simulations resulted in a distribution of average annual infiltration into the waste zone, and average volumetric water contents for each ET cover layer. Infiltration flux into the waste zone ranged from 0.0067 to 0.18 mm/yr, with an average of 0.024 mm/yr, and a log mean of 0.018 mm/yr for the 50 replicates.*

These fluxes are significantly lower than those calculated in v1.2 and provided on p. 45 (Appendix 5): "Infiltration flux into the waste zone ranged from 0.007 to 2.9 mm/yr, with an average of 0.42 mm/yr, and a log mean of 0.076 mm/yr for the 20 replicates" (Neptune 2014b).

Since it appears that the greatest change between v1.2 and v1.4 is that the K_{sat} values were increased in v1.4, it is not clear why the infiltration rates would decrease, since increasing K_{sat} values are typically accompanied by increasing infiltration rates. However, deciphering why the predictions differ is nearly impossible with the output provided. Understanding the outcome requires water balance graphs showing the seasonal hydrologic cycle and the dynamics of water throughout the year. The difference in the predictions may have to do with the shape of the normal distributions that were used. They are similar, but, as described below, using the lower bound constraint may have affected the distribution of K_{sat} values that are predicted.

Probability density functions (PDFs) are shown in Figure 12 that were used to describe uncertainty and spatial variability in the saturated hydraulic conductivity of the radon barrier in the unsaturated zone modeling reports submitted in June 2014 and October 2015 (Neptune 2014b, 2015e). A PDF is analogous to a histogram, describing the probability density associated with a particular value of the random variable for a defined probability distribution (in this case, the three-parameter lognormal distribution). The distributions for 2014 and 2015 were parameterized to the extent practical using the methodology described in the 2014 and 2015 Unsaturated Zone modeling reports. A three-parameter lognormal distribution was used, given that the 2014 and 2015 reports indicate that a lower bound > 0 was stipulated in the 2014 and 2015 reports. A description of the three-parameter lognormal distribution can be found in Zhai and Benson (2006).

For 2014, the distribution was parameterized using a lower bound (ξ) = 0.004 centimeters per day (cm/d), a log-mean (μ) of -0.357 corresponding to a 50^{th} percentile of 0.7 cm/d, and a log-standard deviation (σ) of 1.85. The lower bound and log-mean are equal to the values stipulated in the 2014 report. The log-standard deviation was obtained iteratively by ensuring that the 99^{th} percentile equaled 52 cm/d, as described in the 2014 report.

Two PDFs are shown for 2015 in Figure 12 below because the fitting methodology and parameters cited in the 2015 report lead to ambiguity. The PDF marked "2015 reported" corresponds to ξ = 0.00432 cm/d (lower bound indicated in 2015 report), μ = 1.215

(corresponding to geometric mean of 3.37 cm/d indicated in 2015 report), and $\sigma = 1.17$ (corresponding to 3.23 cm/d referred to in 2015 report as the "geom. sd"). These parameters ("2015 reported"), however, do not yield a 1st percentile of 0.65 cm/d and a 99th percentile of 52 cm/d as indicated in the report (mathematically impossible). Thus, a second parameter set was selected (referred to as "2015 reported and fit"). This parameter set has $\xi = 0.00432$ cm/d (lower bound indicated in 2015 report), $\mu = 1.215$ (corresponding to geometric mean of 3.37 cm/d indicated in 2015 report), and $\sigma = 1.17$. The log-standard deviation (σ) was selected by iteration so that the 99th percentile equaled 52 cm/d, as indicated in the report. However, the 1st percentile could not be matched along with the 99th percentile (mathematically impossible). The 1st percentile hydraulic conductivity for the distribution "2015 reported and fit" is 0.1 cm/d.

The PDFs in Figure 12 provide insight into the unexpected outcomes for the percolation rates predicted in 2014 and 2015, the latter percolation rates being lower despite substantially higher geometric mean saturated hydraulic conductivity. For the PDF marked "2015 reported and fit," which seems to be the PDF most likely used as input to the model, the upper tail of the distribution is much lighter than for the 2014 PDF (e.g., the probability of high hydraulic conductivities is lower in the 2015 modeling). Consequently, the percolation rates tend to be lower in the 2015 report relative to those in the 2014 report. This would not be the case if the parameters corresponding to "2015 reported" were used as input to the model, as the PDF for this case generally has a heavier upper tail relative to the PDF used as input to the 2014 model.

This ambiguity highlights an important issue: reports issued by Energy*Solutions* should include sufficient information for an independent party to reproduce the outcomes without ambiguity. At a minimum, probabilistic descriptions should show a mathematical description of the distribution employed (e.g., probably distribution and definition of parameters) and a list of the values assigned to each parameter for each case being analyzed.

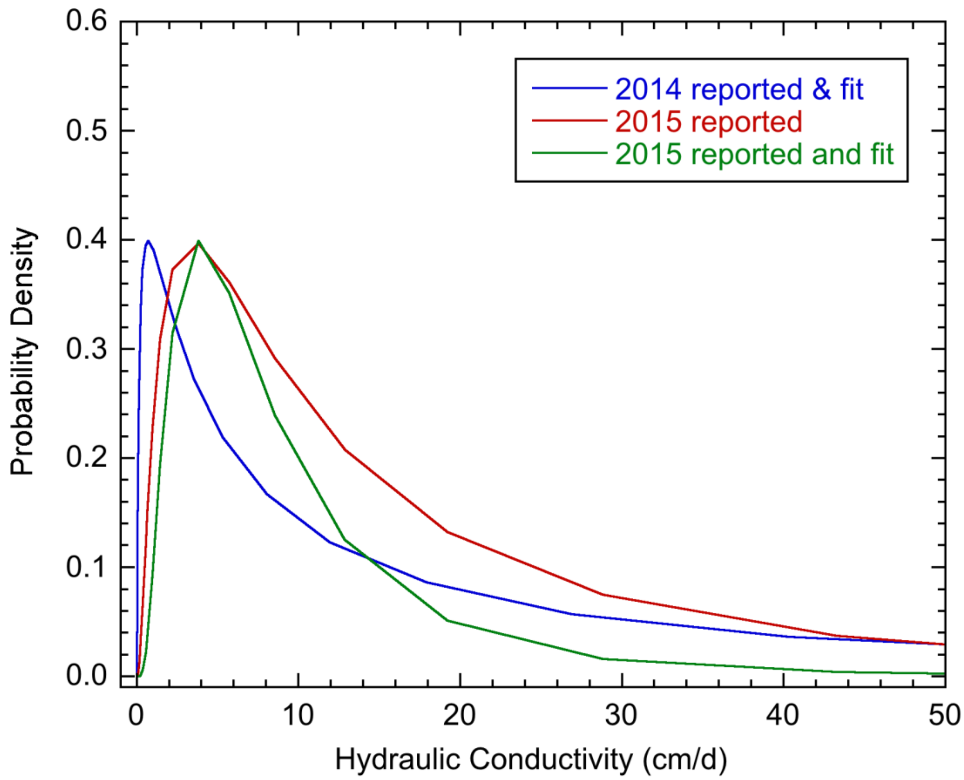


Figure 12. Probability density functions for saturated hydraulic conductivity apparently used as input in the models described in the 2014 and 2015 unsaturated zone modeling reports

DEQ Critique of DU PA v1.4, Appendix 21

Naturalized Cover

Significant disagreement remains regarding appropriate hydraulic properties to represent "naturalized" conditions (Energy*Solutions* nomenclature) for the cover. Energy*Solutions* states correctly that hydraulic properties they developed with the approach recommended in Appendix E to the 2015 SER are significantly different from those used in their previous analyses for the DU PA. This is not surprising, as the hydraulic properties Energy*Solutions* had used in previous analyses (Bingham Environmental 1991) were obtained nearly three decades ago using poorly documented sampling and testing methods. Techniques for undisturbed sampling and measurement of unsaturated hydraulic properties have improved dramatically since the Bingham Environmental data set was created. The quality and relevancy of the Bingham Environmental data used by Energy*Solutions* is suspect, and there is good reason for hydraulic properties obtained using the approach recommended in Appendix E (April 2015 SER) to differ significantly from those Energy*Solutions* has used in past analyses.

Energy*Solutions* also states that the parameters sets obtained with the approach recommended in Appendix E (2015 SER) "are conservative" and "do not represent the likely evolution of the cover system" Neptune 2015j, p. 2). Energy*Solutions* also states that "When included in the model, they produce a model that does not make sense for the site conditions of Clive" (Neptune 2015j, p. 10). Energy*Solutions* will need to provide quantitative evidence to support these assertions. The photographs in Figures 4 and 5 of Appendix 21 are inconclusive and provide no quantitative basis to support inferences that structural development and alterations in hydraulic properties do not occur at Clive. Structural development that occurs in covers due to pedogenesis generally is not visible at the scale represented in these photographs. Moreover, the smearing that occurs in test pits can obscure structure that is present. If Energy*Solutions* wishes to use these analogs as evidence to support hydraulic properties representing long-term conditions significantly different from NUREG/CR-7028 (Benson et al. 2011), Energy*Solutions* should conduct appropriate measurements on these in-place materials to demonstrate that the hydraulic properties are indeed different from the abundance of data in NUREG/CR-7028.

Energy*Solutions* goes on to argue that the Clive location is not represented properly using the data set in NUREG/CR-7028 and indicates that less extensive pedogenic change should be expected at Clive relative to the sites in NUREG/CR-7028. They attribute more extensive pedogenic change to a greater abundance of biota as well as surface and subsurface biomass at sites in humid climates, which is incorrect. Changes in hydraulic properties due to pedogenesis are predominantly caused by cycling in state of stress due to seasonal changes in pore water suction. Those cycles tend to be *larger* in arid regions than in humid regions, which promotes greater volume change and more rapid pedogenesis. In fact, conceptually, pedogenesis should occur more rapidly, and be more extensive, in a more arid climate such as Clive relative to a more humid climate. However, as shown in NUREG/CR-7028, climate effects are not significant over time, as structure develops and hydraulic properties are altered in essentially all climates.

Energy*Solutions* also suggests that the Clive site is outside the range of sites represented in the data included in NUREG/CR-7028. DEQ does not agree with the suggestion that the semi-arid climate at Clive is greatly different from the climate at sites in Apple Valley, California, Monticello, Utah, or Boardman, Oregon. Each of these sites is semi-arid to arid and not greatly different from Clive. To further address this issue, data from other sites in the region should be considered as discussed in Interrogatory 189. These sites include the Monticello Uranium Mill Tailings Repository, the Blue Water Uranium Mill Tailings Reclamation Site near Grants, New Mexico, and the Cheney Disposal Facility near Grand Junction, Colorado. While none of these sites has the same climate as Clive, they are sufficiently similar to be considered reasonable analogs. An argument against the relevancy of these analogs, especially without data, is not logical.

Homogeneous Cover
Energy*Solutions* has used a homogeneous cover profile in the most recent simulations. This was not the intent of our previous comments, and was misconstrued from the parameter recommendations provided in Appendix E of the 2015 SER. The cover profile should retain a layered structure representative of the materials planned for each layer, but with the hydraulic properties of each layer adjusted to reflect pedogenesis. The parameters in the 2015 SER recommendations were presented as a guide for reasonable ranges consistent with the recommendations in NUREG/CR-7028.

Correlation and Range of Hydraulic Properties
The hydraulic properties Energy*Solutions* developed based on the multivariate normal random generator as recommended by DEQ/SC&A are consistent with those in NUREG/CR-7028 for "naturalized" conditions. The cross-correlation structure between K_{sat} and α, based on ln K_{sat} and ln alpha, is also consistent with the literature, as shown in Figure 13.

The scatter in this correlation is characteristic of real data, and the correlation is realistic. However, the range is constrained for both K_{sat} and α because Energy*Solutions* used the lower-end standard deviation provided in the 2015 Appendix E SER recommendations. A broader range would have been obtained using the typical and high-end recommendations for the standard deviation.

Energy*Solutions* indicates that the lower-end standard deviation was used "to keep the input parameters within the ranges" of the 2015 Appendix E SER recommendation, which was not the intent of the recommendation. Energy*Solutions* should conduct their simulation using a typical standard deviation for each parameter. This will likely affect only the tails in the percolation data (high and low percolation rates in Figure 2 of Appendix 21) but likely will affect the 95^{th} percentile doses (reported in Table 5 of Appendix 21).

Furthermore, the NUREG/CR-7028 recommended range of α values utilizes averaged values for the entire cover system for each embankment studied in the NUREG, not individual sampling points, or small parts of an embankment. The information is already presented at the scale needed for application to a single cover system on a single embankment. Therefore, either upscaling, or subsampling of the data, by Neptune to get a narrower range of α values for an embankment cover system would be neither necessary nor appropriate.

For all sets of realizations, the mean and the standard deviation (or ln std deviation for K_{sat} and alpha) should be cited.

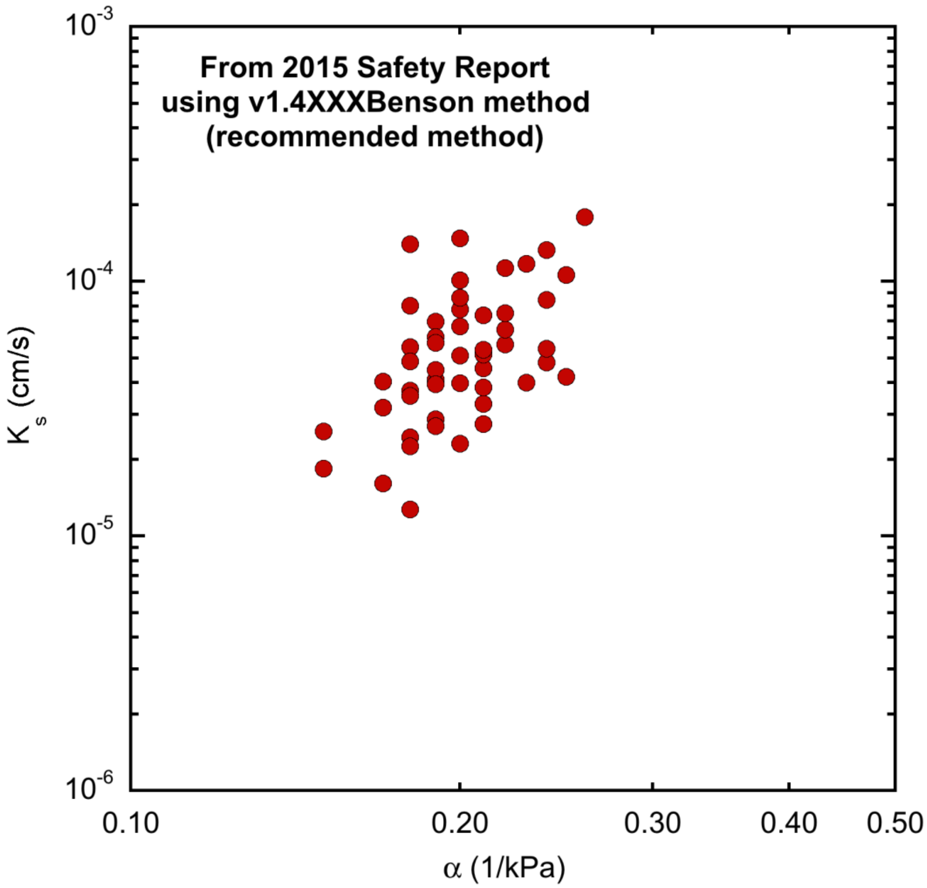


*Figure 13. Fifty realizations of saturated hydraulic conductivity log (K_{sat}) and log(alpha) developed by Energy*Solutions *using the method recommended in 2015 (from Table 2 of Appendix 21).*

Unsaturated Flow Model Output

Percolation rates predicted with the hydraulic properties developed by Energy*Solutions* using the procedure recommended in Appendix E to the 2015 SER are reasonable and consistent with percolation rates measured and predicted for other final covers in regions of similar aridity, as reported in NUREG/CR-7028. Energy*Solutions* predicts percolation rates ranging from 0.57 to 1.31 mm/yr using hydraulic properties developed with the procedure recommended by DEQ/SC&A. As a comparison, percolation rates ranging from 0.0 to 3.8 mm/yr have been measured using an ACAP lysimeter at DOE's Monticello U-Mill Tailings Disposal Facility in Monticello, Utah, over the period 2000–2016. Percolation rates at other arid or semi-arid sites described in NUREG/CR-7028 with comparable cover profiles include Apple Valley, California (0–1.8 mm/yr), Boardman, Oregon (0 mm/yr), and Underwood, North Dakota (1.9–9.4 mm/yr).

As in past reports from Energy*Solutions*, the model predictions are difficult to interpret and evaluate with the level of detail provided. We have requested water balance graphs (see CR R317-6-2.1-20/2, Figure 10), which depict the important interplay between the water balance quantities throughout the water year. Energy*Solutions* has included an annualized water balance chart (Figure 3, Appendix 21), but this chart does not provide the additional information or insight that is necessary for a proper evaluation of the model predictions. Water balance graphs should be provided.

Regression Model

The regression model used in GoldSim was updated using predictions obtained with the hydraulic properties Energy*Solutions* developed based on the method recommended in Appendix E to the April 2015 SER. This model relates the average annual percolation rate into the waste to the hydraulic properties of the cover soils. The regression method is not described in Appendix 21 but is likely the same method used by Energy*Solutions* in the past. Appendix 21 does not include supporting statistics confirming the significance of the regression and each of the independent variables included in the regression model. Thus, the efficacy of the regression cannot be evaluated.

Percolation rates predicted with the regression model and obtained directly from HYDRUS show a good comparison (see Figure 6 of Appendix 21). This is expected, because the regression model is based on the HYDRUS output. A concern raised before, and yet unresolved, is whether good agreement would exist between percolation rates predicted with the regression model and an independent set of predictions from HYDRUS using the same underlying inputs (e.g., a blind forward comparison). That type of evaluation is needed to confirm the validity of the regression model. For example, if an analysis was conducted with the typical standard deviations to obtain a broader range in outcomes, would the comparison between the predictions from the regression model and predictions from HYDRUS be in comparable agreement?

At a minimum, Energy*Solutions* should conduct an independent set of simulations where percolation is predicted with HYDRUS and then compared with predictions obtained with the regression model. This is the only fair means to evaluate the efficacy of the regression model. These predictions should be conducted with the typical standard deviations to get a realistic representation of the tails of the distribution of percolation.

DEQ Discussion of NAC-0106_R0 – July 2019

Radon Barrier K_{sat} Distribution

In response to a DEQ request for clarification with respect to what probability distribution of K_{sat} was used in v1.4, Energy*Solutions*/Neptune provide a detailed explanation. However, exactly how this distribution was incorporated into HYDRUS is still not clear. In response to Interrogatory 20/2: Groundwater Concentrations, Energy*Solutions*/Neptune indicate that all layers were set to homogeneous, naturalized conditions, whereas the response to this interrogatory indicates that the radon barriers were assigned parameter distributions distinct from the other layers. This issue is discussed in greater detail in Section 4.1.2.

Naturalized Cover

In response to a DEQ/SC&A comment regarding there being dramatic improvements in techniques for collecting undisturbed samples and measuring unsaturated zone properties since 1991, *EnergySolutions*/Neptune contend that there has been little change to the standard methods used to determine saturated hydraulic conductivity, volumetric water content, and water retention relations.

The primary issue with Energy*Solutions*/Neptune's position regarding naturalization is that they have not characterized the soil properties from near-surface layers that have undergone weathering and pedogenesis. They have excavated test pits and examined profiles, but for their non-naturalized HYDRUS modeling rely heavily on (1) old data from Bingham Environmental for the radon barrier and (2) Rosetta properties for overlying layers, neither of which is relevant to designing and evaluating an engineered cover.

Homogeneous Cover
DEQ/SC&A requested that hydraulic property recommendations and cover material naturalization presented in Benson et al. (2011) and in Appendix E (DEQ 2015) be used in the performance assessment. DEQ/SC&A also requested that "The cover profile should retain a layered structure representative of the materials planned for each layer, but with the hydraulic properties of each layer adjusted to reflect pedogenesis. The parameters in the 2015 SER recommendations were presented as a guide for reasonable ranges consistent with the recommendations in NUREG/CR-7028." In response to this request, Energy*Solutions*/Neptune state, "Given the UDEQ conceptual model of making no distinction between the properties of storage and barrier layers, the cover can no longer be represented by a layered system" (Neptune 2018f, p. 53). As described in Interrogatory 20/2: Groundwater Concentrations, it is DEQ/SC&A's position that layering can be included and remain consistent with the recommendations in NUREG/CR-7028.

Correlation and Range of Hydraulic Properties
Energy*Solutions*/Neptune contend that the saturated hydraulic conductivity (K_{sat}) and van Genuchten's α parameter used as input to the model are uncorrelated. That is an unlikely occurrence that is inconsistent with other data sets in the literature and suggests an inconsistency in the data set. However, independent simulations conducted by DEQ/SC&A have shown that percolation rates predicted with the saturated hydraulic conductivity (K_{sat}) and α parameter uncorrelated are higher than those predicted with correlation. Thus, ignoring correlation between the K_{sat} and α parameter is acceptable.

With respect to the range of hydraulic properties, Energy*Solutions*/Neptune provide an explanation for the selected variance and estimates of uncertainty and its origins in the Rosetta database. Per the discussion provided in Supplemental Interrogatory Comment 2 (Section 4.1.2), for their naturalized single layer HYDRUS model, Energy*Solutions*/Neptune are using the hydraulic property recommendations and cover material naturalization presented in NUREG/CR-7028. However, there are still related concerns remaining, as discussed in Section 4.1.2.

Unsaturated Flow Model Output
DEQ/SC&A requested plots of flow model water balance components on a daily basis. These components are precipitation, runoff, infiltration, evaporation, transpiration, storage, and percolation (deep drainage). In response to this request, Energy*Solutions*/Neptune discuss how steady-state annual averages of net infiltration and water content from the HYDRUS simulations are the model results used to develop statistical distributions of these parameters for inputs to the GoldSim model for the Clive DU PA. However, as is described in greater detail in Section 4.1.5, annual averages can be misleading because they do not capture larger pulses of percolation rate that can occur during wet periods, such as snow melt events. Assessing the significance of these short-duration higher percolation events is necessary to adequately evaluate the reliability of the DU PA.

Regression Model

A concern raised before, and yet unresolved, is whether good agreement would exist between percolation rates predicted with the regression model and an independent set of predictions from HYDRUS using the same underlying inputs (e.g., a blind forward comparison). That type of evaluation is needed to confirm the validity of the regression model. DEQ/SC&A also requested that, at a minimum, Energy*Solutions*/Neptune should conduct an independent set of simulations where percolation is predicted with HYDRUS and then compared with predictions obtained with the regression model. This is the only fair means to evaluate the efficacy of the regression model. These predictions should be conducted with the typical standard deviations to get a realistic representation of the tails of the distribution of percolation.

In response to these comments, Energy*Solutions*/Neptune provide a detailed explanation for why these model verification tests should not be performed. To reasonably demonstrate that the performance objectives will be met, DEQ/SC&A maintains the position that these verification tests need to be performed to gain adequate confidence that the linear model provides a reasonable abstraction of the HYDRUS output. Furthermore, as discussed in greater detail in Section 4.1.5, the linear model derived from the non-naturalized HYDRUS output and used in GoldSim for percolation rates has been shown to provide a reasonable prediction of percolation rates, except at the extreme case where the linear model underpredicts the percolation rate by approximately a factor of 2. Given the limited number of realizations used in the non-naturalized HYDRUS model (50), the tails of the distribution likely are underrepresented, and a much greater deviation may exist for higher percolation rates. The significance of underprediction in the tails needs greater documentation, and the impact of this underprediction needs to be quantified.

The results of comparable analysis with the naturalized HYDRUS model have not been presented.

This interrogatory remains open.

2.1.6 Interrogatory CR R313-25-8(4)(a)-28/3: Bioturbation Effects and Consequences

DEQ Conclusion from April 2015 SER, Appendix C

As stated in the 2015 DU PA SER, Section 4.4.3, "Effect of Biologicals on Radionuclide Transport":

> *Energy*Solutions *has not shown that the cover system is sufficiently thick or designed with adequate materials to protect the cover system or the underlying bulk waste in the embankments against deep rooting by indigenous greasewood (a species known to penetrate soils at other sites down to 60 feet) or other plants, or against biointrusion by indigenous ants or mammals (e.g., with maximum documented burrowing depths greater than the proposed cover thickness). Higher rates of infiltration are typically associated with higher contaminant transport rates. Under Utah rules, infiltration should be minimized [see UAC Rule R313-25-25(3) and (4)]. DEQ cannot determine the adequacy of the DU PA until Energy*Solutions *accounts for greater infiltration through the cover system at the proposed Federal Cell embankment due to biointrusion by plant roots and by animals.*

Therefore, this interrogatory remains open.

DEQ Critique of DU PA v1.4, Appendix 5

Energy*Solutions*/Neptune retain the same assumptions with respect to biointrusion depths and potential impact on infiltration in v1.4 as were provided in v1.2.

DEQ Critique of DU PA v1.4, Appendix 21

Energy*Solutions* has conducted a series of analyses to evaluate the impact of erosion on percolation rates from the cover. In one case, the simulation included loss of 1.2 meters of cover soil. Energy*Solutions* reports that percolation rates obtained for the full thickness cover and a cover eroded by 1.2 meters are essentially the same.

This is not logical, given that the soil in the cover is required to store the water during cooler and wetter periods, and then to release the water during drier periods. The proposed cover is 1.52 meters thick. If the cover thickness is reduced by 1.2 meters via erosion, then the soil water storage capacity of the cover will be reduced by approximately 80 percent, and the percolation should change accordingly. Without supporting analysis, all of the HYDRUS modeling is suspect.

Additional quantitative and mechanistic evidence is needed to support the outcomes in this part of Appendix 21. Water balance graphs, which depict the temporal variation in water balance quantities (rather than a water balance quantity chart as presented previously by Energy*Solutions*) could be used to illustrate whether the outcomes are reasonable. Water balance graphs typically are created using daily output predicted from a water balance model and show the seasonal variation in each water balance quantity. Examples of water balance graphs are shown in Figure 10 (CR R317-6-2.1-20/2). These graphs depict actual water balance data; water balance graphs from a model prediction would be similar. The soil water storage record in the water balance graph would be compared to the soil water storage capacity of the eroded profile.

Clive lies in an area having a semi-arid climate. Only certain types of plants grow readily at Clive. How will the limited variety and density of plants provide adequate vegetative cover for erosion protection on an embankment? Energy*Solutions* should find and document natural analogs in the area that support their predictions, particularly since the predicted erosion rates appear too low to be realistic.

A related concern is the importance of the biological soil crust for sustaining plant growth and the high uncertainty regarding its characteristics at the Clive site. Energy*Solutions* should provide examples with quantitative data from sites in similar climate and with similar soils. These examples should show how biological soil crust is preserved or reestablished, the timeline for reestablishment, and how the presence (or not) of the biological soil crust affected erosion.

DEQ Discussion of NAC-0106_R0 – July 2019

The need for water balance graphs, typically created using daily output predicted from a water balance model and showing the seasonal variation in each water balance quantity, is discussed in Interrogatory 20/2: Groundwater Concentrations.

Energy*Solutions*/Neptune refer to their response provided in Interrogatory 05/2: Radon Barrier supporting their position that the ET cover design is adequate to protect against intrusion by plants, animals, or ants. As discussed in Supplemental Interrogatory Comment 2, Energy*Solutions*/Neptune apparently have used naturalized parameters in their HYDRUS modeling that incorporate the effects of plants, animals, and insects on infiltration and water redistribution. All remaining issues are discussed in Section 4.1.2.

Concerns regarding the importance of the biological soil crust for sustaining plant growth and the high uncertainty regarding its characteristics at the Clive site are discussed in Interrogatory CR R313-25-8(4)(a)-71/1: Biotic Processes in Gully Formation.

The concerns raised under Interrogatory 28/3: Bioturbation Effects and Consequences are the same as those raised in Interrogatory 20/2: Groundwater Concentrations, Supplemental Interrogatory Comment 2, and Interrogatory 71/1: Biotic Processes in Gully Formation, which all remain open.

2.1.7 Interrogatory CR R313-25-7(3)-60/2: Modeled Radon Barriers

DEQ Conclusion from April 2015 SER, Appendix C

As described under Interrogatory 05, based on several unresolved issues related to the ET cover, DEQ indicated in the 2015 DU PA SER Section 4.1.1.1 that the cover design was deficient and that it cannot determine the adequacy of this portion of the Clive DU PA. (See the description under Interrogatory 05 above for specific details.) Therefore, this interrogatory remains open.

DEQ Critique of DU PA v1.4, Appendix 5, Appendix 21

See Interrogatory 21 for discussion regarding approach and concerns related to modeling the radon barriers.

DEQ Discussion of NAC-0106_R0 – July 2019

For their response to this interrogatory, Energy*Solutions*/Neptune referred to other interrogatories that include the same concerns.

This interrogatory raises the same issues as those included in Interrogatories 5/2: Radon Barrier and 21/2: Infiltration Rates and Supplemental Interrogatory Comment 2, which all remain open.

2.1.8 Interrogatory CR R313-25-8(4)(a)-71/1: Biotic Processes in Gully Formation

DEQ Conclusion from April 2015 SER, Appendix C

In its Round 1 response, Energy*Solutions* indicated that "The mechanism of gully formation (e.g., burrowing animals, tree throw, OHV use, tornados) is not important in the function of the model, only that the gully exists" (ES 2014a, p. 68). The response continued: "In the Clive DU PA Model v1.0, no such sophisticated analysis was done—rather, a simple distribution was used as a screening tool in order to determine whether gully formation would be a significant process at the site." Energy*Solutions* concluded its response by stating that "The thinner cover at gullies could also result in enhanced infiltration and enhanced radon flux from the wastes below, especially if the radon barrier were compromised."

In Round 2, DEQ stated that the "Round 1 Interrogatory Response is satisfactory, provided that the results of the SIBERIA modeling are reflected in the radon flux and other dose models" (DRC 2014a, p. 79).

The Clive DU PA Model includes a gully formation model; however, the DU PA Model v1.2 (p. 3) states that "No associated effects, such as biotic processes, effects on radon dispersion, or local changes in infiltration are considered within the gullies." As indicated in the April 2015 DU PA SER, Section 4.4.2, Energy*Solutions* offered the following explanation for these omissions in its Interrogatory 20 Round 2 response:

> *While the formation of some of the gullies may actually erode through significant depths of the evapotranspirative cover, the ratio of gully footprint to total evapotranspirative cover surface area remains minimal.*

Further, in its Round 3 response to Interrogatory 70, Energy*Solutions* stated that "The influence of gully formation on infiltration and radon transport is negligible given the current below grade disposal design" (ES 2014c, p. 43). The reason given is "that only a small fraction of the cover would have gullies extending through the surface and evaporative zone layers to the top of the frost protection layer."

Nonetheless, the 2015 DU PA SER, Section 4.4.2 concluded the following:

> *Before the DU PA can be determined to be adequate, Energy*Solutions *needs to clarify certain issues relating to Appendix 10 to the DU PA Model v1.2 (…)… DRC is currently reviewing a license amendment request*[6] *to use an ET cover of similar design to that proposed for the Federal Cell in the DU PA. Any recommendations and conclusions from that review must be applied to the proposed Federal Cell as well.*

Therefore, this interrogatory remains open.

DEQ Critique of DU PA v1.4, Appendix 5, Appendix 21

No further analysis has been performed pertaining to biotic processes in gully formation since v1.2.

DEQ Discussion of NAC-0108_R0 – July 2019

DEQ requested that any recommendations and conclusions from review of the Class A West cell be applied to the proposed Federal Cell as well. At the time when this interrogatory was prepared, an ET cover was being considered for both the Class A West Cell and the Federal Cell. Since that time, Energy*Solutions* has decided to use a rock-armored cover on the Class A West cell. Therefore, this portion of the interrogatory is no longer relevant.

This interrogatory also points to soil erosion issues raised in Section 4.4.2 of the April 2015 DU PA SER (DEQ 2015). DEQ expressed concern that gullies will form and enhance radon diffusion, deep infiltration, and contaminant transport. Energy*Solutions*/Neptune used the maximum permissible velocity methodology developed by NRC in NUREG-1623 (NRC 2002), to determine whether or not gullies would form in the most severe storm. According to Energy*Solutions*/Neptune: "A value of 5.0 ft/s was chosen as the maximum permissible velocity (MPV) based on the characteristics of the channel. This is the value listed for gravel in Table CH13-T103 of Colorado Water Conservation Board (CWCB 2006) and in Table 4.7 of Nelson et al. (1986)" (Neptune 2018g, p. 11). Based on the NRC methodology, this value must

[6] See Footnote 5.

be adjusted downward depending on the depth of flow across the embankment surfaces. In the case of the Federal Cell, the adjustment factor is 0.5, which would set the maximum permissible velocity at 2.5 feet per second (ft/s). The calculated flow velocities for the ET cover were 1.60 ft/s for the top slope and 2.03 ft/s for the side slope. Thus, based on an adjusted MPV of 2.5 ft/s, gullies would not form.

However, the selection of 5.0 ft/s as the MPV is not consistent with NRC recommendations. The NRC states in Appendix A of NUREG-1623 that "Additionally, based on examination of data from the Soil Conservation Service (SCS, 1984), the staff recommends that the maximum permissible velocity for grasses covers and channels be limited to about 2½ to 3 ft per second. This limit is necessary because no credit may be taken for active maintenance in designing for long-term stability." Additionally, SCS 1984 states on page 7-7 that "A velocity of 3.0 ft per second should be the maximum, where because of shade, soils, or climate, only a sparse cover can be established or maintained." These sources call into question the assumption used in v1.4 of the DU PA of 5 ft/s. Using the flow depth adjustment factor of 0.5 indicates that the adjusted maximum permissible flow velocity should be 1.5 ft/sec. With the maximum permissible velocities recommended by NRC and SCS, and the NAC-0108_R0 calculated flow velocities, gullies can be expected to form.

Because the permissible velocity assumptions are less conservative than NRC recommendations, this interrogatory remains open.

2.1.9 Interrogatory CR R313-25-7(2) and 7(6)-81/2: Comparison of Disposal Cell Designs

DEQ Conclusion from April 2015 SER, Appendix C

Energy*Solutions* stated the following in its July 8, 2014, response to DEQ's Round 3 interrogatories (ES 2014c, p. 46):

> *A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.*

DEQ does not agree with this statement.

In its Round 3, DEQ provided additional critique:

> *None of the ES responses provided the requested comparison between the Class A West Cell and the Federal Cell cover designs. It is our belief that such a comparison of the structural design and expected performance of the cells with rock-armor and/or ET cover systems is needed to enable DRC to compare proposed and existing designs and ensure that the proposed designs comply with R313-25-7(2) and (6).*
>
> *At present, only a rock-armor cover system has been approved for the Class A West cell, and the proposed ET cover system for that cell is undergoing DRC review and has not yet been approved. ES should compare the proposed Federal Cell with all alternative cover systems that have been proposed for the Class A West cell, or with an approved cover system only.*

> *The proposed Federal Cell that contains the DU waste will need to have an approved design such that its cover system is fully integrated with, or completely isolated from, the existing 11e.(2) cover system, as appropriate, based on applicable federal and state laws and regulations. ES should show how the proposed ET cover system, based on soil, will be integrated with, or isolated from, the existing 11e.(2) rock-armor cover system. ES should describe how the design of that part of the Federal Cell containing DU waste will meet all potentially applicable DOE and NRC regulations, including types of wastes disposed of and connection, or lack of connection, with nearby waste cells, and also types of influence, or lack of influence, on or by other nearby waste cells, including the existing 11e.(2) cell.*
>
> *At this time, DRC does not expect ES to provide a "stand-alone engineering design report," as was requested in the original interrogatory. However, a more complete description of structural design and performance is requested, particularly in the design of features of the proposed cell contrasting with features of existing cells. We look forward to reviewing the revised information.* [DRC 2014b, pp. 93–94]

Energy*Solutions* did not, for example, provide any information about how the DU portion and the 11e.(2) portion of the Federal Cell would be linked or segregated. As discussed in the 2015 DU PA SER, Section 6.2.4:

> *To meet the requirements of UAC R313-25-9(5)(a), Energy*Solutions *shall submit a revised performance assessment that meets the requirements of that provision and that addresses the total quantities of concentrated DU and other wastes, including wastes already disposed of and the quantities of concentrated DU the facility now proposes to dispose in the Federal Cell.*

In addition, as stated Section 6.1.3 of the 2015 DU PA SER:

> *DRC is currently reviewing a license amendment request to use an ET cover of similar design to that proposed for the Federal Cell in the DU PA. Any recommendations and conclusions from that review must be applied to the proposed Federal Cell as well.*

These DU PA SER requirements should provide sufficient analyses and data to remedy the response to this interrogatory. Subsequently, Energy*Solutions* has advised that the proposed Federal Cell will be physically separated from the 11e.(2) cell. Energy*Solutions* has provided only engineering drawings but no written description of the new cell (i.e., Appendices 3 and 16 to the DU PA have not been revised). In addition, no information has been provided on the function of the 1-foot liner protective cover shown in Drawing No. 14002-L1A(0). What material is used? Was it included in performance assessment analyses? Therefore, this interrogatory remains open.

DEQ Critique of DU PA v1.4, Appendix 21

No further analysis has been performed on disposal cell designs since v1.2.

DEQ Discussion of NAC-0101_R0 – July 2019 2018a

At the time this interrogatory was generated, Energy*Solutions* was considering use of ET covers on both the Federal Cell and the Class A West cell. The focus of this interrogatory was to compare the design and expected functionality of the two ET covers. Since the time the interrogatory was developed, Energy*Solutions* has dropped the ET cover from consideration and now plans to use a rock-armor cover on the Class A West cell. Given this change in cover selection, the focus of this interrogatory shifts from a comparison of the two ET covers to an explanation of why a rock armor was determined to be the preferred choice for the Class A West cell while the ET cover was selected for Federal Cell.

We also note that the interrogatory raised a question regarding the cover liner: No information has been provided on the function of the 1-foot liner protective cover shown in Drawing No. 14002-L1A(0). What material is used? Was it included in performance assessment analyses? Energy*Solutions*/Neptune have not provided an answer to these questions.

Therefore, this interrogatory remains open.

2.1.10 Interrogatory CR R313-25-7(1–2)-90/2: Calibration of Infiltration Rates

DEQ Conclusion from April 2015 SER, Appendix C

As noted in Sections 4.1.1.1, 4.1.1.3, and 4.4 of the 2015 DU PA SER, several issues (including infiltration rates) regarding the ET cover remain unresolved. Therefore, this interrogatory remains open.

DEQ Critique of DU PA v1.4, Appendix 21

No further analysis has been performed on calibration of infiltration rates since v1.2.

DEQ Discussion of NAC-0106_R0 – July 2019

For their response to this interrogatory, Energy*Solutions*/Neptune referred to other interrogatories that include the same concerns.

This interrogatory raises the same issues as those included in Interrogatory 5/2: Radon Barrier and Supplemental Interrogatory Comment 2, which all remain open.

2.1.11 Interrogatory CR R313-25-7(1)-100/2: Groundwater Recharge from Precipitation

DEQ Conclusion from April 2015 SER, Appendix C

As noted in Sections 4.1.1.1, 4.1.1.3, and 4.4 of the 2015 DU PA SER, several issues (including recharge) regarding the ET cover remain unresolved. Therefore, this interrogatory remains open.

DEQ Discussion of NAC-0105_R0 – July 2019

Energy*Solutions*/Neptune did not explicitly respond to this interrogatory. The same topics in this interrogatory are discussed in Supplemental Interrogatory Comment 2 pertaining to naturalized parameters in HYDRUS, which remains open (see Section 4.1.2).

2.1.12 Interrogatory CR R313-25-8(4)(a)-108/2: Biointrusion

DEQ Conclusion from April 2015 SER, Appendix C

As discussed in the 2015 DU PA SER (Section 4.4.3), Energy*Solutions* has not shown that the cover system is sufficiently thick or designed with adequate materials to protect the cover system or the underlying bulk waste in the embankments against deep rooting by indigenous greasewood (a species known to penetrate soils at other sites down to 60 feet) or other plants, or against biointrusion by indigenous ants or mammals (e.g., with maximum documented burrowing depths greater than the proposed cover thickness). Higher rates of infiltration are typically associated with higher contaminant transport rates. Moreover, burrowing and rooting into bulk waste in the space below the cover system and above the DU may allow for transport of radioactive contaminants to the surface. If no bulk waste is emplaced, then this would not be an issue. However, since the economics of filling the space with non-radioactive soil versus LLRW are extremely negative, it is highly unlikely that the Licensee would do that. It is reasonably anticipated that this space would be filled with LLRW. The Licensee has dismissed the need to model such transport. Accordingly, DEQ has concerns about the thickness of the cover system. Under Utah rules, infiltration should be minimized (see UAC Rule R313-25-25(3) and (4)). DEQ cannot determine the adequacy of the DU PA until Energy*Solutions* accounts for greater potential infiltration through the cover system at the proposed Federal Cell embankment due to biointrusion by plant roots and by animals. Therefore, this interrogatory remains open.

DEQ Discussion of NAC-0105_R0 – July 2019

Energy*Solutions*/Neptune did not explicitly respond to this interrogatory. The same topics in this interrogatory are discussed in Supplemental Interrogatory Comment 2 pertaining to naturalized parameters in HYDRUS, which remains open (see Section 4.1.2).

2.1.13 Interrogatory CR R313-25-8(4)(a)-112/2: Hydraulic Conductivity

DEQ Conclusion from April 2015 SER, Appendix C

As discussed in the 2015 DU PA SER (Section 4.1.1.1), there are still a number of unresolved issues with respect to the selection of parameter ranges, distributions, and correlations, as well as the modeling approach and predicted sensitivities. These concerns are detailed in Appendix B to the April 2015 DU PA SER. Therefore, this interrogatory remains open.

DEQ Discussion of NAC-0105_R0 – July 2019

Energy*Solutions*/Neptune did not explicitly respond to this interrogatory. All of the concerns raised in this interrogatory are covered in open supplemental interrogatory comments discussed in Section 4.1.

2.1.14 Interrogatory CR R313-25-8(4)(D)-132/2: Sedimentation Model

DEQ Conclusion from April 2015 SER, Appendix C

In its Round 3 responses to Interrogatories 03 and 86, Energy*Solutions* indicated that a revised deep time model had been developed that took into account aeolian deposition, as well as lake sedimentation. The results of applying the revised model were provided to DEQ in the DTSA (Neptune 2014f, 2015l). While the DTSA incorporated the revised aeolian deposition model, the lake sediment model was identical to that used in the DU PA Model v1.0 and v1.2 (Neptune 2011, 2014a). In the 2015 DU PA SER, Section 5.1.1, DEQ evaluated the DTSA and, while agreeing with the revised aeolian deposition distribution, expressed concern regarding the magnitude of the Intermediate Lake sedimentation rate, among other areas of concern. DEQ performed GoldSim analyses to investigate its concerns and calculated radon fluxes that were significantly greater than the DTSA-reported flux.

Since the revised DTSA provided by Energy*Solutions*/Neptune does not address DEQ concerns regarding the large Intermediate Lake sedimentation rate, DEQ believes that there are still open questions related to ground surface radon fluxes reported in the revised DTSA (Neptune 2015l). Therefore, based upon our current understanding of the uncertainties contained within the deep time analysis, DEQ/SC&A is unable to determine at this time that the DTSA portion of the DU PA Model v1.2 is satisfactory, and Interrogatory 132 remains open.

DEQ Critique of DU PA v1.4, Appendix 13

Energy*Solutions*/Neptune continues to use the combination of a 500-year Intermediate Lake duration (Section 7.3) coupled with an Intermediate Lake total sedimentation of 2.82 meters (Section 7.4). As stated previously, this combination results in an Intermediate Lake sedimentation rate of 5.64 mm/yr. Such a large sedimentation rate is unsupported by any of the reviewed literature (see the April 2015 SER, Table 5-2). Energy*Solutions*/Neptune needs to either (1) provide independent documentation that a sedimentation rate of 5.64 mm/yr is plausible or (2) define a plausible, defensible Intermediate Lake sedimentation rate and redo the deep time analysis.

DEQ Critique of DU PA v1.4, Appendix 21

Energy*Solutions*/Neptune indicate that the SER requested that the deep time analysis be redone using an Intermediate Lake sedimentation rate that is 10 times the Large Lake sedimentation rate of 0.12 mm/yr (p. 21). This is incorrect. While the SER makes clear that the Intermediate Lake sedimentation rate of 5.64 mm/yr used in the Energy*Solutions*/Neptune analysis is unsupported, it made no recommendation as to what an appropriate Intermediate Lake sedimentation rate should be. Specifically, regarding the 10 times the Large Lake sedimentation rate, the 2015 SER states, "it can be concluded that a sedimentation rate of 1.2 mm/yr for intermediate lakes is likely too large." SER Table 5-2 includes several published sedimentation rates from eastern Great Basin, Utah, lakes, which could be used to develop an Intermediate Lake sedimentation rate distribution for the deep time analysis (see SER Table 5-3 and Figure 5-5 for examples). Energy*Solutions*/Neptune needs to either (1) provide independent documentation that a sedimentation rate of 1.2 mm/yr is plausible or (2) define a plausible, defensible Intermediate Lake sedimentation rate and redo the deep time analysis.

DEQ Discussion of NAC-0105_R0 – July 2019

The concerns raised by this interrogatory are addressed in Interrogatory 18 and will no longer be discussed under this interrogatory. However, this interrogatory remains open until Interrogatory 18 is closed.

2.1.15 Interrogatory CR R313-25-7(2)-150/3: Plant Growth and Cover Performance

DEQ Conclusion from April 2015 SER, Appendix C

As discussed in the 2015 DU PA SER (Section 4.4.3), concerns remain regarding the potential impacts of biointrusion on infiltration and this interrogatory is open.

DEQ Critique of DU PA v1.4 and Appendix 21

See responses to Interrogatories 10 and 28 for further discussion.

DEQ Discussion of NAC-0106_R0 – July 2019

Energy*Solutions*/Neptune refer to their response provided in Interrogatories 05/2: Radon Barrier and 10/03: Effect of Biologicals on Radionuclide Transport supporting their position that the ET cover design is adequate to protect against intrusion by plants, animals, or ants. As discussed in Supplemental Interrogatory Comment 2, Energy*Solutions*/Neptune have used naturalized parameters in their naturalized HYDRUS modeling; however, a number of issues still remain and are considered in Section 4.1.2.

2.1.16 Interrogatory CR R313-25-8(4)(d)-153/2: Impact of Pedogenic Processes on the Radon Barrier

DEQ Conclusion from April 2015 SER, Appendix C

The focus of Interrogatory 153 is on the impact of pedogenic processes with respect to effects on hydraulic conductivity of the ET cover. As described under Interrogatory 05, based on several unresolved issues related to the ET cover (including issues related to the selection of parameter values, ranges, and correlations), DEQ indicated in the 2015 DU PA SER, Section 4.1.1.1 that the cover design was deficient and that it cannot determine the adequacy of this portion of the Clive DU PA. (See the description under Interrogatory 05 for the specific details.) Therefore, this interrogatory remains open.

DEQ Critique, DU PA v1.4 and Appendix 21

See responses to Interrogatories 10 and 28 for further discussion. In addition, alterations in the hydraulic properties of cover soils are due primarily to changes in the size, shape, and connectivity of the pores in response to volume change. Changes in hydrologic conditions within the cover profile (e.g., wetting or drying, freezing or thawing) induce changes in pore water potential (also known as "pore water suction") that cause volume change. Decreases in pore water due to drying or freezing cause the soil to shrink, resulting in tensile stresses that form cracks and other macropores. Formation of macropores causes the saturated hydraulic conductivity and the van Genuchten α parameter to increase. The "macropores" formed by volume change are larger than the pores in the soil on completion of construction, but they generally are not large cracks that would be visible in a transect or test pit excavated with a clay spade or similar tool.

Cover soils in more arid regions have a greater propensity for volume change and alterations in hydraulic properties because very large changes in pore water potential occur seasonally. Plants in arid regions have the ability to extract water to much higher potentials than plants in humid regions (Gee et al. 1999), resulting in greater volume change and more significant structural changes. However, over time, cycling of pore water potential combined with the effects of biota intrusion result in similar alterations in hydraulic properties regardless of climate (Benson et al. 2007, 2011).

DEQ Discussion of NAC-0106_R0 – July 2019

In their response, Energy*Solutions*/Neptune provide mineralogic data supporting their position that shrinkage and expansion of clays leading to macropores will be minimal. The

Energy*Solutions*/Neptune claims are inconsistent with the field evidence. The West Desert clays are assumed to contain fractures from less than 1 foot to about 15 to 20 feet in depth. See the following statement from the Bureau of Land Management's *Draft Environmental Impact Statement for the West Desert Pumping Project* (p. 83):

> *The salinity of the groundwater has produced fractures in the clays of the Bonneville Salt Flats and in the dikes surrounding evaporation ponds near Wendover. Based on the work of Neal et al. (1968), Lines (1979) estimated that cracks in the clay surface of the Bonneville Salt Flats extend to depths varying from less than 1 foot to about 15 to 20 feet. Similar cracking depths are assumed to occur in the remainder of the west desert.*

Energy*Solutions*/Neptune also refer to their response provided in Interrogatory 05/2: Radon Barrier. As discussed in Supplemental Interrogatory Comment 2, Energy*Solutions*/Neptune have used naturalized parameters in their naturalized HYDRUS modeling; however, a number of issues still remain and are discussed under Supplemental Interrogatory Comment 2 (see Appendix B of the April 2015 SER and Section 4.1.2 of this report).

2.1.17 Interrogatory CR R313-25-7(2)-160/2: Comparison of Class A West and Federal Cell Designs

DEQ Conclusion from April 2015 SER, Appendix C

Energy*Solutions* stated the following in its response to Round 2 interrogatories:

> *Version 1.2 of the Modeling Report has been revised to reflect the construction of an evapotranspirative cover over the proposed Federal Cell. While EnergySolutions recognizes that it is seeking separate approval for construction of a similar cover system over its Class A West (CAW) embankment from the Division, demonstration of the CAW cover's ability to satisfy low-level radioactive waste disposal performance objectives unique to Class A-type waste are unrelated to the requirements imposed on the Federal Cell evapotranspirative cover's ability to satisfy the unique depleted uranium performance criteria addressed in version 1.2 of the Modeling Report.* [ES 2014b, p. 106]

DEQ does not agree with the Energy*Solutions* statement that demonstration of the Class A West cover's ability to satisfy LLRW disposal performance objectives unique to Class A-type waste are unrelated to the requirements imposed on the proposed Federal Cell ET cover's ability to satisfy the unique DU performance criteria addressed in DU PA Model v1.2. DU is a Class A waste. Both cells must contain Class A waste for extended periods of time.

As stated in Section 4.4.2 of the 2015 DU PA SER:

> *Before the DU PA can be determined to be adequate, Energy*Solutions *needs to clarify certain issues relating to Appendix 10 to the DU PA Model v1.2 (June 5, 2014…) as described in Section 4.4.2 of the SER. DRC is currently reviewing a license amendment request to use an ET cover of similar design to that proposed for the Federal Cell in the DU PA. Any recommendations and conclusions from that review must be applied to the proposed Federal Cell as well.*

Therefore, this interrogatory remains open.

DEQ Critique of DU PA v1.4, Appendix 5, Appendix 21:

See also Interrogatory CR R313-25-25(4)-202/1: Use of SIBERIA to Model Federal Cell Erosion.

DEQ Discussion of NAC-0101_R0 – July 2019

See Interrogatory CR R313-25-7(2) and 7(6)-81/2: Comparison of Disposal Cell Designs. An explanation for why a rock armor was determined to be the preferred choice for the Class A West cell while the ET cover was selected for the Federal Cell should be provided.

This interrogatory currently addresses the same issues as Interrogatory CR R313-25-7(2) and 7(6)-81/2: Comparison of Disposal Cell Designs, which remains open.

2.1.18 Interrogatory CR R313-25-22-162/2: Disposal Cell Stability

DEQ Conclusion from April 2015 SER, Appendix C

As stated in Section 4.4.2 of the 2015 DU PA SER:

> *Before the DU PA can be determined to be adequate, Energy*Solutions *needs to clarify certain issues relating to Appendix 10 to the DU PA Model v1.2 (June 5, 2014…) as described in Section 4.4.2. DRC is currently reviewing a license amendment request to use an ET cover of similar design to that proposed for the Federal Cell in the DU PA. Any recommendations and conclusions from that review must be applied to the proposed Federal Cell as well.*

Therefore, this interrogatory remains open.

DEQ Critique of DU PA v1.4, Appendix 21

This interrogatory can be closed because the same issues are raised in Interrogatory CR R313-25-7(2)-160/2: Comparison of Class A West and Federal Cell Designs, which remains open.

(Note: Subsequent review in July 2019 altered this conclusion. See below.)

DEQ Discussion of NAC-0101_R0 – July 2019

This interrogatory is not closed because the same issues are raised in Interrogatory CR R313-25-7(2) and 7(6)-81/2: Comparison of Disposal Cell Designs, which remain open.

2.1.19 Interrogatory CR R313-25-7(2)-175/1: Infiltration Rates for the Federal Cell Versus the Class A West Cell

DEQ Conclusion from April 2015 SER, Appendix C

As DEQ noted in the Round 3 Interrogatories:

> *ES notes that this interrogatory is no longer relevant since the Federal Cell will use an ET cover. We agree with this position. However, a thorough discussion of the modeling of infiltration rates, with soil hydraulic conductivity values as provided in NUREG/CR-7028 (Benson et al., 2011), is expected in the report on the ET cover system.* [DRC 2014b, p. 253]

The role of hydraulic conductivity on infiltration rates is extensively discussed in the 2015 DU PA SER (see Section 4.1.1.1 and Appendix B). As specifically noted in Section 4.1.1.1:

> *There are still a number of unresolved issues with respect to the selection of parameter ranges, distributions, and correlations, as well as the modeling approach and predicted sensitivities. These concerns are detailed in Appendix B. Further, because the model-predicted infiltration rates may be sensitive to the hydraulic properties assigned to each ET layer, the α and K_{sat} values assumed for modeling moisture in each soil layer within the cover system must be correlated based on experimental data. Also, additional justification is required for the soil property values used in the model by Energy*Solutions*. Therefore, DEQ does not consider this portion of the performance assessment resolved.*

Therefore, this interrogatory remains open.

DEQ Critique of DU PA v1.4 and Appendix 21

See responses to Interrogatories 10, 21, 28, and 153 for further discussion.

DEQ Discussion of NAC-0106_R0 – July 2019

Energy*Solutions*/Neptune refer to discussions in the April 2015 SER Appendix B interrogatories, including Supplemental Interrogatory Comments 1 through 9 and 11. Energy*Solutions*/Neptune also indicate that a discussion of the use of correlated α and K_{sat} parameter values for flow modeling is included in the response to Interrogatory 05/2. The topics for Interrogatory 175/1 are covered in these other interrogatories.

2.1.20 Interrogatory CR R313-25-8(5)(a)-176/1: Representative Hydraulic Conductivity Rates

DEQ Conclusion from April 2015 SER, Appendix C

At this time, DEQ does not accept the Energy*Solutions* position that infiltration results are insensitive to radon barrier changes. As discussed under Interrogatory CR R313-25-7(2)-05/2: Radon Barrier, an appropriate modeling analysis needs to be performed, with DEQ agreement as to values of in-service hydraulic conductivity and correlation between K_{sat} and α (see Appendix E to the 2015 DU PA SER). Until that study is performed and the results analyzed, this interrogatory remains open. (See also Appendix B to the 2015 DU PA SER.)

DEQ Critique of DU PA v1.4 and Appendix 21

See responses to Interrogatories 10, 21, 28, and 153 for further discussion.

DEQ Discussion of NAC-0106_R0 – July 2019

In their response, Energy*Solutions*/Neptune describe the importance of water content and the effect on hydraulic conductivity and state:

> *if the water content is slightly reduced from its saturated water content of 0.481 to a water content of 0.4, the hydraulic conductivity is greatly reduced from its saturated value of 4.46 cm/day to a value of 0.04 cm/day. This reduction of hydraulic conductivity with reduced water content is even more pronounced with coarser textured soils. In this example, a small reduction in water content was*

> *shown to produce a 100-fold reduction in hydraulic conductivity.* [Neptune 2018f, p. 69]

This is not a logical argument, in that the *unsaturated* hydraulic conductivity in HYDRUS is linearly proportional to the *saturated* hydraulic conductivity that is assigned to the model, regardless of the water content at any particularly point or time. Thus, any change in *saturated* hydraulic conductivity results in a *comparable* change in *unsaturated* hydraulic conductivity *and* a corresponding change in water flux. Consequently, the lack of sensitivity of percolation rate to saturated hydraulic conductivity is not logical and needs a quantitative and mechanistic explanation. Since Energy*Solutions*/Neptune assume yearly average infiltration, the saturated water content will always remain at average values—one of the main reasons DEQ/SC&A has requested water balance plots of the flow simulation results based on daily output (see Interrogatory CR R317-6-2.1-20/2: Groundwater Concentrations). Furthermore, the single θ_s and K_{sat} values of 0.481 and 4.46 cm/day, respectively, specified in HYDRUS for the evaporative zone (Neptune 2015e, Table 8) may be the reason for the lack of sensitivity of infiltration to K_{sat} and require additional justification.

This interrogatory remains open.

2.1.21 Interrogatory CR R313-25-7(2)-189/3: Modeling Impacts of Changes in Federal Cell Cover-System Soil Hydraulic Conductivity and Alpha Values

DEQ Conclusion from April 2015 SER, Appendix C

As discussed in the 2015 DU PA SER (Section 4.4 and Appendix B), the potential correlation between α and K_{sat} and the changes in K_{sat} with time still need to be resolved. Therefore, this interrogatory remains open.

DEQ Critique of DU PA v1.4 and Appendix 21

See responses to Interrogatories 10, 21, 28, and 153 for further discussion. In addition, data from other facilities in the region near the Clive site also confirm that changes in the hydraulic properties of cover soils occur, and the effectiveness of a cover can change in response to changes in the hydraulic properties.

For example, Benson et al. (2008) report on an assessment of hydraulic properties in the fine-textured layers in the cover over the uranium mill tailings facility in the Monticello, Utah. The investigators found that the saturated hydraulic conductivity of the cover soils in the upper 1.5 meters increased by approximately 10 times. Similarly, α increased by approximately 5 times. Excavation of caisson lysimeters at the site also showed roots and cracks present in the radon barrier, which was 1.6–1.9 mbgs (Figure 2).

The radon barrier at the Grants, New Mexico, reclamation site was evaluated in the summer of 2016, 20 years after completion, by investigators sponsored by the NRC and DOE-LM. At this site, the radon barrier is closer to the surface, with 12 inches of riprap and a sand bedding layer placed directly over the radon barrier. The capillary break provided by the riprap and the sand bedding layer were believed to prevent drying and cracking of the radon barrier.

Large block samples were collected from the radon barrier at Grants, New Mexico, for assessment of field-scale saturated hydraulic conductivity in the laboratory. Block samples were also collected from an analog site representing conditions anticipated in the long term. A summary of the hydraulic conductivities reported to date is included in Figure 14 below. All of the saturated hydraulic conductivities are greater than 10^{-6} centimeter per second (cm/s). Most are within or close to the range described in NUREG/CR-7028 and are approaching the saturated hydraulic conductivity measured at the analog site. None are less than 1×10^{-7} cm/s, as assumed for the lower radon barrier at Clive.

At the Cheney Disposal Facility near Grand Junction, Colorado, data from two large-scale lysimeters indicate that the percolation rate from the cover profile has increased substantially over time, most likely due to structural development within the frost protection layer and the radon barrier at the site. Table 3 summarizes the water balance data from these lysimeters. This cover employs a rock-armor layer, a sand bedding layer, and a frost protection layer over the radon barrier. Herbicide is used to prevent plant intrusion and root development. Thus, conditions at this site should minimize the possibility for pedogenesis and alterations in hydraulic properties. Initially, percolation was on the order of 1 mm/y and less than about 1 percent of precipitation. In less than a decade, however, the percolation rate has risen substantially and was nearly 20 percent of precipitation in Water Year 2016.

As illustrated in NUREG/CR-7028, changes in hydraulic properties occur at sites more arid and more humid than Clive. At the hyperarid Apple Valley site in the arid High Plains desert in southern California, the saturated hydraulic conductivity of a clay barrier similar to the radon barrier at Clive increased from 1.5×10^{-8} to 1.2×10^{-5} cm/s, or 800 times (Benson et al. 2011).

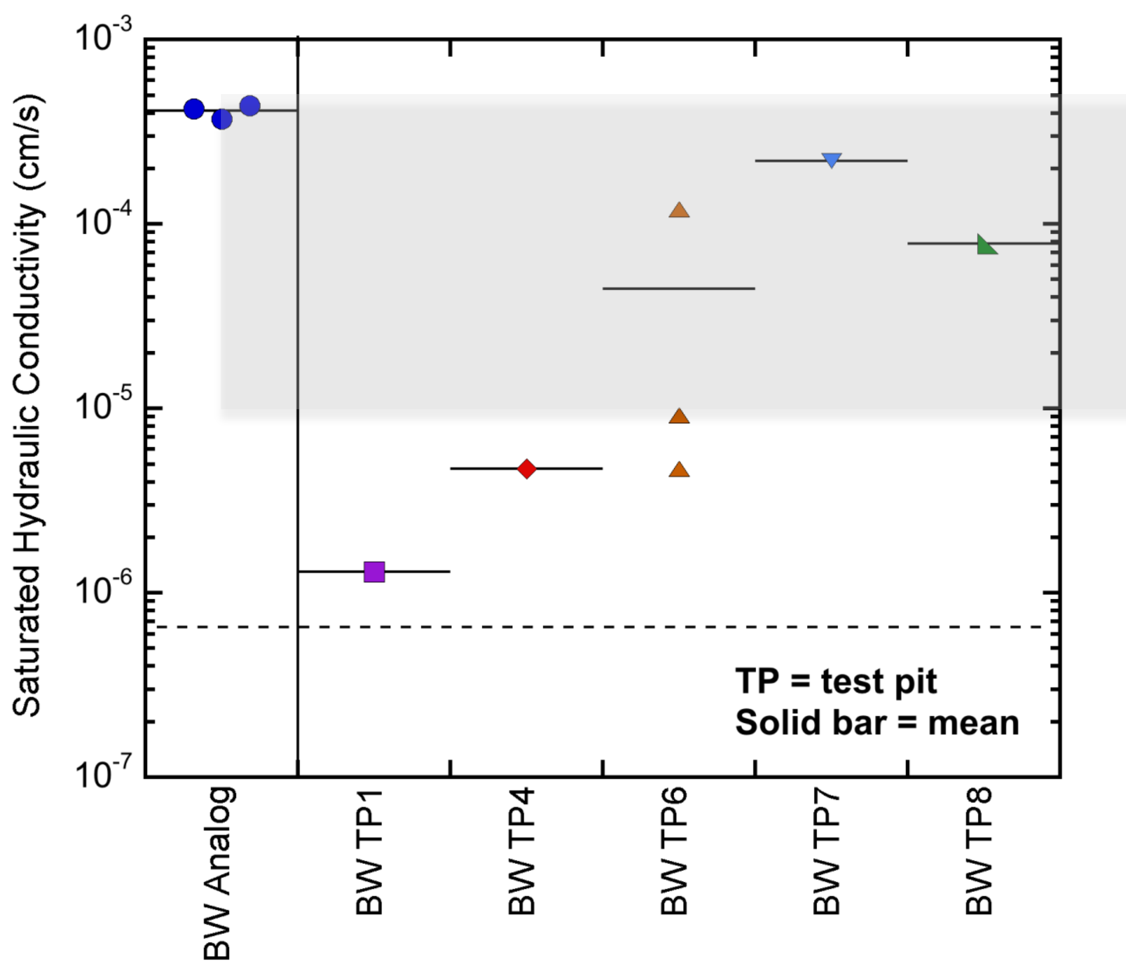
These examples illustrate that structural changes, alterations in hydraulic properties, and alterations in the water balance occur at other sites in the region near Clive, Utah, and at more arid locations. Accordingly, changes in the hydraulic properties should be anticipated in the cover proposed for the Clive site.

Table 3. Summary of Water Balance Quantities from Riprap Cover at the Cheney Disposal Facility near Grand Junction, Colorado

Period	Water Balance Quantities (mm)				
	Precipitation	Runoff	Evapo-transpiration	Change in Storage	Percolation
11/15/07–06/30/08	122.4 (113.3)	0.0 (0.0%)	110.6 (90.3%)	34.4	1.40 (1.1%)
07/01/08–06/30/09	195.1 (170.2)	0.0 (0.0%)	175.7 (90.1%)	2.5	0.45 (0.2%)
07/01/09–06/30/10	209.0 (122.7)	0.0 (0.0%)	203.2 (97.2%)	20.5	0.56 (0.3%)
07/01/10–06/30/11	234.7 (153.7)	0.1 (0.1%)	241.3 (102.8%)	5.9	1.26 (0.5%)
07/01/11–06/30/12	177.0 (150.4)	0.0 (0.0%)	188.0 (106.2%)	-21.7	0.62 (0.4%)
07/01/12–06/30/13	93.8 (140.5)	0.0 (0.0%)	112.4 (119.8%)	-1.0	0.97 (0.1%)

Period	Water Balance Quantities (mm)				
	Precipitation	**Runoff**	**Evapo-transpiration**	**Change in Storage**	**Percolation**
07/01/13–06/30/14	388.2 (245.6)	0.2 (0.1%)	328.2 (84.5%)	28.4	9.04 (2.3%)
07/01/14–06/30/15	331.2 (275.6)	0.1 (0.0%)	278.5 (84.1%)	16.4	20.20 (6.1%)
07/01/15–06/30/16	339.8 (308.4)	4.0 (1.2%)	295.9 (87.1%)	-0.2	58.68 (17.3%)

Source: Benson et al. 2018.



Source: NRC n.d.

Figure 14. Saturated hydraulic conductivity of radon barrier at UMTRCA disposal facility in Grants, New Mexico. Barrier completed in 1996 and tests conducted in 2016. Gray shading corresponds to range of hydraulic conductivities recommended in NUREG/CR-7028.

DEQ Discussion of NAC-0106_R0 – July 2019

Energy*Solutions*/Neptune respond to this interrogatory by explaining why the sites described in Benson et al. (2011) do not provide analogs to the Clive site, and that site-specific observations of soil formation at the Clive site that differ significantly from those described in Benson et al. (2011) are discussed in their response to Interrogatory 05/2. Similar concerns are raised in Interrogatory 05/2, which remains open.

2.1.22 Interrogatory CR R313-25-7(2)-191/3: Effect of Gully Erosion

DEQ Conclusion from April 2015 SER, Appendix C

Interrogatory 191 requested Energy*Solutions* to provide additional information about the ability of steep side slopes to resist gully erosion. In its responses to Round 3 interrogatories (ES 2014c), Energy*Solutions* stated that a detailed response concerning the ability of the side slopes to resist gully formation was available in Appendix K to Energy*Solutions* 2013a and Appendix D to Energy*Solutions* 2013c. After reviewing both documents (i.e., the Hansen, Allen & Luce (HAL) analyses in Appendix K and Appendix D), DEQ believes that the key analysis is Appendix D to Energy*Solutions* 2013c. Appendix D uses both the Universal Soil Loss Equation (USLE) and REHM to calculate rill or sheet erosion, with similar results (0.026 mm/yr with the USLE and 0.016 mm/yr with REHM). Both are well below the U.S. Environmental Protection Agency's (EPA's) criteria for Resource Conservation and Recovery Act/Comprehensive Environmental Response, Compensation, and Liability Act cover systems. One problem with the Appendix D analysis is that it does not describe how the values for the various USLE and REHM parameters were selected. For example, the USLE has R, K, L, S, and C parameters, but only L and S are functions of the embankment's design, so the basis for selecting the other parameters is not clear.

Appendix D states (ES 2013c, p. D-5): "The C factor for the top slopes [0.2] is based on the sparse vegetative cover naturally found in the areas immediately surrounding the Clive facility" and "The C factor for the side slope [0.02] is based on the higher percentage of gravel in the Unit 4 gravel admixture (50% gravel). The 50% gravel admixture on the side slopes results in a pseudo-gravel mulch once some of the fines have been removed." There is little detail here to allow anyone to form an opinion as to the acceptability of these values.

The Natural Resources Conservation Service's *National Agronomy Manual* (2002) states:

> *If the surface soil contains a high percentage of gravel or other non-erodible particles that are resistant to abrasion, the surface will become increasingly armored as the erodible particles are carried away. Desert pavement is the classic example of surface armoring. A surface with only non-erodible aggregates exposed to the wind will not erode further except as the aggregates are abraded.*

The Georgia Soil and Water Conservation Commission's *Erosion and Sedimentation Control Manual* (2000), Appendix B-2, Table B-2.5 gives a C value for crushed stone (240 ton/acre) on a

20-degree slope of 0.02. Based on these two sources, the side slope C value may be acceptable, but this type of justification needs to be documented in Appendix D.

Likewise, the Georgia manual indicates that a C factor of 0.2 is representative of land with 20 percent ground cover.

In conclusion, the analysis performed by HAL may or may not be correct, but before DEQ can accept it, each value selected and used in the analysis needs to be justified. Energy*Solutions*/HAL also needs to address how the embankment will be re-vegetated, how much revegetation is necessary and how much is expected, and how long is it expected to take. Therefore, this interrogatory remains open.

DEQ Critique of DU PA v1.4 and Appendix 21

Gravel Surface

Gravel embedded in the upper layer may migrate upward over time due to environmental effects, such as freeze/thaw or wet/dry cycling phenomena, bringing some particles to the surface. At the same time, aeolian erosion and deposition is likely to occur on the cover, potentially “silting in” gravel particles that move to the surface. Formation of a “gravel mulch” layer (i.e., a clean coarse layer of gravel at the surface) that would impede evaporation is unlikely. A more likely phenomenon is formation of a desert pavement, with finer sands, silts, and clay particles embedding around gravel particles. These finer materials provide a capillary conduit for evaporation.

This phenomenon is observed at sites where riprap or cobbles are used as cover. Fines deposit in the pores between the large particles gradually accumulate and fill the pores. These fines serve as a seed bed and as a capillary conduit, allowing water to flow upward. This was very clear in the armored surfaces at both Uranium Mill Tailings Radiation Control Act (UMTRCA) covers studied in 2016 for the NRC and DOE-LM (NRC n.d.). An example from the Uranium Mill Tailings Reclamation site in Grants, New Mexico, is shown in Figure 15 below. Roots and structure in the radon barrier are being mapped, as shown in Figure 15(a), and brush growing in an adjacent area of the riprap surface layer is shown in Figure 15(b).

The best approach to understand this issue, and to develop a suitable conceptual model for Clive, is to seek out analogs in the area where undisturbed fluvial surficial soils exist with appreciable gravel. Studying the surface of these soils will provide evidence regarding the long-term surface characteristics that can be anticipated at Clive.

Gravel Fraction to Address Erosion

The appropriate gravel fraction necessary to prevent erosion has not been defined with precision, nor has a validated methodology been developed to determine the appropriate gravel fraction as a function of site-specific conditions. Models have been developed, but they have not been validated in the field. For example, Smith and Benson (2016) used the model SIBERIA to evaluate erosion from a top deck with a gravel amendment, but the model was not validated in the field.

The gravel admixtures used at Hanford and Monticello have been effective in controlling erosion. No major erosion issues have been encountered at either site on the shallow top decks. Riprap is used on the steeper side slopes on both sites. There have been no quantitative field studies to evaluate the reduction in erosion achieved with the gravel admixture on the top deck at either site.

Gravel Fraction to Control or Prevent Biointrusion

There should be no expectation that 15 percent gravel, or even 50 percent gravel, will preclude biointrusion. As noted previously, plants readily germinate and root in riprap layers when silt accumulates in the pores (Figure 15). Vegetation is likely to be more robust in a gravel-amended surface layer with smaller particles and more fine-textured particles.

Burrowing animals will readily penetrate a layer containing gravel particles, and plants will readily grow in a fine-textured layer with as much as 50 percent gravel. Biointrusion design to prevent burrowing requires particles larger than the breadth of the animal (precludes particles from being moved through a burrow), and a gradation that results in pore sizes smaller than the breadth of the animal (prevents burrowing between particles).

Homogenization

Pedogenic phenomena are known to create structure and alter the hydraulic properties of earthen cover materials. There is no evidence in the literature that layering in covers diminishes with time or that a homogeneous profile develops. For example, distinct layering has been observed in recent excavations into UMTRCA covers that are 20 years old (Figure 16). Structure has developed in these layers, and the hydraulic properties have changed, but the profile is not homogeneous. A model for Clive should include a layered profile with appropriate hydraulic properties assigned to each layer that reflect realistic development of structure.

DEQ Discussion of NAC-0108_R0 – July 2019

It should be noted that the modeling reported in Energy*Solutions* 2013a and Energy*Solutions* 2013c using the USLE and RHEM addresses sheet and rill erosion and not gully formation. Gully formation will have a greater impact on long-term performance of the Federal Cell. Smith and Benson (2016) have shown that water erosion can result in gullies up to about 24 feet deep on fine-grained soil armored by the addition of up to 40 percent gravel, even in the presence of plant cover, over a period of only 1,000 years. Such erosion would be devastating to the Clive embankment.

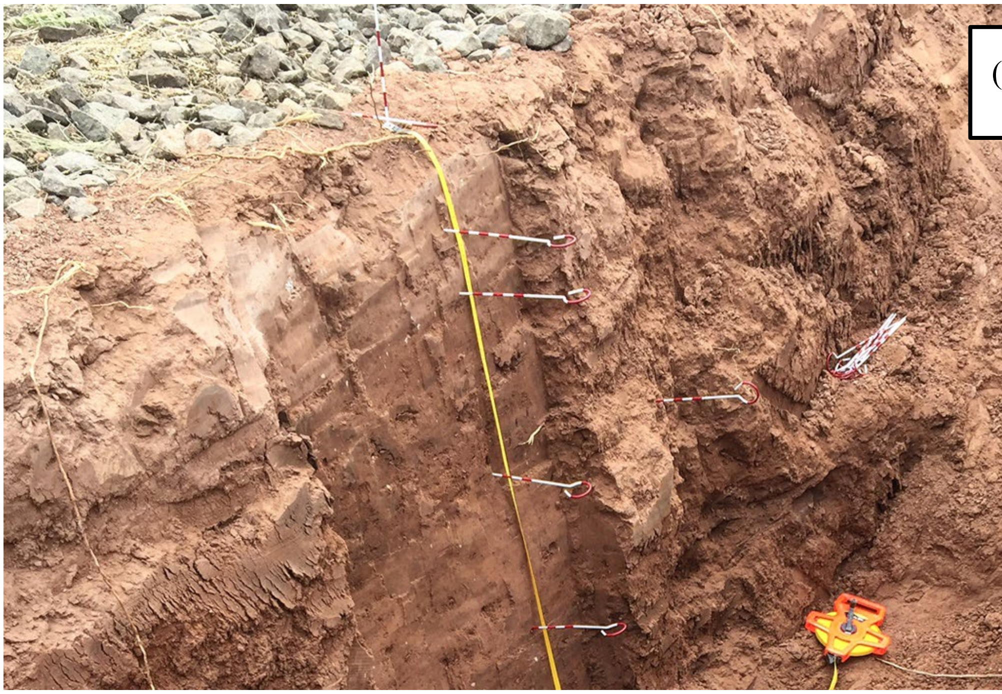
Some questions remain regarding use of the USLE as one of the tools to evaluate the magnitude of sheet erosion. In Table 2 of Neptune 2018g, the parameters used to calculate soil loss were summarized for the top slope and the side slope of the Federal Cell embankment. Sheet erosion was estimated to be 0.24 tons/acre/year for the top slope and 0.19 tons/acre/year for the side slopes. It was possible to reproduce the annual soil loss for the top slope using the Table 2 parameters. However, it was not possible to reproduce the side slope soil loss rate from the Table 2 parameters. Using the available data, the side slope soil loss rate was calculated to be 0.038 tons/acre/year. Incorrect parameters for the top slope gradient (4 percent instead of 2.4 percent) and for the length of the slope (942 feet instead of 521 feet) were used. When applying the correct parameters, the erosion of the top slope is 0.107 tons/acre/year and for the side slope is 0.04 tons/acre/year. However, we question the calculational approach of treating the top slope and the side slope independently.

As quoted above from Appendix D (ES 2013c, p. D-5): "The C factor for the top slopes [0.2] is based on the sparse vegetative cover naturally found in the areas immediately surrounding the

Clive facility." Additionally, the Georgia Soil and Water Conservation Commission's *Erosion and Sedimentation Control Manual* (2000) indicates that a C factor of 0.2 is representative of land with 20 percent ground cover. However, a recent Energy*Solutions*/Neptune report (Neptune 2015m) cites measured vegetative cover fractions on three plots at the Clive Site as 5.9, 9.1 and 14.4 percent. In light of these differences, Energy*Solutions* must justify the assumption of a 20 percent vegetative cover.

Although the Neptune 2018g USLE results are conservative relative to the results determined by DEQ, the fact that there are errors in the calculations bring into question the quality assurance/quality control (QA/QC) that was or was not performed for Neptune 2018g. This interrogatory remains open until those QA/QC questions can be resolved. Please provide DEQ with the NAC-0108 supporting calculations and the procedure under which they were performed, so that the calculations can be audited. Assuming that these QA/QC issues can be satisfactorily resolved, there are still some basic questions as to the appropriateness of the USLE model. There are two slopes: the top slope, and the side slope. The USLE is poorly equipped to analyze a dual-slope erosion line from the crest of the cell, over the top-slope/side-slope shoulder, down to the cell base. This is needed, because top-slope water flow and erosion affects side-slope water flow and erosion. The eroded materials ending up near the edge of the cell may travel in total as much as half the total embankment width, or about 721 feet. This is considerably more than 521 feet (which covers only the top slope). Assuming that, for side-slope erosion, the USLE program is run for only the length of the side slope is not consistent with physical reality.

This interrogatory remains open.



(a)

(b)

Figure 15. Photographs from Grants, New Mexico, showing root and structure mapping in a radon barrier beneath a riprap surface (a) and established brush on the riprap surface (b).

Figure 16. Photograph of test pit at Falls City, Texas, Uranium Mill Tailings Disposal Facility showing topsoil layer (dark brown), protection layer (tan vertical side wall), and radon barrier (floor).

2.1.23 Interrogatory CR R313-25-7(2)-192/3: Implications of Great Salt Lake Freezing on Federal Cell Performance

DEQ Conclusion from April 2015 SER, Appendix C

As discussed in the 2015 DU PA SER (Section 4.4.4), calculations need to be performed to estimate potential frost depths. Therefore, this interrogatory remains open.

DEQ Critique of DU PA v1.4, Appendix 2

In the Updated Site-Specific Performance Assessment (ES 2013c), Appendix E, Energy*Solutions* presents a calculation of frost depth at the Clive site based on the modified Berggren equation, which first presented by Berggren (1943), refined by Aldrich and Paynter in 1953, and later adopted by the U.S. Army Corps of Engineers and other agencies as their preferred method for frost depth determination (Departments of the Army and Airforce, 1988).

In their July 8, 2014 (ES 2014c), response to this interrogatory, Energy*Solutions* points to Appendix E of the Updated Site-Specific Performance Assessment (ES 2013c) for the calculation of the potential frost depth; however, that reference (nor any other estimation of frost depth) is not provided in v1.4, Appendix 2 (Neptune 2015b).

Therefore, this interrogatory will remain open until an estimate of the potential frost depth has been incorporated into DU PA Appendix 2, either by reference to or reproducing Energy*Solutions* (2013c), Appendix E, or by providing a similar calculation of the potential frost depth. Additionally, if Energy*Solutions* (2013c), Appendix E, is referenced or reproduced, any open interrogatories against Appendix E must be resolved before it is incorporated into DU PA Appendix 2.

DEQ Critique of DU PA v1.4, Appendix 21

An estimate of the potential frost depth has not been provided in Appendix 21.

DEQ Discussion of NAC-0106_R0 – July 2019

Energy*Solutions*/Neptune refer to their response to Interrogatory 05/2 for a description of frost depth calculations for the Clive site. See the discussion under Interrogatory 05/2: Radon Barrier, since the same issues with respect to the frost depth calculations are considered there. The interrogatory remains open.

2.2 Interrogatories Closed since May 2017

2.2.1 Interrogatory CR R313-25-8(4)(a)-08/1: Groundwater Concentration Endpoints

DEQ Conclusion from April 2015 SER, Appendix C

DEQ has stated that no DU waste containing recycled uranium will be allowed to be disposed at Clive, so this interrogatory was closed.

DEQ Discussion of NAC-0103_R0 – July 2019

In their 2018 comments, Energy*Solutions*/Neptune objected to the DEQ proposed ban on DU waste containing recycled uranium (Neptune 2018c, NAC-0103_R0). However, Energy*Solutions*/Neptune did not consider the fact that both technetium-99 (Tc-99) and transuranic radionuclides can exceed the Class A limits, as discussed below.

The modeling approach used in v1.4 of the DU PA (Neptune 2015a) and previous versions of the DU PA assumes that the contaminants introduced from using recycled uranium are uniformly distributed throughout the waste mass. Hightower et al. (2000) indicate that the cylinders used to store recycled DU contain residual heels. Some of these residual heels contain higher concentrations of technetium and transuranic elements than contained in the average feedstock. The contaminant concentrations in these heels may exceed regulatory concentrations for Class A waste. For example, the Tc-99 concentration for Class A waste is 0.3 curies per cubic meter (Ci/m^3) as specified in UAC R313-15-1009, "Classification and Characteristics of Low-Level Radioactive Waste." The following calculations describe situations where this limit would be exceeded.

As described in Appendix C to Hightower et al. (2000), the authors estimated that 95 kilograms (kg) of Tc-99 remained in the heels of all feed cylinders processed by the three gaseous diffusion plants (GDPs) (estimated upper bound, Table C.6), and the mass of a cylinder heel was about 25 kg. Thus, the average concentration of Tc-99 in the heels would be 1.66 grams (g) of Tc-99 per gram of heel (95,000 g of Tc-99 in 57,122 cylinders), assuming that the technetium is uniformly distributed over all cylinders. This is a conservative assumption, since it has been estimated that recycled uranium was confined to about 15 percent of the cylinders. (Henson 2006).[7]

Assuming that the heel is nominally UO_2F_2 (Sheaffer et al., 1995; and Brumburgh et al., 2000). with a crystal density of 6.37 g per cubic centimeter (DOE 2019), then the volume of a cylinder heel is 0.0039 cubic meter (m^3). Based on the above data and a specific activity of 1.7E-02 for Tc-99, the technetium volumetric concentration in the heels would be 7.2 Ci/m^3 (1.66 g Tc/g heel × 1.7e-02 Ci/g Tc ÷ 0.0039 m^3/g heel) – a value well in excess of the Class A limit for Tc-99 of 0.3 Ci/m^3 as specified in UAC R313-5-1009.

Similarly, the limit for transuranic wastes to be considered Class A is 10 nanocuries per gram (nCi/g). Hightower et al. (2000, Appendix C) cite bounding values for transuranic radionuclides in cylinder heels as follows:

- Plutonium-238 (Pu-238): 5 ppb_U
- Pu-239: 1,600 ppb_U
- Neptunium-237 (Np-237): 54,000 ppb_U

Based on these bounding values, the respective concentrations of these radionuclides in the heels are:

- Pu-238: 6.6 nCi/g
- Pu-239: 77 nCi/g
- Np-237: 29 nCi/g

Thus, Pu-239 and Np-237 could individually exceed the Class A limits of 10 nCi/g. Both the transuranic radionuclide and the Tc-99 concentrations would preclude wastes containing these contaminants from being classified as Class A wastes.

The analysis presented here assumes that concentrations cannot be averaged over the feed material cylinder and its contents but rather only over the cylinder heels. On May 16, 2016, DEQ requested clarification from the NRC on averaging low-level radioactive wastes with transuranic wastes. NRC provided the requested clarification to DEQ in a September 19, 2016 letter (NRC 2016a, p. 3). The NRC stated that

> *Therefore, the generic positions of the CA BTP would not permit averaging the heels with the remaining waste in the containers.*

("CA BTP" refers the 2015 revision of the NRC's Concentration Averaging and Encapsulation Branch Technical Position.)

[7] Hightower 2000 (Appendix C) has estimated bounding heel concentrations for Tc-99 as follows:

- Oak Ridge GDP – 1,600,000 parts per billion uranium (ppb_U)
- Paducah GDP – 260,000 ppb_U
- Portsmouth GDP – 5,700,000 ppb_U

In NAC-0103_R0, *Recycled Uranium Responses for the Clive DU PA Model* (Neptune 2018c), the authors state that "The April 2015 SER claimed that the PA Model concentrations were as much as 3.7 times too low when compared to the value of 5,700,000 ppb." This statement is not correct. The source of the 3.7 factor was Interrogatory R313-25(9) 89/3, which based the factor on the ratio of total Tc-99 in the heels (95 kg) from Table C.6 of Hightower et al. (2000) to the mean Tc-99 content of 25.7 kg used in the DU PA.

Based on these arguments, cylinders containing heels with recycled uranium may not meet Class A waste standards and thus cannot be disposed of at Clive. However, if it can be demonstrated that the cylinders do not contain recycled DU heels, then such cylinders can be considered for acceptance at Clive. Based on available assays of the depleted uranium trioxide (DUO_3) waste from the Savannah River Site (SRS), that waste may be considered for acceptance, since cylinders with heels are not involved and assays show that this material will meet Class A standards (Neptune 2015d).

This interrogatory is closed based on DEQ's announced intention to not allow cylinders that were used to handle recycled uranium to be disposed at Clive unless the cylinders do not contain heels or, if heels are present, the contamination will not exceed Class A limits. Note that this is a ban on the disposal of the cylinders that were used to store recycled DU, not a ban on the disposal of the recycled DU itself. Assays of the triuranium octoxide depleted in uranium-235 (DU_3O_8) will be required to demonstrate compliance with Class A limits.

2.2.2 Interrogatory CR R313-25-7(9)-51/3: Nature of Contamination

DEQ Conclusion from April 2015 SER, Appendix C

This interrogatory is closed because any license amendment or new license activity will contain a license condition that disposal of recycled uranium is not allowed in the DU waste. Furthermore, the license condition will indicate that DU-waste containers shall contain neither heels of enriched uranium at average concentrations greater than that allowed in the license nor heels of transuranic compounds at average concentrations greater than 10 pCi/g (the Class A limit).

DEQ Discussion of NAC-0103_R0 – July 2019

This interrogatory is closed based on the DEQ decision that cylinders used to store recycled uranium will not be acceptable for disposal due to the potential for heels to exceed Class A limits. See Interrogatory CR R313-25-8(4)(a)-08/1: Groundwater Concentration Endpoints.

2.2.3 Interrogatory CR R313-25-7(2)-59/2: Bathtub Effect

DEQ Conclusion from April 2015 SER, Appendix C

Until the issues are resolved regarding the design of the cover and infiltration rates (see the 2015 DU PA SER, Section 4.1.1.1 and Appendix B) the potential for bathtubbing effects cannot be ruled out. Therefore, this interrogatory remains open.

DEQ Critique of DU PA v1.4, Appendix 21

No further analysis has been performed since v1.2.

DEQ Discussion of NAC-0106_R0 – July 2019

In response to DEQ concerns about bathtubbing effects, Energy*Solutions*/Neptune noted the much greater capacity of the clay liner to allow water to flow through it in comparison to the 99th percentile of net infiltration rates, making the bathtub effect impossible.

This interrogatory is closed based on the comparison of the percolation rate to rate of flow through the clay liner.

2.2.4 Interrogatory CR R313-25-7(2)-70/3: Gully Screening Model

DEQ Conclusion from April 2015 SER, Appendix C

As noted in Section 4.4.2 of the 2015 DU PA SER:

> *Before the DU PA can be determined to be adequate, Energy*Solutions *needs to clarify certain issues relating to Appendix 10 to the DU PA v1.2 (June 5, 2014…) as described in Section 4.4.2. DRC is currently reviewing a license amendment request to use an ET cover*[8] *of similar design to that proposed for the Federal Cell in the DU PA. Any recommendations and conclusions from that review must be applied to the proposed Federal Cell as well.*

Therefore, this interrogatory remains open.

DEQ Critique of DU PA v1.4, Appendix 5, Appendix 21

This interrogatory can be closed because the same issues are raised in Interrogatory CR R313-25-7(2)-160/2: Comparison of Class A West and Federal Cell Designs, which remains open. (Note: Subsequent review in July 2019 altered this conclusion. See below.)

DEQ Discussion – July 2019

This interrogatory remains open because the same issues are raised in Interrogatory CR R313-25-7(2) and 7(6)-81/2: Comparison of Disposal Cell Designs, which remains open.

2.2.5 Interrogatory CR R313-25-7(6)-84/3: Below-Grade Disposal of DU

DEQ Conclusion from April 2015 SER, Appendix C

As noted in Sections 4.1.1.1, 4.1.1.3, and 4.4 of the 2015 DU PA SER, several issues regarding the ET cover remain unresolved. Therefore, this interrogatory remains open.

DEQ Critique of DU PA v1.4, Appendices 3 and 4

The main point of Interrogatory 84 was to "Explain how Figure 1-2 [(ES 2013b)] demonstrates that the entire inventory of DU can be disposed below grade" (SC&A 2014). However, the subsequent interrogatory responses and critiques have focused on the ET cover design and whether there is a requirement for an intruder barrier. This critique returns to Interrogatory 84's main point: ET cover designs are adequately covered in other interrogatories (e.g., Interrogatory 05); also, according to UAC R313-25-26(2), intruder barriers are only required for Class C waste disposal and then only to last for at least 500 years.

[8] See Footnote 5.

In DU PA v1.4, Appendix 4, Section 3.4.2, the maximum number of 12 foot by 4 foot DU cylinders that can be disposed of is calculated to be 48,628 (Neptune 2015d). This number of DU cylinders (i.e., 48,628) is repeated in v.14, Appendix 4, Table 1; v.14, Appendix 16, Table 40 (Neptune 2015h); and is entered into GoldSim Pro – Clive DU PA Model v1.4, Num_CylindersDisposed. Also, Appendix 4, Table 1, gives the number of DU drums from SRS as 5,408. No other DU drums are discussed in Appendix 4.

In v1.4, Appendix 3, Figure 7 shows an estimated 20,300 cylinders in a single layer and 10,500 cylinders in a double layer, for a total of 30,800 cylinders (Neptune 2015c). In addition to the 5,408 SRS DU drums, Figure 7 shows up to 170,800 drums of DU disposed of on top of the single layer of DU cylinders. No discussion of the Figure 7 number of cylinders or drums is provided in the text of Appendix 3.

Please explain the difference between v1.4 Appendices 3 and 4 regarding the maximum number of cylinders and drums, and demonstrate how the entire DU inventory can be disposed below grade. If Energy*Solutions* intends to repackage the DU it receives in cylinders into drums, that operation needs to be reviewed and approved by DEQ before it can begin.

DEQ Critique of DU PA v1.4, Appendix 21

No further analysis was performed in Appendix 21 on the below-grade disposal of DU.

DEQ Discussion of NAC-0101_R0 – July 2019

In NAC-0101_R0, Energy*Solutions*/Neptune agree that different disposal scenarios are presented in Appendices 3 and 4 but point out the actual disposal will be limited to the number of waste containers that can be emplaced below grade. A license condition will insure that this objective is achieved.

This interrogatory is closed.

3.0 DU PA V1.4 INTERROGATORIES

3.1 Open DU PA V1.4 Interrogatories as of July 2019

3.1.1 Interrogatory CR R313-25-3 and R313-25-8-195/1: Aquifer Characterization

Preliminary Finding

Refer to UAC R313-25-3, "Pre-licensing Plan Approval Criteria for Siting of Commercial Radioactive Waste Disposal Facilities":

> *(5) The plan approval siting application shall include hydraulic conductivity and other information necessary to estimate adequately the ground water travel distance.*
>
> *(6) The plan approval siting application shall include the results of studies adequate to identify the presence of ground water aquifers in the area of the proposed site and to assess the quality of the ground water of all aquifers identified in the area of the proposed site.*

Refer to UAC R313-25-8, "Specific Technical Information":

> *(1) A description of the natural and demographic disposal site characteristics shall be based on and determined by disposal site selection and characterization activities. The description shall include geologic, geochemical, geotechnical, hydrologic, ecologic, archaeologic, meteorologic, climatologic, and biotic features of the disposal site and vicinity.*

Interrogatory Statement

Please provide information assessing the aquifer hydraulic properties and groundwater quality for the lower confined aquifer (e.g., at 70–100 feet) and valley-fill or basal-aquifer-system aquifers (e.g., at 450–750 feet) at the Clive site. Specific types of information include, for example, groundwater flow velocities, aquifer transmissivities, water quality, sorption properties, and the degree of hydraulic interconnection between the upper and basal aquifers. Calculations should be shown for horizontal and vertical components of groundwater flow and contaminant migration velocities.

Basis for Interrogatory

The possibility exists that contaminated groundwater could flow from the upper aquifer to the basal aquifer, resulting in exposure to inadvertent intruders or members of the public who use the lower aquifer groundwater for beneficial purposes, including consumption of drinking water after treatment (e.g., by reverse osmosis). UAC R313-23-3(6) requires that the quality of **all aquifers** (including the basal aquifer) be assessed.

DEQ Discussion of NAC-0104_R0 – July 2019

The purpose of this interrogatory is to demonstrate compliance with the above regulations, not with the groundwater ingestion dose pathway. UAC R313-25-3(6) uses the term "all aquifers identified in the area." It is not limited to only drinking water aquifers. DEQ/SC&A do not believe that the current level of knowledge for the deep aquifer (especially the valley-fill or basal-aquifer-system aquifers (e.g., at 450–750 feet)) satisfies UAC R313-25-3(6).

The following statements (emphasis added) from NAC-0104_R0, *Groundwater Exposure Responses for the Clive DU PA Model* (Neptune 2018d), Section 1.2, "Interaction of Shallow and Lower Aquifers," seem to support the DEQ/SC&A position:

- "Groundwater level measurements and geochemical data **suggest** minimal flow from the shallow aquifer to the basal and lower aquifers" (p. 3).
- "This evidence **suggests** that contamination of the lower aquifer due to the natural flow from the shallow aquifer is unlikely" (p. 3).

To DEQ/SC&A, the use of the word "suggests," rather than a more definitive word (e.g., indicates, demonstrates, proves), shows that the current studies are inadequate to quantify the groundwater properties of the deep aquifer.

Energy*Solutions*/Neptune must obtain data to "include hydraulic conductivity and other information necessary to estimate adequately the ground water travel distance" and "to assess the quality of the ground water of **all aquifers identified in the area**" (emphasis added).

This interrogatory remains open.

3.1.2 Interrogatory CR R313-25-9(5)(A)-196/1: Non-DU Waste Characteristics

Preliminary Finding

Refer to UAC R313-25-9, "Technical Analyses":

> *(5)(a) Notwithstanding Subsection R313-25-9(1), any facility that proposes to land dispose of significant quantities of concentrated depleted uranium (more than one metric ton in total accumulation) after June 1, 2010, shall submit for the Director's review and approval a performance assessment that demonstrates that the performance standards specified in 10 CFR Part 61 and corresponding provisions of Utah rules will be met for the total quantities of concentrated depleted uranium and other wastes, including wastes already disposed of and the quantities of concentrated depleted uranium the facility now proposes to dispose. Any such performance assessment shall be revised as needed to reflect ongoing guidance and rulemaking from NRC. For purposes of this performance assessment, the compliance period shall be a minimum of 10,000 years. Additional simulations shall be performed for the period where peak dose occurs and the results shall be analyzed qualitatively.*

Interrogatory Statement

Please provide an analysis to demonstrate that DU PA v1.4 assumed homogeneous Unit 4 silty clay material used to model the layer above the DU is representative of the various types of DOE-generated Class A waste Energy*Solutions* intends to dispose of in that layer. Density, among other factors, should be considered.

Basis for Interrogatory

UAC R313-25-9(5)(a) requires that "the performance standards specified in 10 CFR Part 61 and corresponding provisions of Utah rules will be met for the total quantities of concentrated depleted uranium **and other wastes**" (emphasis added). In DU PA v1.4, Appendix 18, Section 3.1, Energy*Solutions* states: "Directly atop the DU waste lies generic Class A waste, which is represented in the DU model as Unit 4 material with no inventory" (Neptune 2015i, p. 2). This means that the current DU PA does not address the other waste. Therefore, to address the UAC R313-25-9(5)(a) "other waste" requirement, a revised performance assessment, or a separate performance assessment, must be prepared by Energy*Solutions* and approved by DEQ before any "other waste" (understood to be DOE-generated Class A waste) is disposed of above the DU. This requirement was stated previously in Section 6.2.4 of the April 2015 SER (DEQ 2015).

UAC R313-25-9(5)(a) states that, "for purposes of this performance assessment, the compliance period shall be a minimum of 10,000 years. Additional simulations shall be performed for the period where peak dose occurs and the results shall be analyzed qualitatively." This means that the performance assessment must account for doses not only of the DU waste but also of the other waste such that peak doses to the public and to inadvertent intruders can be simulated in models, with the results being analyzed qualitatively. A performance assessment that does not account for incremental doses from waste placed above the DU waste is not acceptable for Director approval of the placement of both DU waste and the other waste that would be placed above the DU waste. If the performance assessment is changed to propose only inert material above the DU waste, then financial assurance for placement of the inert material must be accounted for prior to DU waste emplacement.

DU PA v1.4, Appendix 16, Section 4.3 (Neptune 2015h, p. 9) states:

> *Unit 4 is a silty clay, the uppermost unit deposited in the region by ancestral lakes. Certain parts of the engineered system are constructed using Unit 4 material which is subjected to compaction; in its compacted form, Unit 4 has the properties listed in Table 8. The particle density in Table 8 is common to all materials derived from Unit 4 (including compacted engineered layers, uncompacted evapotranspiration layers, and Aeolian deposition layers). All Unit 4 materials are assigned* K_d *values for silt.*

DEQ Discussion of NAC-0102_R0 – July 2019

In DU PA v1.4, Appendix 18, Section 3.1, Energy*Solutions*/Neptune (2015i, p. 2) state that:

> *The cover system for the portion of the Federal Cell that is allocated for disposal of DU (the Federal DU Cell), however, is more complex. Instead of using a single material in the cover, the layering above the DU waste is as follows, from the bottom up: Directly atop the DU waste lies generic Class A waste, which is represented in the DU model as Unit 4 material with no inventory.*

However, Energy*Solutions*/Neptune state in NAC-0102_R0 (Neptune 2018b), Section 2.1.1, that Appendix 18 contains an error in defining the waste overlying the DU (i.e., "reference to Unit 4 material is in error"); it should be Unit 3 material.

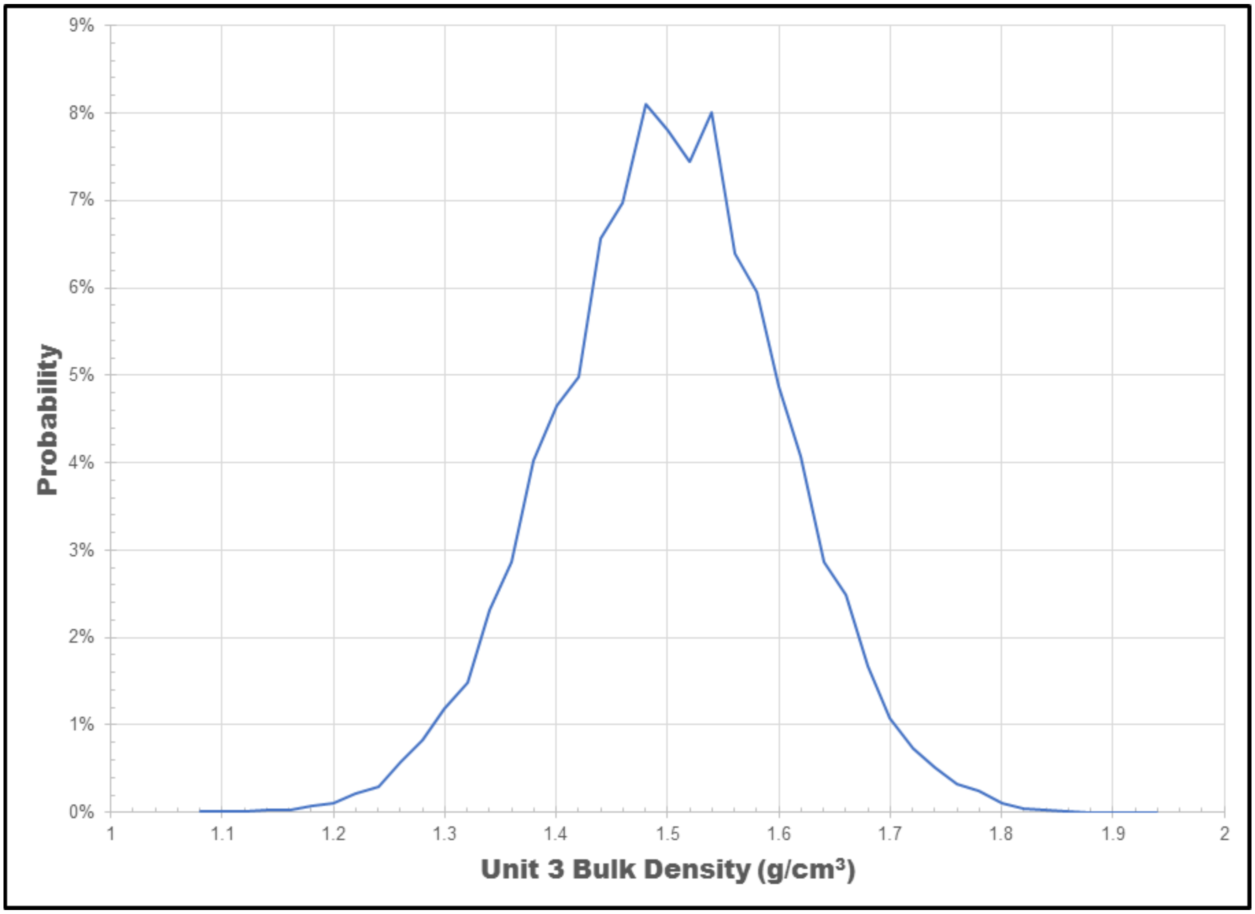
As noted elsewhere in Neptune 2018b (p. 3):

> *Appendix 2 to Neptune (2015a),* Conceptual Site Model for Disposal of Depleted Uranium at the Clive Facility, Clive DU PA Model v. 1.4 *(Neptune 2015*[b]*),*

> *Section 8.1, remains consistent with Clive's prior approved PAs in this respect: "All wastes are assumed to have the characteristics of local Unit 3 sandy soil."*

The basis for the statement is that prior approved performance assessments have used Unit 3 sandy soil as a surrogate for the waste requires documentation. DEQ notes that the most recent Whetstone infiltration and transport modeling report (May 2012) says: "A value of 1.8 gm/cm^3 was used for the bulk density of the waste. This value is consistent with previous modeling and the range of density determined by Energy*Solutions* (1.75 to 1.80 gm/cm^3) for the compacted, in-place waste" (Whetstone 2012, Section 7.1.2, p. 64).

As shown below in Figure 17, using the data from DU PA v1.4, Appendix 5, Table 1 (Neptune 2015e), the Unit 3 density has the distribution shown in the figure, i.e., from about 1.1 to 1.9 grams per cubic centimeter (g/cm^3) with a mean of about 1.6 g/cm^3. It is not clear that "This value is consistent with previous modeling and the range of density determined by Energy*Solutions* (1.75 to 1.80 gm/cm^3) for the compacted, in-place waste."



Source: Neptune 2015e

Figure 17. Unit 3 bulk density probability distribution.

When DEQ compared this Unit 3 density distribution to the typical densities of different types of Class A waste (see the tables reproduced below), it was found that the many of the waste types lay outside of the Unit 3 density distribution range. Also, in Example 2 of Energy*Solutions*' *Bulk*

Waste Disposal and Treatment Facilities Waste Acceptance Criteria (Revision 10, October 2015, ES 2015c), the density of dry active waste is given as 0.25 g/cm^3.

DEQ is concerned that the differences between the density used for Unit 3 in DU PA v1.4 and Class A waste are not representative of the Class A waste that Energy*Solutions* intends to dispose of above the DU.

Additionally, DU PA v1.4 assumed that the material in Unit 3 was homogeneous. In reality, Class A waste is heterogenous, as the tables reproduced below demonstrate. This heterogeneity may result in preferred pathways for water to infiltrate into the DU and/or for radon to diffuse from the DU to the surface of the embankment.

Table 4. Table B-12, "Typical Densities of Different Materials," from NUREG/CR-4370, Volume 1

Waste Form	Density (g/cm^3)
Waste solidified in cement	1.7
Waste solidified in vinyl ester styrene	1.2
PWR filter cartridges, unsolidified	1.3
Dewatered ion exchange resins	0.9
Dewatered filter sludge	0.9
Uncompacted compressible trash	0.13
PWR compacted trash (VR=3)	0.4
BWR compacted trash (VR=2)	0.3
Aqueous liquids	1.0
Scintillation liquids	0.9
Structural concrete	3.0
High density concrete	4.5
Rolled steel	7.85
Lead	11.4
Wood	0.4 - 0.7
Demolition material, mixed, noncombustible	1.4
Broken pavement or sidewalk	1.5
Dirt, sand or gravel (uncompacted)	1.4
Biological waste	1.1
Air	0.0013

Source: Envirosphere1986

Table 5. Table 2-5, "Institutional and Industrial Low-Level Waste Streams and Average Densities," from NUREG/CR-6147, Volume 2

Waste Streams	Waste Density – g/cm^3	
	Range	Average
Dry Solid	0.39–3.66	1.47
Non-compacted dry active waste	0.45–1.68	0.79
Solidified liquid	1.17–2.15	1.45
Solidified oil	1.06–1.55	1.22
Compacted dry active waste	0.36–1.77	0.75
Absorbed aqueous liquid	0.53–1.13	0.83
Animal carcasses in lime & sorbent	0.53–0.73	0.59

Waste Streams	Waste Density – g/cm³	
	Range	Average
Solidified resins	1.21–1.52	1.35
Resins & dewatered resins	0.75–0.95	0.88
Non-cartridge filter media	1.26–1.43	1.35
Activated metals & concrete	3.1	-na-
Evaporator bottoms	1.35–1.60	1.48
Cartridge filter media	0.69–1.53	1.11
Biological – other	1.47	-na-
Aqueous liquid in vials	0.53	-na-
Other waste	1.11	-na-

(a) Includes weight of the waste and container.

Source: SC&A 1994

Table 6. Table 2-6, Average and Density Distributions for Utility Low-Level Waste," from NUREG/CR-6147, Volume 2

Waste Stream	Average Density (g/cm³)
Dry solid	0.86
Compacted dry active waste	0.80
Non-compacted dry active wastes	0.59
Solidified liquids	1.68
Solidified oils	1.20
Solidified resins	1.46
Dewatered resins	0.81
Evaporator bottoms	1.53
Non-cartridge filter media	1.14

Source: SC&A 1994

This interrogatory remains open pending resolution of questions involving the density of the waste (i.e., Unit 3) and how that density may affect infiltration.

3.1.3 Interrogatory CR R313-25-25(4) 197/1: Properties of Embankment Side Slope Materials

Preliminary Finding

Refer to UAC R313-25-25(4):

> *Covers shall be designed to minimize, to the extent practicable, water infiltration, to direct percolating or surface water away from the disposed waste, and to resist degradation by surface geologic processes and biotic activity.*

Refer also to UAC R313-25-23, "Stability of the Disposal Site after Closure":

> *The disposal facility shall be sited, designed, used, operated, and closed to achieve long-term stability of the disposal site and to eliminate, to the extent practicable, the need for ongoing active maintenance of the disposal site following closure so that only surveillance, monitoring, or minor custodial care are required.*

Interrogatory Statement

Please explain and justify how, from an erosion perspective, the properties of Unit 4 material "are sufficiently similar" to the Federal Cell side slope, which consists of a mixture of Unit 4 soil with 50 percent gravel, to support this "sufficiently similar" modeling assumption. Also, please explain how the properties of Unit 4 material are sufficiently similar to Class A waste, which would be included over the DU waste. See also Interrogatory 203/1 below.

Basis for Interrogatory

The side slope of the Federal Cell is designed as a 50/50 mixture of Unit 4 material and gravel. One of the assumptions for modeling erosion of the ET cover is that:

> *The borrow pit materials (Unit 4) are sufficiently similar to the layers of the embankment (Unit 4 with gravel, Unit 4, and radon barrier clays).* [DU PA v1.4, Appendix 10, Neptune 2015f, p. 3]

DEQ Discussion of NAC-0108_R0 – July 2019

In this interrogatory, DEQ requested explanation and justification of how, from an erosion perspective, the properties of Unit 4 material "are sufficiently similar" to the Federal Cell side slope, which consists of a mixture of Unit 4 soil with 50 percent gravel, to support this "sufficiently similar" modeling assumption. An explanation was also requested showing how the properties of Unit 4 material are sufficiently similar to Class A waste, which would be included over the DU waste. See also Interrogatory 203/1 below.

Energy*Solutions*/Neptune did not supply the requested explanations and justifications, noting that: "While there are differences in the characteristics of the borrow pit and the embankment, this analysis provides another line of evidence in addition to the more conventional modeling used to demonstrate the stability of the proposed ET cover design described below" (Neptune 2018g, p. 21). It is not clear how the borrow pit analysis provides another line of evidence (as to the embankment stability) when Energy*Solutions*/Neptune have not demonstrated that the properties of the borrow pit are sufficiently similar to the Federal Cell cover.

Energy*Solutions*/Neptune go on to say: "These models, however can be used in an exploratory context to gain insight into processes (Skinner et al. 2017) and to provide additional evidence to support the results of cover stability analyses using methods recommended by EPA and NRC" (p. 21). In the absence of an explanation showing that the borrow pit properties are sufficiently similar to those of the Federal Cell, the usefulness of SIBERIA modeling approach in demonstrating cover stability is questionable.

In NAC-0108_R0, Energy*Solutions*/Neptune provide several lines of evidence regarding the stability of the Federal Cell cover. However, there are problems with each.

- Use of the USLE predicts losses that are below the EPA-recommended value of 2 tons/acre/year. However, there appear to be errors in the soil loss calculations that must be corrected. (See Interrogatory CR R313-25-7(2)-191/3: Effect of Gully Erosion.)
- Use of RHEM predicts soil loss rates similar to those calculated with USLE. However, as noted under Interrogatory 200, the RHEM code is no longer functional.

- The maximum permissible velocity method from NUREG-1623 uses a limiting velocity at variance with NRC guidance. (See Interrogatory CR R313-25-8(4)(a)-71/1: Biotic Processes in Gully Formation.)
- Use of the borrow pit at Clive to model land form evolution with SIBERIA is flawed because no attempt is made rationalize the borrow pit parameters with those of the Federal Cell. Additionally, the description of the borrow pit modeling in Appendix 10 to DU PA v1.4 is confusing and lacking in detail.

This interrogatory remains open.

3.1.4 Interrogatory CR R313-25-25(4)-198/1: Gravel Content of Embankment Materials

Preliminary Finding

Refer to UAC R313-25-25(4):

> *Covers shall be designed to minimize, to the extent practicable, water infiltration, to direct percolating or surface water away from the disposed waste, and to resist degradation by surface geologic processes and biotic activity.*

Refer also to UAC R313-25-23:

> *The disposal facility shall be sited, designed, used, operated, and closed to achieve long-term stability of the disposal site and to eliminate, to the extent practicable, the need for ongoing active maintenance of the disposal site following closure so that only surveillance, monitoring, or minor custodial care are required.*

Interrogatory Statement

Please provide the design bases and justification for the amount and sizing of the gravel in the top and side slopes of the Federal Cell. The proposal for the gravel admixture in the top slope (15 percent) appears too small. Also, please provide evidence for existing semi-arid or arid sites where only 15 percent gravel has been added to form a successful cover-system surface layer for a landfill. Please describe actual analog sites where 50 percent gravel for side slopes has been demonstrated to be effective against erosion.

Basis for Interrogatory

As described in Appendix 3 to DU PA v1.4, Figure 6, the surface layer in the top slope of the Federal Cell cover contains 15 percent gravel, while the side slope includes 50 percent gravel (Neptune 2015c). DWMRC has noted previously in its June 21, 2016, comments to Energy*Solutions* on blended waste disposal (DWMRC 2016, Interrogatory 3, p. 8):

> *It is by no means certain that the addition of 15% gravel to the Surface Layer soil in the top slope as is currently proposed in the PAs would be sufficient to minimize erosion in that area to acceptable levels. That conclusion has not been established in any model whose results have been accepted by the Division to date. Use of 15% gravel is much less than the industry standard accepted levels of 24-50% (e.g., see Stenseng and Nixon, 1997; Waugh and Richardson, 1997; Anderson and Storm*[o]*nt, 2005; Anderson and Wall, 2010a,b). Use of 15%*

> *gravel floating in soil or on top of soil does not create stable rock armor having, as described in Abt et al. (1988), "a finer soil matrix filling in voids between rock materials."*

As noted previously in Interrogatory 191/3, gravel admixtures are used at Hanford and Monticello for controlling erosion. However, this is only for top slopes. Riprap is used on the steeper side slopes on both sites.

Discussion of NAC-0108_R0 – July 2019

Based on discussion provided by Energy*Solutions*/Neptune, the 15 percent gravel admixture results in a soil erodibility factor (K) of 0.18 (Neptune 2018g). With this K factor, the annual average erosion rate is 0.107 tons/acre/year for the top slope using the USLE. This rate is well below the limit of 2 tons/acre/year specified by EPA (1989). Thus, a gravel admixture of 15 percent appears to be adequate to control the top slope stability. We have two problems from deriving too much comfort from this information. First, the EPA limit is for land disposal sites where the expected lifetime is tens to hundreds of years, while the Clive site must retain its integrity for at least 10,000 years. Secondly, as noted under Interrogatory 191 above, the USLE methodology addresses only rill and sheet erosion but not gully formation, which is a more destructive process.

Other useful information on embankment stability is available from the Hanford Site, where DOE has constructed the Prototype Hanford Barrier (PHB) to test methods for isolating and containing subsurface contaminants. Operating experience from 1994 through 2015 is presented in DOE/RL-2016-37 (DOE 2016). The test barrier operates in a semi-arid climate. The top surface has a 2 percent slope and contains 15 percent pea gravel in a silt-loam matrix.

Underlying this PHB silt is a geotextile and more than a foot of filter material. Underlying these materials is over 5 feet of coarse riprap or drainage gravel to handle water, if it breaks through, such that the water is not traveling entirely in the upper silt material laterally and contributing to internal erosion therein. The geotextile, filter zone material, and coarse riprap and gravel are not found in the proposed Federal Cell cover system. The proposed Federal Cell cover system has no way to convey away water that makes it past the storage zone in the upper 2 feet or so of the system. It is possible that water moving through the system could find its way to the surface on a slope, causing piping erosion. Water may make it past the storage system on days with relatively low evaporation but high rates of precipitation, as during a spring storm.

According to DOE (2016, p. 3.26):

> *The 19-year PHB record showed practically no evidence of wind or water erosion of the ETC barrier, despite 3 years of triple the mean annual precipitation; three simulated 1000-year-return, 24-hour precipitation events; and an intense, controlled fire that burned off all vegetation across half the barrier surface. The only evidence of water erosion occurred during the first simulated 1000-year-return rainstorm in March 1995, about half a year after PHB construction, when the vegetation was only in the seedling stage.*

However, this encouraging information must be tempered: "The primary structural differences between the PHB and other proposed barriers are increased thicknesses of individual layers, number of layers, the inclusion of a coarse-fractured basalt layer and the asphalt concrete (AC) layer, and side slopes to control biointrusion and to limit inadvertent human intrusion" (DOE 2016, p. 1.3). Unlike the proposed Federal Cell, the PHB has over 6 feet of silt loam in the upper part of the cover. The silt loam used on the PHB has sufficiently high permeability that runoff rarely occurs, greatly minimizing erosion by water. This would not be true of the Unit 4 clay material (with 15 percent gravel) planned for the surface of the Federal Cell at Clive.

By design, the upper part of the PHB cover is covered with grasses. That would greatly help to reduce erosion. However, there is no evidence to suggest that grasses will grow satisfactorily on the Federal Cell cover. Recent reclamation attempts to get grass to grow in nearby borrow pits at Clive have notably failed. A lack of grasses growing on the Clive cover would greatly diminish its ability to resist erosion.

The PHB has side slopes consisting of either pit-run gravel or basalt riprap. These would be expected to handle erosion (and help contain erosion on the top slope) much better than would a gravelly fine-grained material, as proposed for the Federal Cell. The PHB cover system also utilizes a capillary break that helps prevent subsurface piping, which, based on DEQ field experience at Clive, may contribute to rapid erosion on fine-grained slopes, even when some gravel is present.

The DOE conclusion is that the PHB cover system is very likely to perform for a 1,000-year design life. However, the need for modeling the integrity of the proposed Federal Cell cover system extends, according to current Utah rule, at least throughout its 10,000-year compliance period, and preferably far beyond that.

Regarding justification of the use of 50 percent gravel, Energy*Solutions*/Neptune provided the following information in NAC-0108_R0 (Neptune 2018g, p. 24):

> *No sites were found that have used a gravel admixture on side slopes at or above 20%. Similarly, there were no methodologies found that specifically address the calculation of gravel admixtures for slopes greater than 10%, other than the general methods found in NUREG-1623 and NUREG/CR-4620 (Nelson et al. 1986; NRC 2002). For slopes over 9%, Simanton et al. (1984) found that the rate of water erosion decreases exponentially with increasing rock fragment cover. The effect of biological soil crust is also difficult to quantify. These crusts are expected to become established along the slopes as has been observed along natural slopes in the Clive area. The required lengthy post-closure care period provides the greatest opportunity for verification of the design methodology described previously by Simanton et al. (1984).*
>
> *The design process completed to determine the acceptability of the 50% gravel admixture on the20% side slopes is in accordance with EPA and Nuclear Regulatory Commission guidance. These guidance procedures contain no requirements that existing sites be used as evidence to support proposed designs. While it is acknowledged that such evidence would be helpful, each site is different and contains unique design constraints based on physical layout, climate, material availability, and project goals that make determinations based on sound methodologies necessary.*

Energy*Solutions*/Neptune have provided modeling and in-service information on covers with a 15 percent gravel admixture suggesting that such a cover material may function adequately. However, little useful information on side slopes with a 50 percent gravel admixture was located.

This interrogatory remains open for several reasons, including:

- Use of USLE to model cover erosion does not consider effects of gully erosion.
- Inadequate justification is provided for using a 50 percent gravel mixture on the side slopes, especially when in-service tests of riprap side slopes is promising.

3.1.5 Interrogatory CR R313-25-25(4)-199/1: Uncertainties in Erosion Modeling

Preliminary Finding

Refer to UAC R313-25-25(4):

> *Covers shall be designed to minimize, to the extent practicable, water infiltration, to direct percolating or surface water away from the disposed waste, and to resist degradation by surface geologic processes and biotic activity.*

Refer also to UAC R313-25-23:

> *The disposal facility shall be sited, designed, used, operated, and closed to achieve long-term stability of the disposal site and to eliminate, to the extent practicable, the need for ongoing active maintenance of the disposal site following closure so that only surveillance, monitoring, or minor custodial care are required.*

Interrogatory Statement

Please provide quantitative estimates of the uncertainties involved using the borrow pit model as an analog for estimating erosion of the Federal Cell, including use of RHEM to develop input parameters for SIBERIA, and modeling uncertainties inherent in the selection of SIBERIA.

Basis for Interrogatory

As described in Appendix 10 (Neptune 2015f, p. 3) to the DU PA v1.4, "A borrow pit model has been used in the Clive DU PA Model as an analog to evaluate the influence of erosion on embankment performance." While not cited as the reference in Appendix 10 (as it should be), the borrow pit model is described in considerably more detail in *Modeling Report: Surface Erosion Modeling of a Borrow Pit at the Energy*Solutions *Clive, Utah Facility*, prepared by Neptune and Company, dated July 7, 2014 (Neptune 2014e).[9] Neptune states on p. 21 of this report that:

> *SIBERIA model predictions of long-term erosion effects for the borrow pits should be considered as approximate assessments of their evolution. The lack of site-specific runoff and sediment-yield data and the assumption of steady-state landscape forming events make long-term predictions uncertain.*

Some quantification of the "approximate" nature of the assessments needs to be provided; i.e., is it 10 percent, 50 percent, an order of magnitude, or more?

[9] This report had been included with the DU PA v1.2 submittal.

DEQ Discussion of NAC-0108_R0 – July 2019

As stated in NAC-0108_R0, Section 2.5.1 (Neptune 2018g, p. 25),

> *This interrogatory requests that quantitative uncertainty estimates be provided for the use of the borrow pit erosion model results as an analog to evaluate the influence of erosion on embankment performance at 10,000 years. While potentially interesting,* ***such estimates are not necessary for demonstrating erosion resistance of the Federal Cell ET Cover****. Furthermore, LEMs* [landscape evolution models] *have been used as exploratory models providing insight into landscape–climate processes for many years, but they have not been developed to the level of other types of environmental modeling (Skinner et al. 2017). Typical methods used for calibration, sensitivity analysis, and uncertainty analysis are difficult to apply to LEMs since little data is available for calibration and verification (Skinner et al. 2017); (Temme et al. 2009). LEMs, however, even at this early stage, can be useful in providing insight into landscape-climate processes.* [Emphasis added.]

As Temme et al. (2009) note:

> *In the light of increasing societal interest in the effects of climate change, geomorphologists face the task of discriminating between natural landscape changes and landscape changes that result from human-induced climate change. Landscape Evolution Models (LEMs) are available for this purpose, but their application for prediction of future landscapes is problematic. Calibration of LEMs on a sufficiently long paleo-record of landscape change solves some of these problems, but large uncertainties in input (e.g. climate) records and process descriptions remain.*

Temme et al. also note that

> *the application of a global SA* [sensitivity analysis] *should become a vital step in any investigation using LEMs. This paper has demonstrated that the use of the MM* [Morris method] *is efficient for this purpose and can ultimately feed back into model set-up, as well as future model development.*

DEQ questions the statement that uncertainty estimates "are not necessary for demonstrating the erosion resistance of the Federal Cell ET cover." How can the regulator make a judgement on embankment performance without some knowledge of the quality of the performance indicators? Temme et al. (2009) support the need for sensitivity analysis in any investigation using LEMs. If the LEMs are not sufficiently developed to perform uncertainty or sensitivity analyses, then their value in analyzing the erosion performance for regulatory purposes is open to question.

Energy*Solutions*/Neptune have presented arguments for not providing the requested uncertainty assessment, based on the current, immature state of LEM development. If that is a fair evaluation of the status of model development, DEQ believes that the SIBERIA modeling adds little to the ability to characterize the erosion behavior of the Federal Cell. This interrogatory remains open.

3.1.6 Interrogatory CR R313-25-25(4)-200/1: Use of RHEM to Develop Parameters for SIBERIA

Preliminary Finding

Refer to UAC R313-25-25(4):

> *Covers shall be designed to minimize, to the extent practicable, water infiltration, to direct percolating or surface water away from the disposed waste, and to resist degradation by surface geologic processes and biotic activity.*

Refer also to UAC R313-25-23:

> *The disposal facility shall be sited, designed, used, operated, and closed to achieve long-term stability of the disposal site and to eliminate, to the extent practicable, the need for ongoing active maintenance of the disposal site following closure so that only surveillance, monitoring, or minor custodial care are required.*

Interrogatory Statement

Please remodel erosion of the Federal Cell cover using the newer version of the RHEM model (Al-Hamdan et al. 2015) applicable to disturbed soils and concentrated surface-water flow. The SIBERIA model results in the DU PA v1.4 should be compared with those of SIBERIA modeling of erosion for the site based on the Grand Junction embankment modeling by Smith (2011). Modeling of the latter embankment indicates that significant gullying can occur over time on side slopes, even with vegetated soil on the embankment having considerable (i.e., 40 percent) added gravel (Smith 2011).

Basis for Interrogatory

As described in Neptune 2014e (p. 7), “In the absence of site-specific or analog site data, fluvial parameters for the [SIBERIA] borrow pit model were estimated by matching to synthetic data produced by the RHEM Model (Nearing et al., 2011).” The DU PA v1.4 used an older version of the RHEM model (i.e., Nearing et al. 2011). That version has limited application to describing erosion by concentrated flow on disturbed soils, as would be expected at Clive. The Nearing et al. (2011) paper indicated that, at the time of publishing, work was under way to improve the model for application to disturbed soils. The authors indicated that more work was necessary to define RHEM parameters for conditions in which flow is concentrated. In 2015, Nearing and other developers of RHEM published a description of a newer version of the RHEM model that could be calibrated, and could be run, so as to account for erosion by concentrated flow on disturbed soils (Al-Hamdan et al. 2015).

DEQ Discussion of NAC-0108_R0 – July 2019

DEQ requested that erosion calculations for the Federal Cell cover be redone using a newer version of RHEM that considers disturbed soils and concentrated surface water flows. In response, Energy*Solutions*/Neptune (2018g, p. 26) note that “changes to the RHEM model have made it currently inapplicable to modeling scenarios at Clive. HAL (2018) note that slope length is no longer a functioning input variable to RHEM; all simulations have a set slope length of 50 meters (164 ft).” DEQ also notes that Appendix 10 of v1.4 of the DU PA does not provide any discussion of the input parameters derived from RHEM and used as input to SIBERIA.

Based on the inability to perform additional RHEM calculations with a model that considers such factors as slope lengths, disturbed soils, and concentrated surface water flows, Energy*Solutions*/Neptune should provide an alternative approach for modeling Federal Cell erosion and to provide fluvial parameters for the SIBERIA model. These parameters then need to be provided in Appendix 10 for DEQ review. Pending resolution of the cited problems with RHEM, this interrogatory remains open

Any site will be different from the Clive site. This does not preclude a comparison of the predictions for the Clive site with the outcomes reported by Smith and Benson (2016) in NUREG/CR-7200 for the Grand Junction site. Rather, the comparison needs to be made in context of both the similarities and differences, with the inferences drawn based on data and facts. For example, while the distribution of particle sizes of the surface layer at the Clive site is different from that assumed in NUREG/CR-7200, the differences are relatively small, and an inference could be drawn considering how these modest differences in surface layer properties would affect the outcomes. Drawing an inference that no comparison can be made is inconsistent with these modest differences and with the overall modest differences between the Grand Junction and Clive sites.

3.1.7 Interrogatory CR R313-25-25(4)-201/1: Estimating Rainfall Intensity

Preliminary Finding

Refer to UAC R313-25-25(4):

> *Covers shall be designed to minimize, to the extent practicable, water infiltration, to direct percolating or surface water away from the disposed waste, and to resist degradation by surface geologic processes and biotic activity.*

Interrogatory Statement

It is not clear that the Probable Maximum Precipitation (PMP) was determined using the procedures outlined in the National Oceanic and Atmospheric Administration and U.S. Army Corps of Engineers publication Hydrometeorological Report No. 49 (HMR 49) (1977). According to Energy*Solutions*, these procedures resulted in a "1-hour PMP rainfall intensity of 9.9 inches." However, DWMRC finds that a value of 9.8 or 9.9 inches is not the intensity, but rather the 1-hour PMP, or the maximum precipitation expected over 1 square mile when averaged over an hour (DWMRC 2015).

Please recalculate the PMP using NUREG/CR-4620, as outlined below.

Basis for Interrogatory

The intensity would be the maximum precipitation occurring over the time of concentration at the Clive embankment divided by that time. The time of concentration is defined by the U.S. Department of Agriculture (2010): "Time of concentration (Tc) is the time required for runoff to travel from the hydraulically most distant point in the watershed to the outlet." For the embankment, that would be only minutes. During that time, when the rate of precipitation is greatest, intensity is generally much greater than that calculated as the hour-long average precipitation for the 1-hour PMP. DEQ has assessed the intensity, assuming a 1-hour PMP of 9.8 inches for the square-mile Section 32, to be approximately 4 to 5 times the PMP. Energy*Solutions* will need to use Table 2.1 and Equations 2.1 and 2.2 of NUREG/CR-4620

(Nelson et al. 1986) to determine the intensity (*i*) from the PMP based on the time of concentration at the site (only minutes). The intensity should correspondingly be much greater than 9.9 inches/hour. This revision should increase the value of *Q* (the runoff discharge). Energy*Solutions* should then reassess erosion potential based on the new calculations. An isochrones map, showing equal time of travel for the catchment area, should also be provided.

Discussion of NAC-0108_R0 – July 2019

Energy*Solutions*/Neptune agreed that rainfall intensity was not calculated correctly and provided revised estimates in NAC-0108_R0 (Neptune 2018g). The corrected values for the Federal Cell are presented in Table 6 of that document. Under this interrogatory, Energy*Solutions*/Neptune also discussed the NRC maximum permissible velocity (MPV) approach for gully formation (NRC 2002). See also Interrogatory 71. We believe that the Energy*Solutions*/Neptune-selected maximum permissible velocity of 5 ft/s is not consistent with NRC recommendations. Using an MPV of 2.5 to 3 ft/s as recommended by the NRC (2002, Appendix A, p. A-3) results in calculated flow velocities that exceed the MPV.

This interrogatory remains open because the MPV used was not consistent with NRC guidance.

3.1.8 Interrogatory CR R313-25-25(4)-202/1: Use of SIBERIA to Model Federal Cell Erosion

Preliminary Finding

Refer to UAC R313-25-25(4):

> *Covers shall be designed to minimize, to the extent practicable, water infiltration, to direct percolating or surface water away from the disposed waste, and to resist degradation by surface geologic processes and biotic activity.*

Interrogatory Statement

DEQ is concerned that the SIBERIA model referenced in DU PA v1.4 discussions assumes a modeling-realm geometry inconsistent with that of the proposed Federal Cell. The Federal Cell embankment is approximately 30 feet high[10] compared to the model analog height of 10 feet. Also, the SIBERIA model allows for several hundred meters of ground surface upslope from the sloping pit face, but that ground surface only has a 0.3 percent (0.003) grade in the model. By contrast, as described in Appendix 3 to the DU PA v1.4 (Neptune 2015c), the waste under the top slope above and upslope from the side slopes of the embankment has a grade of up to 2.4 percent. This is about eight times greater. Energy*Solutions* needs to explain how these differences affect the results and how the Federal Cell modeling results can be reconciled against similar modeling studies conducted by Smith and Benson (2016) for the Grand Junction Uranium Mill Tailings Disposal Site.

Basis for Interrogatory

DEQ is concerned that the Energy*Solutions* conclusion that "compensating features" allow "the borrow pit erosion modeling results to be applicable" is not verifiable without modeling the described conditions (DEQ 2016). DEQ questions the model results that gully depths of only 15.9 cm will occur on the top slope over 10,000 years (DU PA v1.4, Appendix 10, page 5,

[10] Height of waste under top slope and above grade.

Neptune 2015f). Based on the Division's experience, site-specific observations, and literature review, such results seem unlikely. SIBERIA modeling done by Benson et al. (2011) and by Smith (2011) using the Grand Junction Uranium Mill Tailings Disposal Site in Grand Junction, Colorado, as a basis for geometry, but with gravel-amended cover soil and vegetative cover, indicates that significant gullying will likely occur over time on side slopes of such an embankment. The work on the Grand Junction tailings site noted above has recently been issued as NUREG/CR-7200 (Smith and Benson 2016). Figure 4.1 of that document shows that the maximum elevation change after 1,000 years for a disposal cell with a surface layer containing 40 percent gravel in a semi-arid climate is greater than 6 meters.

DEQ Discussion of NAC-0108_R0 – July 2019

In responding to this interrogatory, Energy*Solutions*/Neptune stated in NAC-0108_R0, section 2.5.1 (Neptune 2018g, p. 30):

> *SIBERIA is employed in the DU PA model as a supplementary line of evidence for embankment stability. If SIBERIA results were the sole or primary basis for demonstrating embankment stability, the distinctions noted in the interrogatory could be relevant; however, LEMs such as SIBERIA are acknowledged to be subject to further development before their results should be considered conclusive in licensing situations.*

There are several issues that more information and more analysis. Two of these issues are as follows:

1. Model details, including the selection process for input parameters, are not included here. The long-term trajectory of evolving gully landscapes exogenically forced by rainfall, surface runoff, and hillslope diffusivity depend critically on the model input parameters (e.g., Tucker and Hancock 2010; Hancock et al. 2016). Ideally, these model input parameters would be closely aligned with onsite observations.
2. Model verification, including the various methods and indices to demonstrate this, are not included here. At noted in previous communications, no attempt has been made to quantify the predictive accuracies and uncertainties associated with SIBERIA. It is expected that the uncertainty predictions from this model are not insignificant (see West Valley Demonstration Project Erosion Working Group, 2013), and that the magnitudes of these uncertainties increase markedly with the timeframe in which they are employed; the uncertainty bounds increase with forecast time (e.g., Tucker and Hancock, 2010; Hancock et al., 2016; West Valley Erosion Working Group Modeling Team, 2018). Ideally, these predictive uncertainties would be included in the database of predicted gully areas and depths simulated for the Clive facility 10,000 years from now.

Energy*Solutions*/Neptune chose not to discuss why the borrow pit modeling was applicable to describing the Federal Cell cover performance and stated that use of SIBERIA in its present state of development should not be considered to provide conclusive results for licensing decisions. Consequently, we question the use of SIBERIA to demonstrate embankment stability. This interrogatory remains open.

3.1.9 Interrogatory CR R313-25-9(5)(a)-206/1: Temporal Uncertainty in Performance Assessment

Preliminary Finding

Refer to UAC R313-25-9(5)(a):

> *Notwithstanding Subsection R313-25-9(1), any facility that proposes to land dispose of significant quantities of concentrated depleted uranium (more than one metric ton in total accumulation) after June 1, 2010, shall submit for the Director's review and approval a performance assessment that demonstrates that the performance standards specified in 10 CFR Part 61 and corresponding provisions of Utah rules will be met for the total quantities of concentrated depleted uranium and other wastes, including wastes already disposed of and the quantities of concentrated depleted uranium the facility now proposes to dispose. Any such performance assessment shall be revised as needed to reflect ongoing guidance and rulemaking from NRC. For purposes of this performance assessment, the compliance period shall be a minimum of 10,000 years. Additional simulations shall be performed for the period where peak dose occurs and the results shall be analyzed qualitatively.*

Interrogatory Statement

Please provide an explanation as to why the DU PA GoldSim Model v1.4 uncertainty seems to be decreasing with increasing time.

Basis for Interrogatory

As the following quotes indicate, it is reasonable to expect that the uncertainty of the performance assessment results would increase the further into the future the analysis is extended.

- "We recognize that there are significant uncertainties in the supporting calculations and that **the uncertainties increase as the time at which peak risk occurs increases**" (NAS 1995, p. 56; emphasis added).
- "There are difficulties in showing compliance with safety criteria over long timescales because of **the increase with time of the uncertainty associated with the results of predictive models**" (Fearnley 1997, p. 233; emphasis added).
- "PAWG [Performance Assessment Working Group] also recognizes that **the uncertainties in calculations increase with time**, thus for very long timeframes (such as beyond 10,000 years) such calculations are best used for making qualitative evaluations" (NRC 2000, p. 7; emphasis added).
- "It is recognized that radiation doses to individuals in the future can only be estimated and that **the uncertainties associated with these estimates will increase for times farther into the future**" (IAEA 2006, p. 36; emphasis added).
- "Uncertainties associated with the performance of natural and engineered systems may increase, and uncertainties associated with human behavior definitively increase, over extended periods of time. Uncertainty, in this context, can render the result of the

calculation meaningless as input to regulatory decision-making. In the context of waste disposal, uncertainty is not a suitable reason to dispose of waste, but it may be a suitable reason to not dispose of waste if the uncertainty in the consequences is unacceptably large" (NRC 2011, p. 4).

Energy*Solutions*/Neptune provided DEQ/SC&A with the input files for the latest DU PA GoldSim model in December 2015 (i.e., "Clive DU PA Model v1.4.gsm"). DEQ/SC&A ran the GoldSim v1.4 model.gsm file. Although Energy*Solutions*/Neptune ran v1.4 for 10,000 realizations, to reduce the execution time DEQ/SC&A only ran it for 1,000 realizations. To save additional execution time, DEQ/SC&A did not check the "Perform dose calculations" box. Therefore, the only metric DEQ/SC&A was able to check with this GoldSim v1.4 run was the groundwater (or well water) concentrations at 500 years, which are presented in Neptune 2015a, Table 2. Because DEQ/SC&A only ran 1,000 realizations, the DEQ/SC&A results are similar to the Energy*Solutions*/Neptune results but do not match them exactly.

For Tc-99, iodine-129 (I-129), and uranium-238 (U-238), Figure 18, Figure 19, and Figure 20 below present the median, mean, and 95th percentile well water concentrations DEQ/SC&A calculated with the DU PA GoldSim model v1.4. To check the results, Table 7 compares the DEQ/SC&A calculated median, mean, and 95th percentile concentrations to those reported in Neptune 2015a, Table 2.

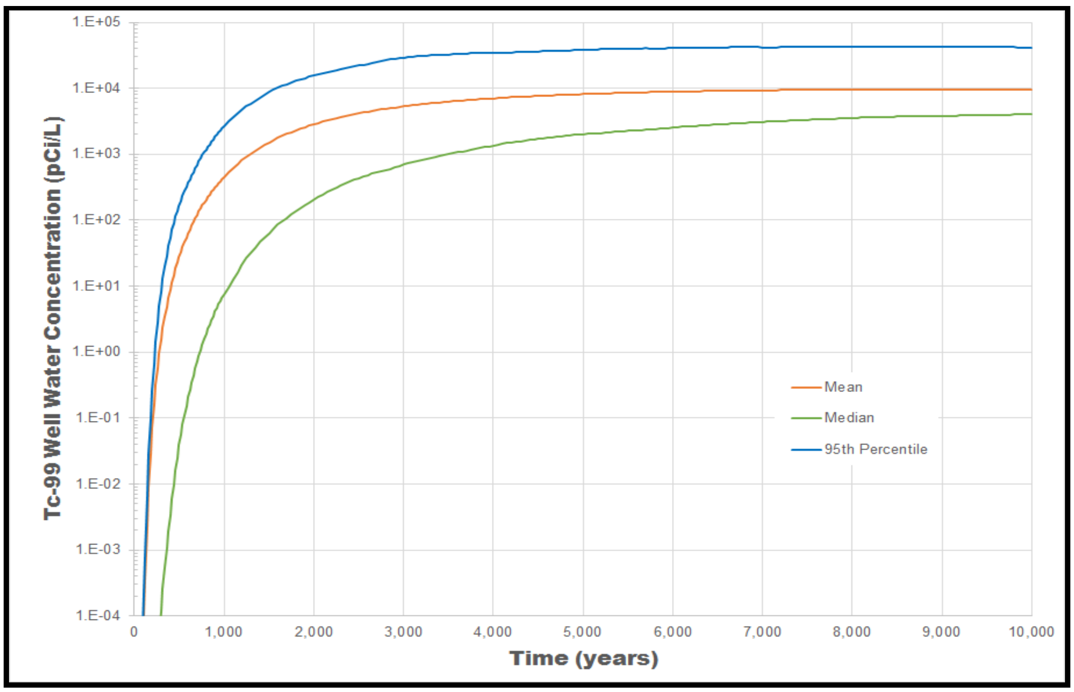


Figure 18. DU PA GoldSim Model v1.4 Tc-99 well water concentration

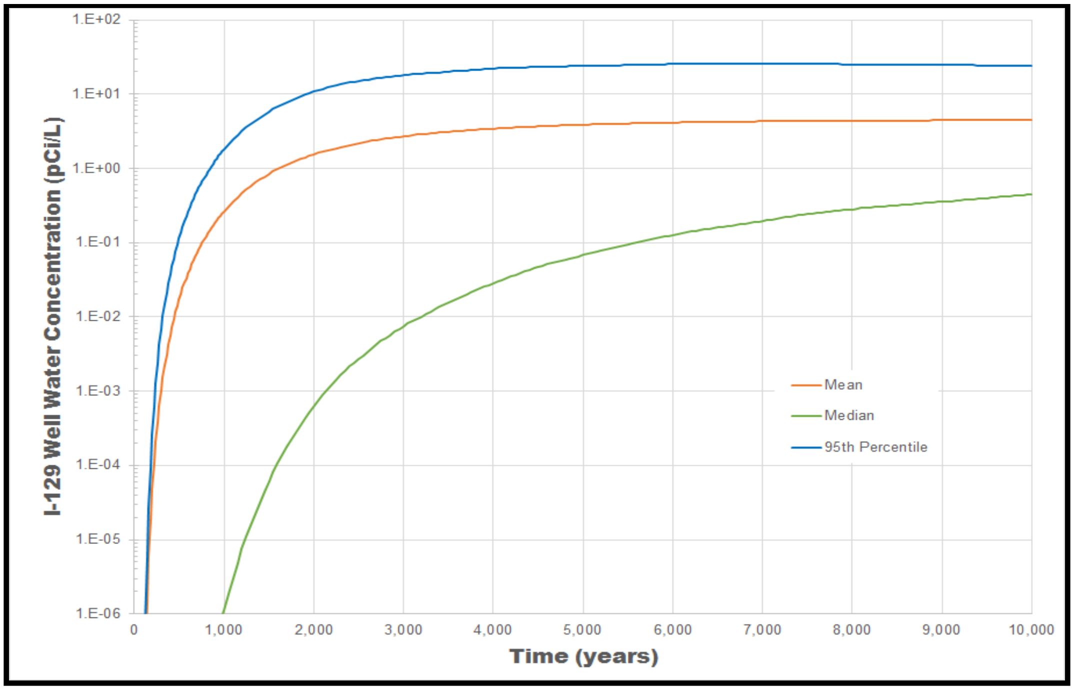


Figure 19. DU PA GoldSim Model v1.4 I-129 well water concentration

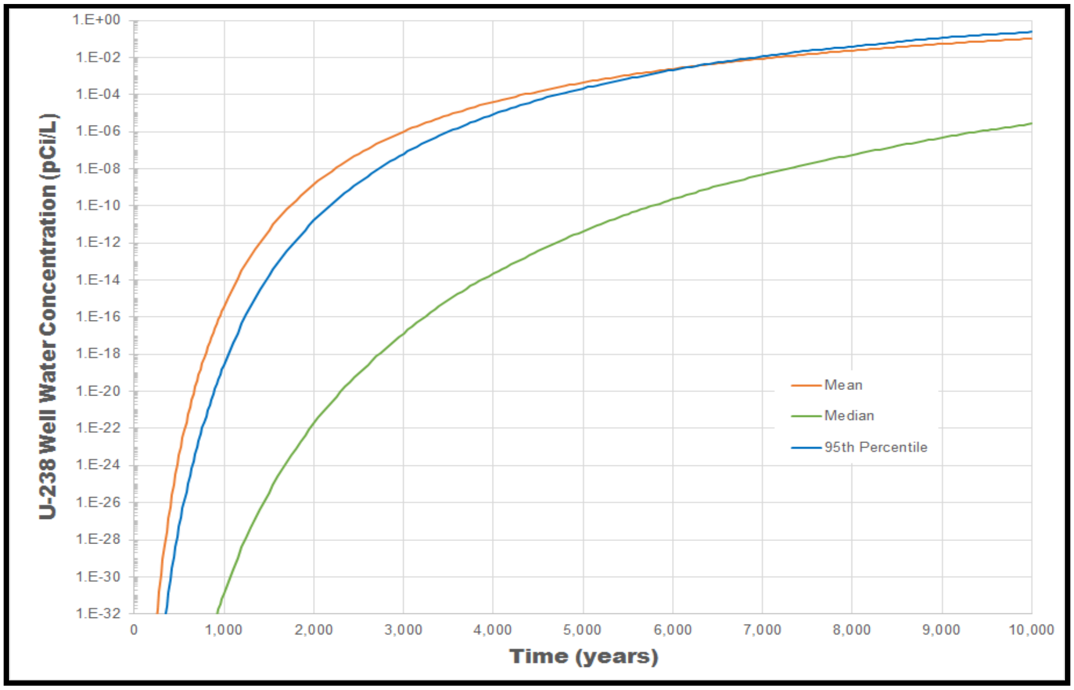


Figure 20. DU PA GoldSim Model v1.4 U-238 well water concentration

Table 7. DU PA GoldSim Model v1.4 Well Water Concentrations at 500 Years

Nuclide	@500 Years			DU PA v1.4 (Neptune 2015a), Table 2		
	Mean	Median	95th Percentile	Mean	Median	95th Percentile
Tc-99	28	3.9E-02	160	26	4.3E-02	150
I-129	1.7E-02	6.4E-11	1.1E-01	1.7E-02	4.3E-11	1.1E-01
U-238	3.5E-24	0	5.1E-28	1.5E-22	0	1.8E-27

As Table 7 shows, the agreement between the Energy*Solutions*/Neptune results and the DEQ/SC&A results is quite good, especially for Tc-99 and I-129. For U-238, there are differences, but in both cases the U-238 concentrations are quite small and the differences are likely due to the additional realizations run by Energy*Solutions*/Neptune (i.e., if one or more of those additional 9,000 realizations had large U-238 concentrations, it could account for the difference).

To obtain a measure of the uncertainty associated with the DU PA GoldSim model v1.4, SC&A/DEQ calculated well water concentrations by comparing the mean to the median concentrations. Because the 5th percentile results are all zeros, it was not possible to calculate a 90 percent confidence limit. We could have compared the 95th percentile to the median concentrations and produced what is called a one-sided upper confidence limit. However, we chose to use the mean, because the mean is what is recommended by the NRC (2016b, p. 2-68) as the metric for comparison to the regulatory limit. Because the mean closely follows the 95th percentile (see Figure 18, Figure 19, and Figure 20), the conclusions would be similar regardless of which was used.

Table 8 presents the results of the DEQ/SC&A analysis at 1,000 and 10,000 years. For all three radionuclides examined—Tc-99, I-129, and U-238—Table 8 indicates that the mean-to-median ratio at 1,000 years is larger than at 10,000 years—meaning that the uncertainty is decreasing with increasing time.

Table 8. DU PA GoldSim Model v1.4 Well Water Concentrations at 1,000 and 10,000 Years

Nuclide	@1,000 Years			@10,000 Years		
	Mean	Median	Ratio	Mean	Median	Ratio
Tc-99	4.5E+02	7.5E+00	6.0E+01	9.7E+03	4.0E+03	2.4E+00
I-129	2.6E-01	1.1E-06	2.3E+05	4.4E+00	4.4E-01	1.0E+01
U-238	3.6E-16	1.2E-31	3.0E+15	1.0E-01	2.6E-06	4.0E+04

Since the Table 8 results are unexpected and seem to contradict the five references quoted above, please provide an explanation for why the DU PA GoldSim Model v1.4 uncertainty seems to be decreasing with increasing time.

3.1.10 Interrogatory CR R313-25-23-207/1: Stability of Disposal Site

Preliminary Finding

Refer to UAC R313-25-23:

> *The disposal facility shall be sited, designed, used, operated, and closed to achieve long-term stability of the disposal site and to eliminate, to the extent practicable, the need for ongoing active maintenance of the disposal site following closure so that only surveillance, monitoring, or minor custodial care are required.*

Interrogatory Statement

The footprint of the Federal Cell embankment is situated directly adjacent to the 11e.(2) Cell. Please provide an analysis of the impact of the Federal Cell on the stability of the adjacent 11e.(2) Cell and demonstrate that consolidation settlement will not negatively affect the performance of the Federal Cell.

Basis for Interrogatory

The effects of the considerably heavier embankment configuration on the foundation soil profile need to be evaluated:

1. A heavier embankment will induce a deeper foundation profile into consolidation settlement.
2. A heavier embankment that is too close to an adjacent embankment (i.e. the 11e.(2) embankment) could induce consolidation settlement of the foundation soil beneath the lighter and older adjacent embankment and affect the performance of a completed radon barrier of the adjacent embankment.

Secondary settlement has been evaluated for the Class A West embankment configuration for a time frame of at least 500 years. The effects of secondary settlement need to be evaluated for 10,000 years.

3.2 Closed DU PA V1.4 Interrogatories

3.2.1 Interrogatory CR R313-25-9(5)(a)-203/1: Inclusion of Other Wastes in PA

Preliminary Finding

Refer to UAC R313-25-9(5)(a):

> *Notwithstanding Subsection R313-25-9(1), any facility that proposes to land dispose of significant quantities of concentrated depleted uranium (more than one metric ton in total accumulation) after June 1, 2010, shall submit for the Director's review and approval a performance assessment that demonstrates that the performance standards specified in 10 CFR Part 61 and corresponding provisions of Utah rules will be met for the total quantities of concentrated depleted uranium and other wastes, including wastes already disposed of and the quantities of concentrated depleted uranium the facility now proposes to dispose.*

Interrogatory Statement

Please describe how Energy*Solutions* proposes to address the requirements of UAC R313-25-9(5)(a) to demonstrate that the performance assessment considers the "total quantities of concentrated depleted uranium **and other wastes**" (emphasis added).

Basis for Interrogatory

In Section 6.2.2 of Appendix 21 to DU PA v1.4, Neptune discusses the influence of cover erosion on contaminant transport and receptor dose. Specifically, Neptune states that:

> *Doses to the rancher receptor are increased due to a thinner amount of material above the DU waste. The thinner cover results in increased radon flux at the surface. The scenario with 4 feet of erosion showed a larger increase, as expected. However, even 4 feet of erosion across the entire cover produced less than an order of magnitudes increase, and the 95th percentile doses still remain less than 0.5 mrem/year. These results demonstrate that while receptor doses do increase with an eroded cover, doses still remain low despite the assumption of site-wide erosion of the cover.* [Neptune 2015j, p. 18]

This analysis fails to recognize that Energy*Solutions* plans to bury non-DU waste from DOE above the DU. As noted in Figure 10 of Appendix 3 to DU PA v1.4 (Neptune 2015c), space is provided in the Federal Cell embankment for 9.4 meters of non-DU waste. Utah regulation R313-25-9(5)(a) requires that a performance assessment will need to be submitted demonstrating that the performance standards specified in 10 CFR Part 61 and corresponding provisions of Utah rules will be met for the total quantities of concentrated DU and other wastes, including wastes already disposed of and the quantities of concentrated DU the facility now proposes to dispose. It is important to note that performance assessment requires consideration of the "total quantities of concentrated depleted uranium **and other wastes**" (emphasis added).

An additional concern is that DU PA v1.4 assumed a density of 1.5 g/cm^3 for the material uniformly spread over the DU (i.e., Unit 4 soil). Quite often, LLRW has a density that is less than that, and very seldom is LLRW uniform. For example, the Energy*Solutions* Waste Acceptance Criteria for bulk waste give a dry active waste density of 0.25 g/cm^3. Both nonuniformity and lower density would result in higher doses and radon fluxes on the embankment surface if the Unit 4 material is replaced by LLRW. In addition, with heterogeneous LLRW rather than homogeneous LLRW expected in the embankment above the DU, preferential pathways for fluid flow may be created that would allow for faster transport of radionuclides to the liner and the groundwater table than are currently modeled in the performance assessment.

DEQ Discussion of NAC-0102_R0 – July 2019

As stated by Energy*Solutions*/Neptune in NAC-0102_R0, Section 2.2.1:

> *As provided in draft Condition 4 of the 2015 SER, prior to disposing of Class A LLRW other than DU in the Federal Cell, Energy*Solutions *will obtain approval of additional modeling. Energy*Solutions *does not intend or request to dispose of other Class A LLRW above the DU until such time as a PA accounting for the combined effects of DU and other Class A LLRW is approved. This does not preclude approval to dispose of DU in the interim.* [Neptune 2018b, p. 4]

This position is consistent with that of DEQ. Therefore, this interrogatory is closed.

3.2.2 Interrogatory CR R313-25-20-204/1: Exposure to Groundwater

Preliminary Finding

Refer to UAC R313-25-20, "Protection of the General Population from Releases of Radioactivity":

> *Concentrations of radioactive material which may be released to the general environment in ground water, surface water, air, soil, plants or animals shall not result in an annual dose exceeding an equivalent of 0.25 mSv (0.025 rem) to the whole body, 0.75 mSv (0.075 rem) to the thyroid, and 0.25 mSv (0.025 rem) to any other organ of any member of the public. No greater than 0.04 mSv (0.004 rem) committed effective dose equivalent or total effective dose equivalent to any member of the public shall come from groundwater. Reasonable efforts should be made to maintain releases of radioactivity in effluents to the general environment as low as is reasonably achievable.*

Interrogatory Statement

Please revise your June 8, 2014, partial response to Interrogatory 182 by extending it to 10,000 years and including the groundwater consumption pathway, and include the results of the extended analysis in the next revision of the DU PA, including the Appendix 19 sensitivity analyses.

Basis for Interrogatory

In partial response to Interrogatory 182, Energy*Solutions* provided an analysis of the exposures due to the use of contaminated groundwater. Because the analysis was stopped at 500 years and because it did not address the groundwater consumption pathway, the June 2014 response provided (ES 2014b) is considered by DEQ to only be a partial response to Interrogatory 182.

While preparing the April 2015 SER, DEQ/SC&A extended the Energy*Solutions* Interrogatory 182 partial response to 10,000 years and included the groundwater consumption pathway as well as several postulated scenarios, including a leaking well casing, a nearby failed or abandoned well that presents a direct path between the upper and lower aquifer, and fresh water in the lower aquifer. The results of this DEQ/SC&A analysis are given in the white paper, *Groundwater Pathway Doses, Part 2*, Revision 2 (Marschke 2015).

Although Energy*Solutions* provided the results of their partial groundwater analysis in the June 2014 response to Round 2 interrogatories (ES 2014b), the results were not provided in the November 2015 final report for the Clive DU PA Model v1.4. To allow DEQ to conclude that the DU PA is complete, the results from a complete Energy*Solutions* analysis of the potential exposures due to the use of contaminated groundwater need to be provided in the DU PA.

DEQ Discussion of NAC-0104_R0 – July 2019

In NAC-0104_R0, *Groundwater Exposure Responses for the Clive DU PA Model* (Neptune 2018d), Section 2.1.3, "Updated Groundwater Ingestion Tc-99 Concentration Estimate," presents the requested analysis. Section 2.1.3 presents Tc-99 concentrations in the upper aquifer well location out to 10,000 years and shows that the 95th percentile concentration was 45,000 picocuries per liter (pCi/L). Since the upper aquifer water would need to be treated to make it drinkable, treatment would likely be reverse osmosis (RO), as assumed in Neptune 2018d. Although Marschke (2015) conservatively assumed only an RO decontamination factor (DF) of 10, Neptune (2018d) is correct in stating that larger DFs are regularly achieved. We conclude that a DF of 12 or more should be readily achievable. With an RO DF of 12 or more, the 95th percentile Tc-99 is reduced to 3,760 pCi/L or less—the GWPL.

Although Energy*Solutions*/Neptune did not carry the analysis to the actual calculation of the drinking water ingestion dose (i.e., mrem/yr), the use of the Tc-99 GWPL as a surrogate for 4 mrem/yr from the drinking water pathway is acceptable.

Therefore, as long as the concentration of Tc-99 and other radionuclides remains as predicted via v1.4 of the DU PA, this interrogatory can be considered closed.

3.2.3 Interrogatory CR R313-25-25(4)-205/1: Erosion Analysis

Preliminary Finding

Refer to UAC R313-25-23:

> *The disposal facility shall be sited, designed, used, operated, and closed to achieve long-term stability of the disposal site and to eliminate, to the extent practicable, the need for ongoing active maintenance of the disposal site following closure so that only surveillance, monitoring, or minor custodial care are required.*

Interrogatory Statement

As discussed below, there appears to be an issue with the FractionGully 1.52-meter depth data. Please explain why the 1.52-meter depth percentages are smaller than the 1.97-meter and 2.42-meter depth results.

Basis for Interrogatory

First, SC&A was able to reproduce DU PA v1.4 Appendix 10, Figure 2 using the GoldSim data lookup table: FractionGully (see Figure 21). FractionGully is a lookup table that has the results of the 1,000 realizations of the erosion analysis for 15 depths (the 11 cap layers (5 feet total) and four waste layers (0.4485 meter each)). FractionGully has very small percentages for the top cap layer (0.01 meter). This implies that erosion is greater than 0.01 meter almost everywhere on the embankment.

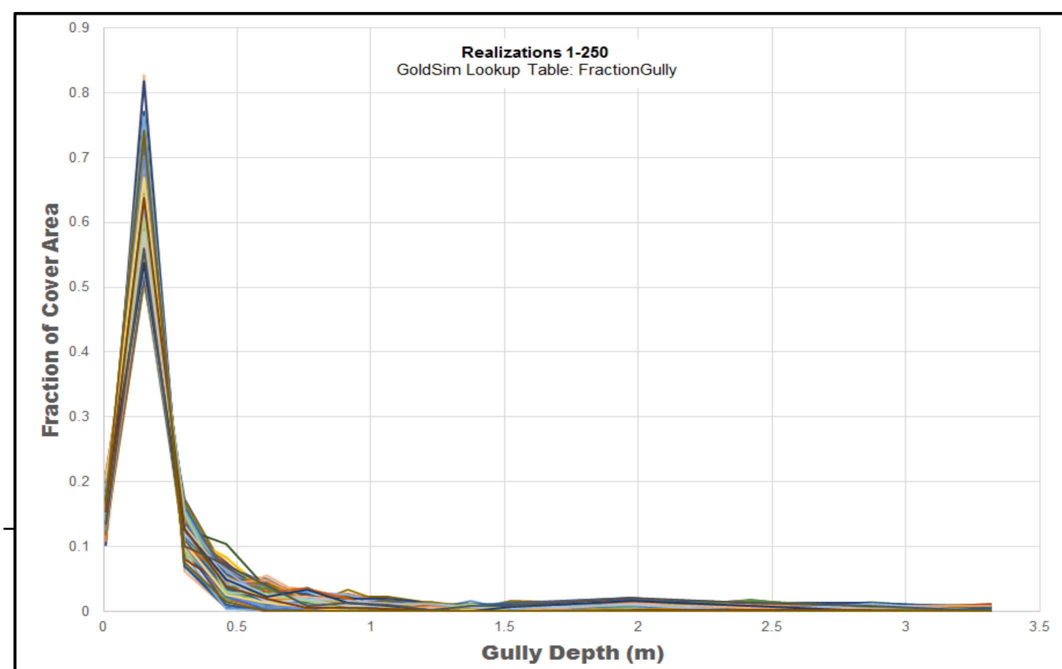


Figure 21. Reproduction of DU PA v1.4 Appendix 10, Figure 2, using the GoldSim data lookup table FractionGully.

Next, Figure 22 shows the percentage of realizations that have a fraction of the cover area covered by gullies of 1.07, 1.52, 1.97, 2.42, 2.87, and 3.32 meters depth. For example, 0.5 percent of the cover area is covered with 1.07-meter-deep gullies for almost 60 percent of the realizations, and 0.5 percent of the cover area is covered with gullies 3.32 meters deep for only about 8.5 percent of the realizations.

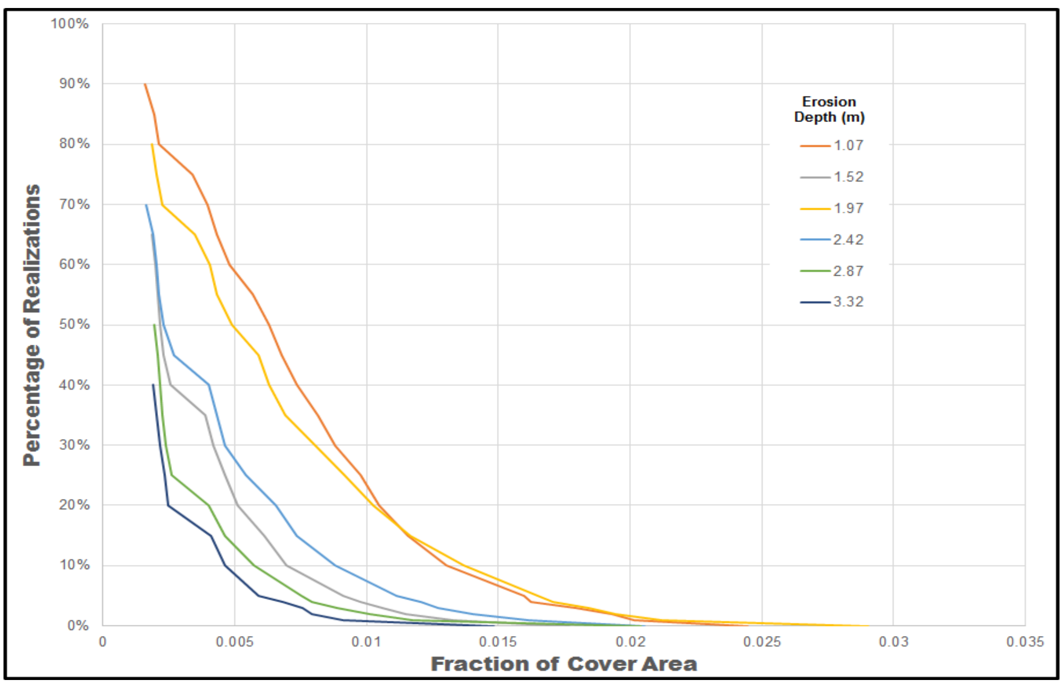


Figure 22. Percentage of realizations that have a fraction of the cover area covered by gullies of various depths.

Table 9 tabulates the data presented in Figure 22.

Table 9. Percentage of Realizations that Have a Fraction of the Cover Area Covered by Gullies of Various Depths

Eroded Area		Depth of Gully Percentage of Realizations					
Fraction	m^2	1.07 m	1.52 m	1.97 m	2.42 m	2.87 m	3.32 m
0.005	1,087	58.9%	21.2%	49.4%	27.6%	13.3%	8.5%
0.01	2,173	23.3%	3.7%	21.1%	7.4%	2.1%	0.8%
0.015	3,260	6.7%	0.6%	7.6%	1.5%	0.6%	0.0%
0.02	4,346	1.2%	0.0%	1.7%	0.1%	0.0%	0.0%
0.025	5,433	0.0%	0.0%	0.5%	0.0%	0.0%	0.0%

In addition to presenting the cover area fraction, Table 9 presents the actual area impacted by the gullies, based on an embankment dimensions of 1,317.8 feet by 1,775 feet (401.7 meters by 541 meters). An eroded area of 1,087 square meters (m^2) means that the entire perimeter of the embankment has eroded back 0.6 meter (1.9 feet), and a 5,433 m^2 eroded area means the perimeter has eroded 2.9 meters (9.5 feet). Of course, to form a gully, some areas will have eroded more and others less.

Finally, there appears to be an issue with the FractionGully 1.52-meter depth data: Why are the 1.52-meter depth percentages smaller than the 1.97-meter and 2.42-meter depth results? This could be due to the random nature of the probabilistic method used to calculate FractionGully.

Figure 23 below is similar to DU PA v1.4 Appendix 10, Figure 2 (Neptune 2015f), except that it presents cumulative distribution functions.

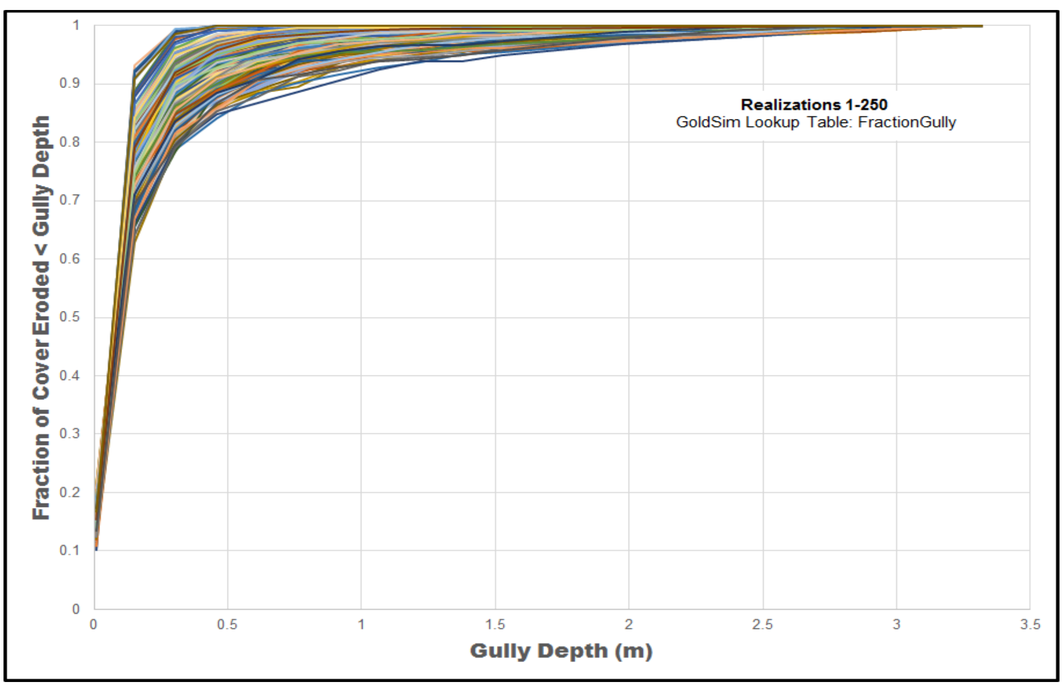


Figure 23. Two hundred fifty realizations of fraction of cover area for each elevation change (depth) interval.

Figure 24 shows the minimum, mean, and maximum complementary cumulative distributions based on Figure 23. (Note that the median and geometric mean were also calculated but do not vary significantly from the mean.)

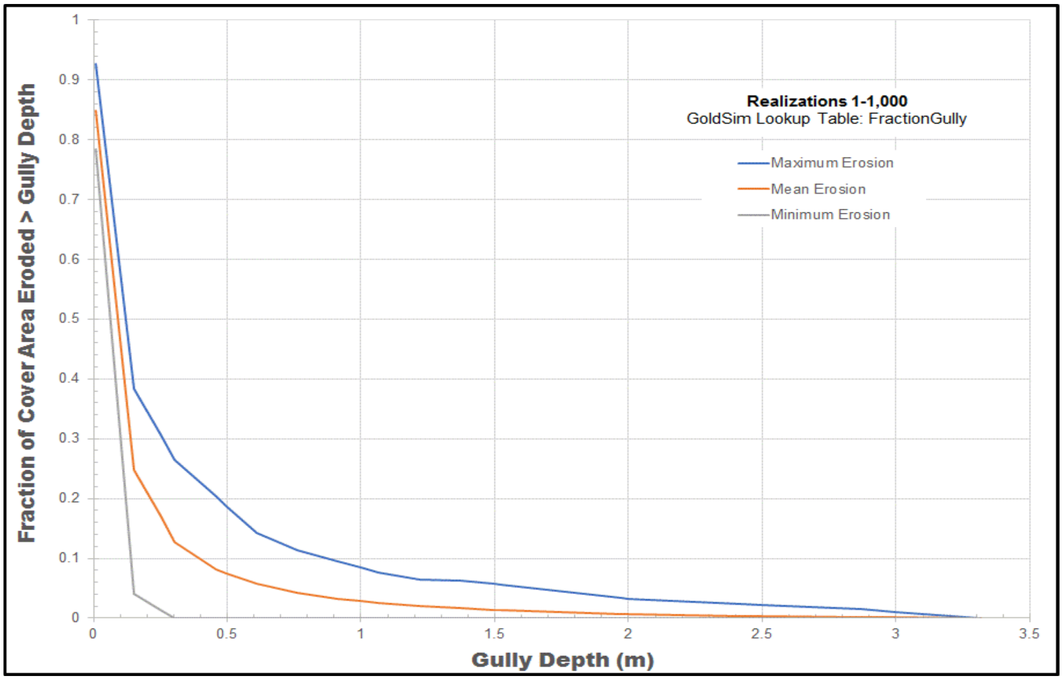


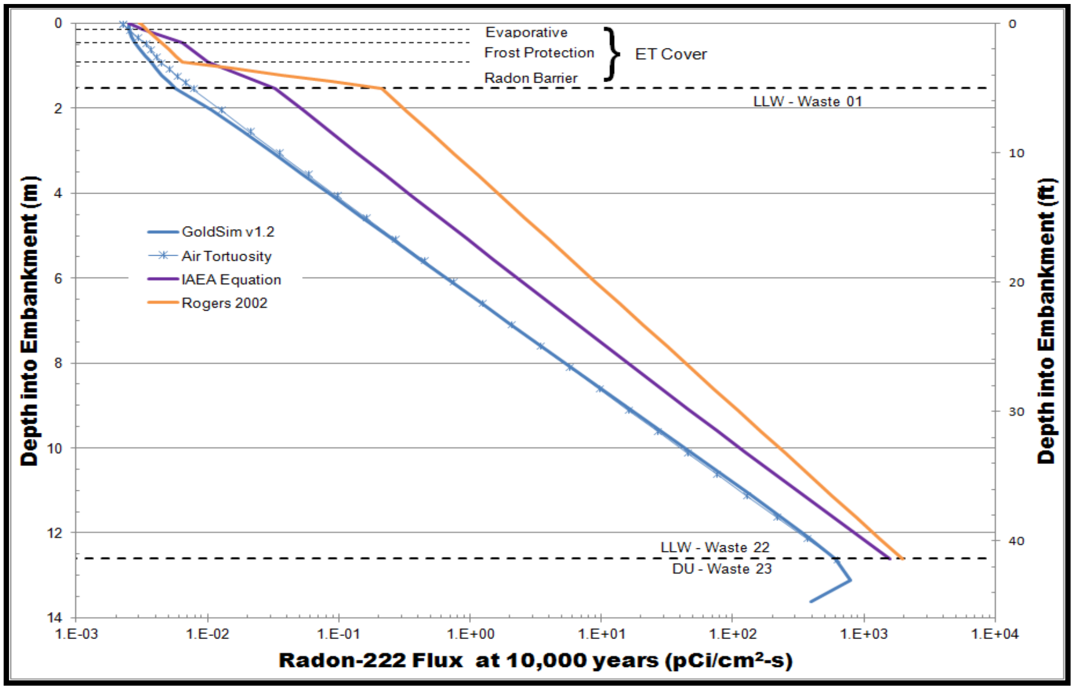
Figure 24. Minimum, mean, and maximum complementary cumulative distributions based on Figure 23

Using the data from Figure 24, Table 10 shows the amount of the embankment that will have a mean erosion greater than the specified depth. For example, 17.1 percent of the embankment will have mean erosion greater than 0.25 meter, but only 0.1 percent of the embankment will have mean erosion greater than 3 meters.

Table 10. Amount of the Embankment that Will Have a Mean Erosion Greater Than the Specified Depth

Depth (m)	Greater Erosion	
	Fraction	m^2
0.25	17.1%	37,192
0.5	7.4%	16,118
1	2.8%	6,132
1.5	1.4%	3,018
2	0.7%	1,527
2.5	0.3%	703
3	0.1%	230

The April 2015 SER, Volume 1, Figure 4-5, presented the radon flux as a function of embankment depth and has been reproduced below as Figure 25.



Source: DEQ 2015, Volume 1, Figure 4-5

Figure 25. Mean radon flux in the embankment

As shown, several different models were used in the SER to calculate the radon flux on the surface of the embankment. Table 11 shows the increase in the localized radon flux as a function of (gully) depth into the embankment for two of those models: GoldSim v1.2 (SC&A is not aware of any changes to the radon flux model between v1.2 and v1.4) and Rogers (2002).

Table 11. Increase in the Localized Radon Flux as a Function of Gully Depth into the Embankment for Two Models

Embankment Layer	Depth		Cumulative Flux Multiplier	
	m	ft	GoldSim v1.2	Rogers 2002
Surface	0.01	0.03	1.0	1.0
	0.15	0.5	1.0	1.1
Evaporative	0.30	1.0	1.0	1.3
	0.46	1.5	1.1	1.5
Frost Protective	0.61	2.0	1.2	1.7
	0.76	2.5	1.3	1.9
	0.91	3.0	1.5	2.1
Upper Radon Barrier	1.1	3.5	1.6	5.1
	1.2	4.0	1.8	12.2
Lower Radon Barrier	1.4	4.5	2.0	29.1
	1.5	5.0	2.3	69.7
Waste	2.0	6.5	4.2	105.6

Embankment Layer	Depth		Cumulative Flux Multiplier	
	m	ft	GoldSim v1.2	Rogers 2002
	2.4	7.9	7.4	159.8
	2.9	9.4	12.5	242.0
	3.3	10.9	21.0	366.4

The main difference between the GoldSim v1.2 model and the Rogers (2002) model is that the Rogers (2002) model takes more credit for radon attenuation within the radon barrier layers of the cap. In other words, in the GoldSim v1.2 model, the radon barrier layers are no more effective at attenuating radon than the evaporative and/or frost protection layers, as pointed out in the April 2015 SER, Section 4.2.1.

This is believed to be due to the GoldSim model use of a correction factor to obtain "close agreement between exact and corrected GoldSim fluxes" (Neptune 2015i, p. 4) on the embankment's surface (see DU PA v1.4, Appendix 18, Table 3). Because similar correction factors were not derived for the various layers within the embankment, it is not surprising that the GoldSim results differ from the Rogers (2002) results at the various depths shown in Table 11. For this reason, only the Rogers (2002) radon fluxes should be used to estimate the impact of erosion on the radon flux. For example, if an individual were to stand within a 1.5-meter-deep gully, instead of on the embankment's surface, then his dose due to the radon flux would increase by a factor of 69.7.

On the other hand, because a 1.5-meter-deep gully only occurs over 1.4 percent of the embankment's surface, it would not be reasonable to assume that the dose receptor would spend all of his time over the entire year in that gully, or he may not enter the gully at all. Therefore, the increase in the critical receptor's radon dose would be less (maybe significantly less) than the values shown above.

DEQ Discussion of NAC-0108_R0 – July 2019

Energy*Solutions*/Neptune expressed some concerns with the analysis performed by DEQ/SC&A in developing this interrogatory. They performed their own independent analysis of the FractionGully data, with their results presented in their Figure 4 of NAC-0108_R0. Based on the Figure 4 results, Energy*Solutions*/Neptune found that the FractionGully data "are not 'in order' by depth [which] is the same" conclusion as expressed by Interrogatory 205/1 (Neptune 2018g, p. 32).

Energy*Solutions*/Neptune also postulate that this effect may be due to "the stochasticity incorporated in the creation of the fractions at each depth interval *within* a single realization" (Neptune 2018g, p. 31; emphasis in original). After further investigation, DEQ/SC&A has determined that stochasticity is not the reason for the non-decreasing FractionGully values, as explained below.

The FractionGully is the fraction of the eroded material that originates in each layer of the embankment. Thus, it is the product of the eroded embankment area and the thickness of the cap/waste layers. Because the waste layers are about 3.3 times thicker than the cap layers, the value of FractionGully in the first waste layers can be larger than in the last cap layer. This may be seen in Figure 26, which shows the cap layer and waste layer volumes getting progressively smaller, but at the transition from cap layers to waste layers, the volume gets larger (e.g., compare the purple and dark green volumes in Figure 26). This also explains why the 1-cm thick first cap layer FractionGully values are always significantly smaller than the second cap layer values.

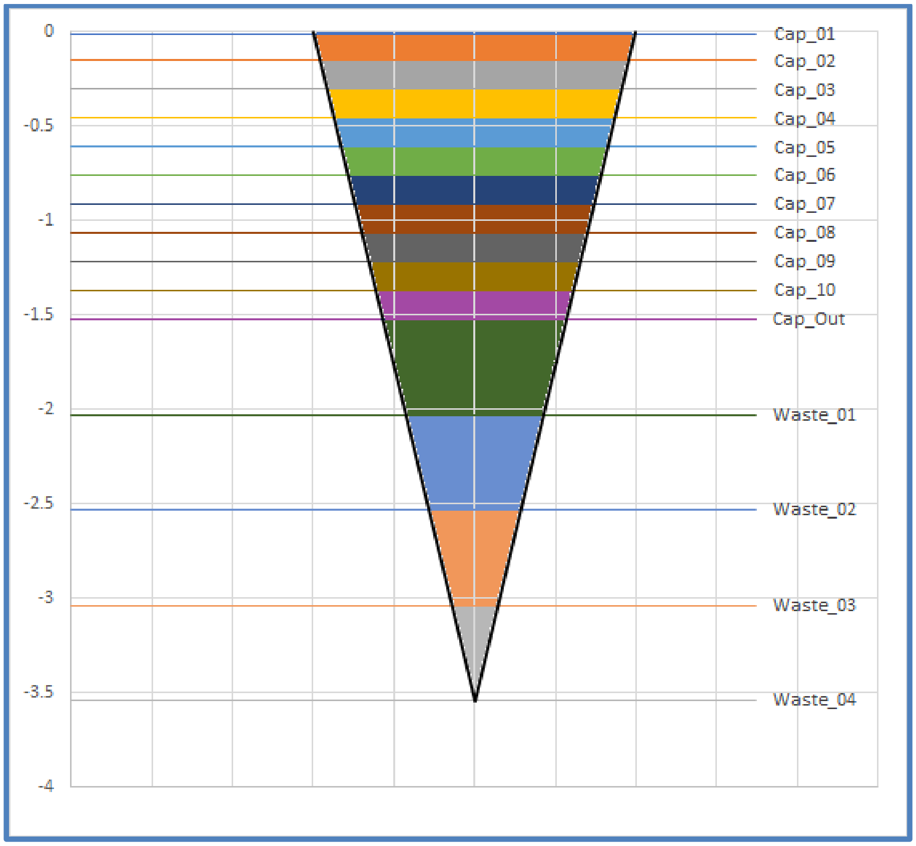


Figure 26. FractionGully as a function of embankment depth

However, there are problems with how the FractionGully parameter is used within the GoldSim v1.4 model. Because it is a volume fraction, it is appropriate to use FractionGully to calculate the WasteVolRemovedByGullyLowest parameter (which is misnamed, since the waste volume is calculated for all waste layers, not only the lowest). However, DU PA v1.4 also uses FractionGully to calculate the WasteAreaExposedGully parameter. This is incorrect; FractionGully must be adjusted for each layer's thickness before it can be utilized to calculate area.

There are additional concerns with the SiberiaErosionCalcs portion of the DU PA v1.4 model:

1. Why does TotalWasteVolRemoved_byLayer sum all the waste from the lower waste layers into each waste layer? This appears to be increasing the volume/mass of eroded waste in violation of conservation of mass.
2. Why is WasteAreaFan simply the sum of each eroded waste layer's area? This implies that the fan has the same thickness as the waste layers and that each eroded waste layer deposits separately.

3. Why is TotalWasteAreaExp_Gully simply twice the area of WasteAreaFan? This does not appear correct because the gully area would be limited by its sidewalls and not be able to spread out like the fan.

Finally, the text of DU PA v1.4, Appendix 10, Section 4.2 needs to be corrected to indicate that FractionGully is a volume fraction, and not a cover fraction. For example, the Figure 2 caption wording needs to be revised from "fraction of cover area" to "fraction of eroded volume," and, likewise, the four y-axis titles shown in Figure 2 need to be corrected.

In conclusion, Interrogatory CR R313-25-25(4)-205/1: Erosion Analysis is considered to be closed.

Although not necessary for its development, the interrogatory went on the discuss the radon flux. This was done in order to estimate the magnitude of flux increase within an erosion gully, which was not considered in the GoldSim v1.2 model. The overall conclusion of the discussion was that while the radon flux would increase when a receptor is in the gully, the short amount of time spent in a gully would limit the increase in the receptor's dose.

Nonetheless, Energy*Solutions*/Neptune provided a response to this portion of the interrogatory. We have a couple of observations regarding the Energy*Solutions*/Neptune radon flux response. First, Energy*Solutions*/Neptune stated, "UDEQ correctly states that the DU PA Model v1.4 is calibrated to focus on agreement with known analytical solutions of the flux at the ground surface rather than fluxes deep in the waste zone, **which are generally not important to dose calculations**" (Neptune 2018g, p. 33; emphasis added). This is only true if the effects of gullies eroding into the embankment are ignored, as is the case for the GoldSim v1.2 and v1.4 models. If the models were to incorporate erosion into the dose model, then the flux below the current ground surface would become important.

Second, Energy*Solutions*/Neptune also stated that the results from the IAEA Equation are generally within an order of magnitude of the DU PA Model v1.4 results, and that radon fluxes are adequately attenuated by the embankment due to the depth of burial of radon-generating wastes. As stated in the April 2015 SER, we agree with the second of these two Energy*Solutions*/Neptune statements. However, we do not agree that "within an order of magnitude" differences are acceptable. Like it or not, Regulatory Guide 3.64 (NRC 1989) is the benchmark for determining radon fluxes for nuclear licensing applications. If a model, such as GoldSim v1.2, can only produce results that are "within an order of magnitude" of the Regulatory Guide 3.64 results, then that model should be abandoned.

DEQ/SC&A does not endorse the GoldSim v1.2 or v1.4 radon flux models. However, for the 10,000-year compliance period, it has been adequately demonstrated that the DU is at a sufficient depth that the radon flux is a negligible exposure pathway. However, when determining the radon flux in the deep time, when much of the material above the DU has been washed away, the Regulatory Guide 3.64 model should be used.

4.0 SUPPLEMENTAL INTERROGATORIES PERTAINING TO THE EVAPOTRANSPIRATION COVER

Based on its review of Round 3 Interrogatories, DEQ had additional questions regarding the expected performance of the ET cover. These concerns were discussed with Energy*Solutions*/Neptune, and, on August 11, 2014, DEQ submitted additional interrogatories for Energy*Solutions*/Neptune to address (DEQ 2014). DEQ also requested that Energy*Solutions*/Neptune conduct some additional bounding calculations with HYDRUS to provide greater transparency as to how the percolation model performed. Energy*Solutions*/Neptune's replies were documented in August 18, 2014, "Responses to August 11, 2014 – Supplemental Interrogatories Utah LLRW Disposal License RML UT 2300249 Condition 35 Compliance Report" (ES 2014d).

DEQ reviewed the August 18, 2014, responses and determined that the information provided was not sufficient to resolve the supplemental interrogatories. DEQ's discussion of these deficiencies was included in Appendix B to the April 2015 SER. In general, there needed to be much more detailed descriptions of how the analysis proceeded from the input data to the results.

On November 25, 2015, Energy*Solutions* submitted Version 1.4 of the DU PA (Neptune 2015a). The revised performance assessment was designed to address concerns raised in the interrogatories discussed here and in the April 2015 SER. On April 2, 2018, Energy*Solutions* submitted responses to the still-open DEQ interrogatories (ES 2018b). Included in the responses was Neptune Report NAC-0106_R0, *ET Cover Design Responses for the Clive DU PA Model*, issued February 23, 2018 (Neptune 2018f), presenting additional responses to interrogatories concerning the proposed ET cover.

Each interrogatory includes the following topics:

- Summary of Energy*Solutions*' Response (August 18, 2014)
- DEQ Critique from April 2105 SER, Appendix B
- DEQ Critique of DU PA v1.4, Appendix 21
- DEQ Discussion of NAC-0106_R0 – July 2019

4.1 Open Supplemental Interrogatories as of July 2019

4.1.1 Supplemental Interrogatory Comment 1 – Adequate Characterization of Parameter Uncertainty

1) Demonstrate why 20 HYDRUS runs are sufficient to capture the parameter uncertainty.

*Summary of Energy*Solutions*' Response (August 18, 2014)*

Energy*Solutions* discusses how the van Genuchten's alpha (or "α") and *n* in the Surface Layer and Evaporative Zone Layer soils and the saturated hydraulic conductivity (K_{sat}) in the radon barriers were varied at random in the HYDRUS runs from distributions implied by the summary statistics for the Rosetta data (Schaap 2002) for van Genuchten's α and *n*, and from values published in Benson et al. (2011) and the Energy*Solutions* design specification for K_{sat}. The K_{sat} values for the radon barriers were sampled from developed distributions derived from data provided in Whetstone (2011) and Benson et al. (2011). Energy*Solutions* scaled the distributions for van Genuchten's α and *n* in GoldSim to reflect the coarser nature of the cell structure. The following statement is the most direct response from Energy*Solutions* with respect to whether 20 HYDRUS runs are adequate to capture the parameter uncertainty (ES 2014d, p. 5):

> *Given the scaling that is appropriate for the Clive DU PA model, in effect the range of the inputs to HYDRUS are much greater than the range used in the Clive DU PA model for the Genuchten's alpha and n parameters (by a factor of the square root of 28). This has the effect of smoothing across the range of the parameters of interest in the Clive DU PA model, but was considered a reasonable approach assuming that the regression implied by the HYDRUS runs could be used directly across a smaller range of values in the Clive DU PA model. Because of this difference in scaling, 20 HYDRUS runs are considered sufficient to support the Clive DU PA v1.2 model.*
>
> *In addition, the resulting water contents and infiltration rates in the Clive DU PA model seem reasonable given the conceptual model for the ET cap (see responses to Comments #7 through #9).*

DEQ Critique from April 2105 SER, Appendix B

Energy*Solutions*' response provided to this comment did not address the comment satisfactorily.

DEQ understands that the regressions (Equations 39 and 40 of Appendix 5 to the DU PA v1.2 (Neptune 2014b)) were created as simplified surrogate models that relate percolation from the base of the cover and water content in each layer of the cover profile to hydraulic properties of the cover soils. This regression model was developed based on output from HYDRUS from 20 sets of input parameters.

Because only 20 cases were used for the simulations, the tails of the distributions describing the hydraulic properties are poorly sampled, and more extreme cases may be inadequately represented. Consequently, the regressions may represent average or mean conditions sufficiently but may not adequately represent the more extreme cases. No information has been provided to demonstrate that the extreme cases in the tails of the distributions are adequately represented by the regression, or that 20 cases are sufficient to capture the effects of the tails of the distributions. For heavy-tailed distributions such as those used for hydraulic properties, many more simulations would be needed to adequately represent events driven by properties associated with the tails of the distributions.

The predictions in Energy*Solutions* (2014d) Figure 5 (see the discussion on Supplemental Interrogatory Comment 7 below) suggest that the process of developing the regression model has resulted in predictions that are centered more around the mean behavior and that are insensitive to the tails. The percolation predicted from the regression varies within a narrow range of around 0.3 mm/yr, whereas percolation predicted by HYDRUS predictions for all realizations ranges from approximately 0.01 mm/yr to 10 mm/yr. The response suggests that this insensitive behavior is due to the variance reduction in the hydraulic properties to account for spatial averaging, but another plausible reason is that the regression is based on mostly mean behavior and is relatively insensitive to extremes represented by the hydraulic properties in the tails of the distributions.

A well-documented justification is needed that demonstrates that Equations 39 and 40, based on predictions from 20 simulations using 20 sets of randomly sampled properties, adequately predict the percolation rate and the water contents for cases near the mean and more extreme cases in the tails of the distributions.

In addition, the analysis fails to adequately account for (1) correlations between parameters α and K_{sat} in the same soil layer, and (2) correlations between the values of each parameter within different soil layers. These deficiencies need to be resolved. DEQ also notes that the Energy*Solutions* response contains no substantive discussion of how and why scaling was conducted and how it impacts the results. This discussion must be provided.

DEQ Critique of DU PA v1.4, Appendix 21

See Interrogatory 21 in Section 2.6 (CR R313-25-8(4)(d)-21/2) for a description of the HYDRUS model parameter uncertainty.

DEQ Discussion of NAC-0106_R0 – July 2019

Energy*Solutions*/Neptune's response describes input and output for the fifty non-naturalized HYDRUS-1D simulations that were conducted to evaluate the uncertainty in infiltration flux into the waste zone, and that the 50 HYDRUS-1D simulations resulted in a distribution of average annual infiltration into the waste zone, and average volumetric water contents for each ET cover layer. Infiltration flux into the waste zone ranged from 0.0067 to 0.18 mm/yr, with an average of 0.024 mm/yr and a log mean of 0.018 mm/yr for the 50 replicates. The following discussion pertains to the non-naturalized HYDRUS simulations, since the HYDRUS results for the naturalized conditions have not been provided. Energy*Solutions*/Neptune need to submit the 50 naturalized HYDRUS simulations and conduct similar infiltration comparisons, statistical testing, and resolve scaling issues for the naturalized conceptual model as described below.

In Appendix 5 (DU PA v. 1.2, p. 45, Neptune 2014b), Energy*Solutions*/Neptune indicate that the 20 HYDRUS-1D simulations resulted in a distribution of average annual infiltration into the waste zone, and average volumetric water contents for each ET cover layer. Infiltration flux into the waste zone ranged from 0.007 to 2.9 mm/yr, with an average of 0.42 mm/yr and a log mean of 0.076 mm/yr for the 20 replicates.

In their 2014 response to this Interrogatory, Energy*Solutions*/Neptune indicate that due to the appropriate scaling approach taken, 20 HYDRUS runs are considered sufficient to support the Clive DU PA v1.2 model states (ES 2014d, p. 6).

The reasons for the differences in infiltration predicted with the 50 versus 20 replicates are not clear. The differences could be associated with model input parameters, the number of replicates, or scaling factors. The potential sensitivity to scaling is described in Energy*Solutions* (2014d), and different scaling factors resulted in a discrepancy between the net infiltration rates obtained from the 20 HYDRUS simulations and the GoldSim modeling runs.

Energy*Solutions*/Neptune's response states, "The 50 cases were run at sets of values chosen to explore the part of the input parameter space used for the DU PA Model, thus putting the effort and resources into the portion of the parameter space most important to support the model. The values chosen are directly from the distributions developed for Clive DU PA Model v1.4, and the use of values is adequate to expect to sample from the tails of the distributions" (Neptune 2018f,

p. 76). It is not clear on what basis Energy*Solutions*/Neptune are drawing this conclusion. Typically, to ensure that a sufficient number of replicates are selected, a statistical convergence test is conducted that involves increasing the number of replicates until the statistical criteria (e.g., range, mean) do not significantly change. Energy*Solutions*/Neptune need to demonstrate that the number of replicates selected adequately samples the entire distribution.

Scaling of the van Genuchten α and *n* parameters it is an identical issue to the scaling concerns raised under aeolian deposition in Interrogatory R313-25-8(5)(A)-18/3 (see Section 2.1.3). In both cases, Energy*Solutions*/Neptune proposed replacement of the standard deviation in the normal distribution with the standard error to account for spatial and temporal scaling. The only difference is the number of samples used to convert the standard deviation to the standard error: 28 for the van Genuchten parameters and 11 for the aeolian deposition.

Conceptually, we agree that "some" correction could legitimately be made to account for the spatial and temporal variations. However, we do not believe that Energy*Solutions*/Neptune have provided justification for the approach that they are taking. Energy*Solutions*/Neptune need to provide a detailed, step-by-step description of how they conducted the averaging process, and how this process compared to accepted procedures for spatial averaging of hydraulic properties in spatially correlated geo-media.

For the aeolian deposition interrogatory (see Section 2.1.3), we demonstrated that, when the embankment area is broken into subareas, the standard deviation narrows and is equal to the standard error if the number of subareas is equal to the number of samples. However, we pointed out two problems with this approach: (1) the justification for dividing the embankment into the number of sample subareas and (2) in order for the mathematics to work, each subarea needs to be independent, which could lead to the implausible condition where one subarea has a parameter at the upper percentile, while the adjoining subarea has the same parameter at the lower percentile. In Section 2.1.3, our latest response to Energy*Solutions*/Neptune regarding aeolian deposition under Interrogatory R313-25-8(5)(A)-18/3, we state that we have reviewed the three references provided earlier in the response by Energy*Solutions*/Neptune (i.e., Blöschl and Sivapalan (1995); Neuman and Wierenga (2003); Zhang et al. (2004)), and, while the references describe the need for upscaling, they do not "technically establish" the use of the standard error in this manner. Zhang et al. (2004) do state that "scaling should only be applied over a limited range of scales and in specific situations," while Neuman and Wierenga (2003) states that "One approach has been to postulate more-or-less ad hoc rules for upscaling based on numerically determined criteria of equivalence". DEQ remains concerned that (1) the proposed embankment is not a specific situation that allows for upscaling and (2) the approach taken by Energy*Solutions*/Neptune is "an ad hoc rule" rather than a "technically established" approach.

Figures 27 and 28 below show the van Genuchten α and *n* parameter distributions using both the standard deviation and the standard error methods, as well as the parameter distributions from the 50 HYDRUS runs. The tails from both standard deviation distributions extend well beyond the standard error distribution, as expected.

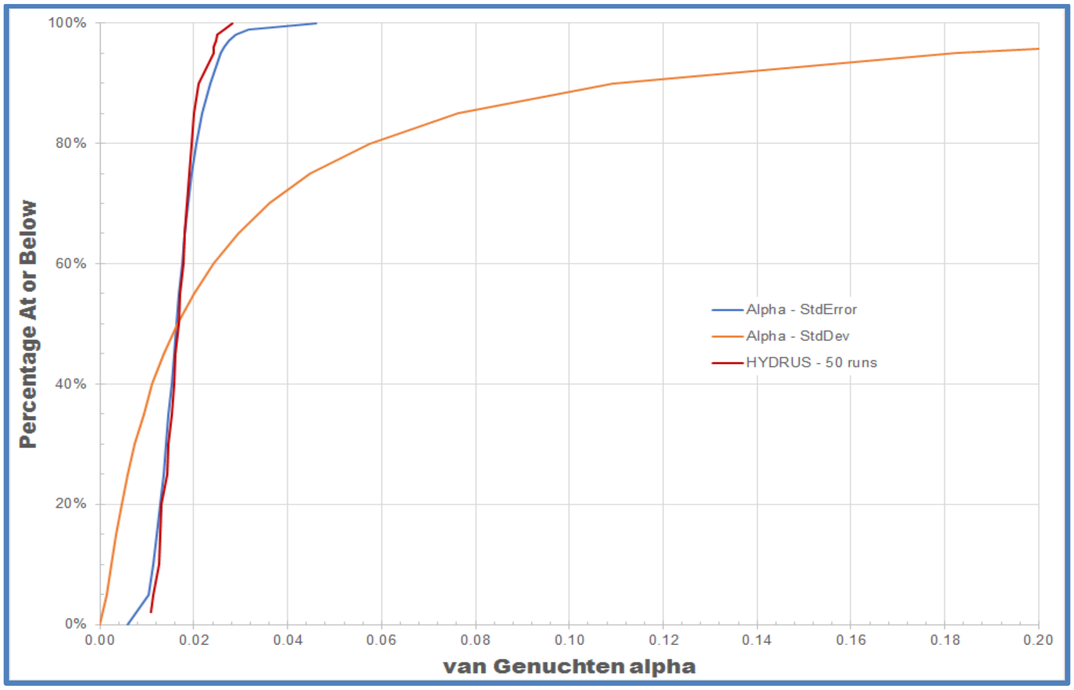


Figure 27. Comparison of upscaled and non-upscaled van Genuchten α (1/cm)

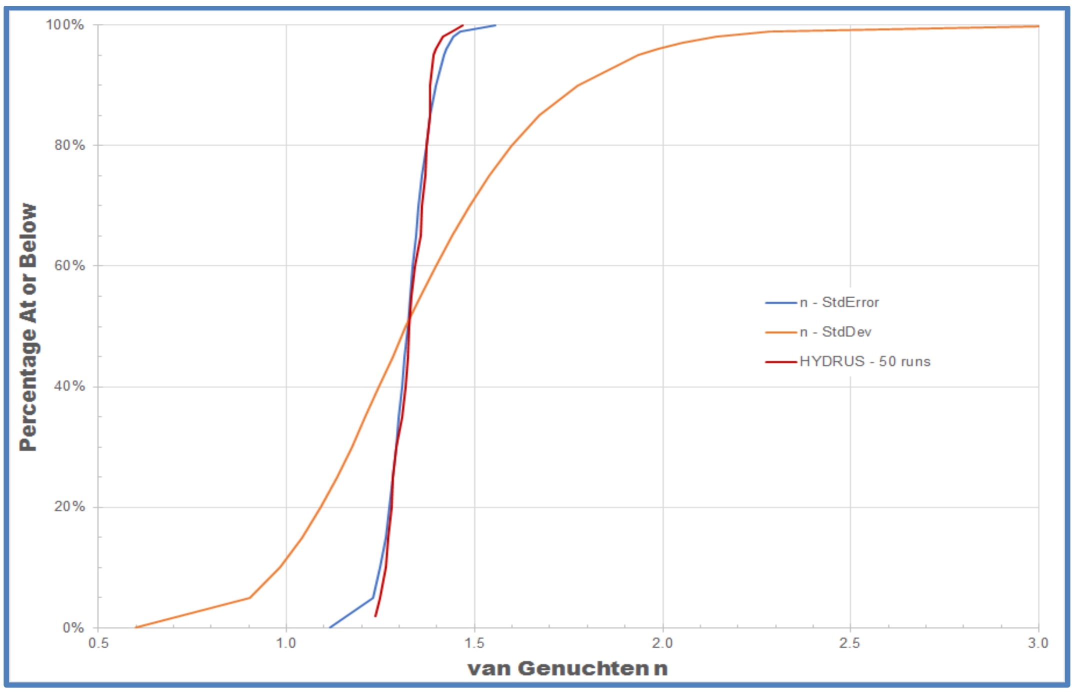


Figure 28. Comparison of upscaled and non-upscaled van Genuchten n

We do not have any HYDRUS runs beyond the standard error range. However, if we assume that the infiltration rate abstracted from the 50 HYDRUS runs applies over the standard deviation range for both alpha and *n*, then Figure 29 compares the infiltration rate calculated using the standard error distribution to the rate calculated via the standard deviation distribution.

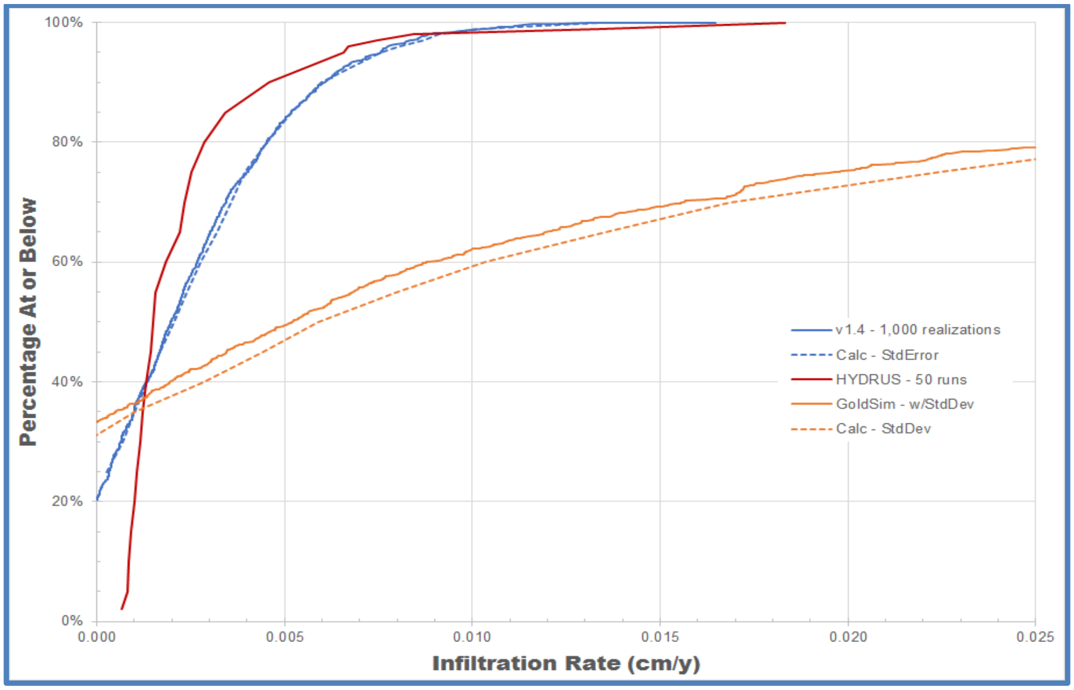


Figure 29. Comparison of upscaled and non-upscaled infiltration rates

Not shown in Figure 29 is the 95th percentile standard deviation infiltration rate, which was calculated to be 0.11 centimeters per year (cm/yr), compared to the standard error rate of 0.009 cm/yr.

Finally, Table 12 below shows the Tc-99 well water concentration at 500 years for three cases: (1) as reported by Neptune (2015a) in Table 2, (2) as calculated by SC&A using Energy*Solutions*/Neptune's unaltered GoldSim v1.4 model, and (3) as calculated by SC&A using Energy*Solutions*/Neptune's GoldSim v1.4 model, with the standard error replaced by the standard deviation in the Van Genuchten alpha and *n* parameter distributions.

Until the approach taken to scaling is better justified and the sensitivities of scaling factors on infiltration rates are evaluated, this interrogatory will remain open.

Table 12. Tc-99 Well Water Concentrations at 500 Years

Data Source	Tc-99 Well Water Concentration (pCi/L)						
	Mean	S.D.	Percentile				GWPL
			25%	50%	75%	95%	
Neptune 2015a, Table 2	26	N.P.	N.P.	0.043	N.P.	150	3,790
SC&A - StdError	24.2	77.7	0	0.014	4.2	110.9	
SC&A - StdDev	655	2,519	0	0.017	28	3,843	

Note: N.P. = not predicted; S.D. = standard deviation; GWPL = groundwater protection level.

4.1.2 Supplemental Interrogatory Comment 2 – Bounding of Parameter Distributions

2) The Table 9 HYDRUS parameters (Neptune 2014b) do not appear to "bound" the α, *n*, and K_{sat} distributions. For example, in the distribution, K_{sat} ranges from 0.0043 to 52 cm/day, but in the 20 HYDRUS runs, K_{sat} only ranged from 0.16 to 10.2 cm/day.

*Summary of Energy*Solutions*' Response (August 18, 2014)*

As described in the response to Supplemental Interrogatory Comment 1, the three input parameters (variables) were randomly drawn from input distributions for the 20 HYDRUS runs. Twenty observations are drawn at random from the distribution for K_{sat}. These randomly drawn values range from 0.16 to 10.2 centimeters per day (cm/day), with a mean of 2.28 cm/day. Energy*Solutions* considers these values sufficiently extreme to evaluate the influence of K_{sat} on the HYDRUS model outputs, and, therefore, to determine the influence of K_{sat} on the water content and infiltration model outputs.

Energy*Solutions* also notes that K_{sat} is not a predictor of the HYDRUS infiltration endpoint in either the linear or quadratic regressions (that is, it is not close to statistical significance and has a correlation of negative 0.10 with infiltration). However, Energy*Solutions* did include K_{sat} in the regression models for water content in the upper layers, and these regression models were used in the Clive DU PA v1.2 GoldSim model (Neptune 2014a). Energy*Solutions* further states that "It was shown very clearly in the sensitivity analysis for the Clive DU PA v1.2 GoldSim model that K_s [K_{sat}] is not a sensitive parameter for any of the PA [performance assessment] model endpoints" (ES 2014d, p. 7).

DEQ Critique from April 2015 SER, Appendix B

Energy*Solutions*' response indicates that the input "values are considered sufficiently extreme to evaluate the influence of K_s on the HYDRUS model outputs, and hence to determine the influence of K_s on the water content and infiltration model outputs." The basis for the conclusion "considered sufficiently extreme" needs to be demonstrated rather than stipulated.

As cited in the response to Supplemental Interrogatory Comment 1 (above), a well-documented justification is needed that demonstrates that Equations 39 and 40 (Neptune 2014b), based on predictions from 20 simulations using 20 sets of randomly sampled properties, adequately predict the percolation rate and the water contents for cases near the mean and more extreme cases in the tails of the distributions. This demonstration should also provide a physical basis for excluding some of the variability in key hydraulic properties normally considered to affect percolation strongly, such as K_{sat} in the shallow cover-system layers (i.e., the Surface Layer and the Evaporative Zone Layer). Any exclusion of this parameter or its full range of variability from other aspects of modeling, correlation, or sensitivity analysis should also be justified. Although the Clive DU PA v1.2 appears superficially to have illustrated that the output was not sensitive to K_{sat}, this conclusion may be the result of predictions from a cover hydrology model for which unrealistic parameters were used as input (e.g., changing some parameter values but not others for a given soil layer). A separate quantitative demonstration is needed showing that Equations 39 and 40, based on the 20 sets of hydraulic properties used as input, are representative.

DEQ Critique of DU PA v1.4, Appendix 21

See Interrogatory 21 in Section 2.6 for a description of the HYDRUS model input distribution, ranges, and bounds.

DEQ Discussion of NAC-0106_R0 – July 2019

Ambiguity remains regarding which hydraulic properties are the basis for the current water fluxes employed in the performance assessment. As indicated previously, naturalized hydraulic properties should be used for all layers in the cover, and those properties should be consistent with recommendations in NUREG/CR-7028 (Benson et al. 2011).

Energy*Solutions*/Neptune (Neptune 2018f) indicate that they have employed hydraulic properties consistent with NUREG/CR-7028 and provide Table 6, reporting the 50 realizations that were employed in HYDRUS. In particular, Neptune (2018f, p. 80) states:

> *The equivalent of Table 9 of Appendix 5 of DU PA Model v1.2 (Neptune 2014*[b]*) cited in the interrogatory is reproduced here from Appendix 5 of DU PA Model v1.4 (Neptune 2015*[e]*). This table, Table 6 below, contains the values of α, n, and K_s drawn from the distributions described above and used in 50 HYDRUS simulations of net infiltration and volumetric water content.*

As discussed below, DEQ/SC&A has done an independent assessment of the tabular data (Neptune 2018f, Table 6) provided for the 50 realizations of hydraulic properties relative to NUREG/CR-7028. They are consistent with the recommendations in NUREG/CR-7028, and we believe the Monte Carlo method used to generate this set of 50 realizations is appropriate. However, concerns remain regarding hydraulic properties used for the five-layer model (particularly the residual volumetric water content). These properties are not adequately justified.

Figures 30, 31, and 32 are graphs showing the distribution of hydraulic properties (saturated hydraulic conductivity (K_{sat}), α, and *n*) from the 50 random realizations from the simulation. Values for each property are presented with a two-graph pair. The left graph in each pair is a box plot, and the right graph is a dot plot. Both illustrate the parameter range and relative distributions for all 50 realizations. The graphs make use of percentiles: the Xth percentile corresponds to the point in the data set where X percent of the data are smaller in magnitude.

For box plots, the center horizontal line in the box corresponds to the median (50th percentile: half of realizations larger and half smaller), and the outer edges of the box define the interquartile range (25th and 75th percentiles). The thin vertical lines extending upward and downward from the box are referred to as “whiskers.” The ends of the whiskers defined the 5th and 95th percentiles. Realizations outside the 5th and 95th percentiles are shown as individual data points. A wide box corresponds to a broad distribution, while a narrow box corresponds to a more compact distribution of realizations. The whiskers provide similar information and also describe the weight of the tails of the distribution (heavy with significant extreme values, or light with fewer extremes).

The dot plots provide a more direct visualization of the sample size and distribution of realizations but provide less quantitative information about the distribution. The central horizontal line in the dot plot is the median (50th percentile). Combining dot plots and box plots provides direct visual and quantitative information about the distribution of realizations.

How these properties were specifically used in the modeling is not clear, however. Were these hydraulic properties used for the radon barrier, the overlying layers, all layers? In Neptune (2018f), there is discussion of the entire cover profile being treated as a single layer with one set of properties, but other discussion of the radon barrier being separate from other layers in the hydrologic model. Moreover, the statement quoted above from Neptune (2018f) is ambiguous. Were the fluxes obtained from the HYDRUS runs made with these properties used in the final GoldSim model? We do believe that Energy*Solutions*/Neptune have used properties consistent with NUREG/CR-7028 in their modeling, but we are not clear on whether the outcomes from that modeling were carried through into the GoldSim model.

The ambiguities encountered when evaluating Energy*Solutions*/Neptune's reports for this project are a substantial challenge that make the process more onerous for both parties. The process would be easier if Energy*Solutions*/Neptune could be specific in their reports on what they have done and how the findings are being used to address queries, with summary tables in each section describing inputs and outputs. This interrogatory remains open until the remaining ambiguities are clarified.

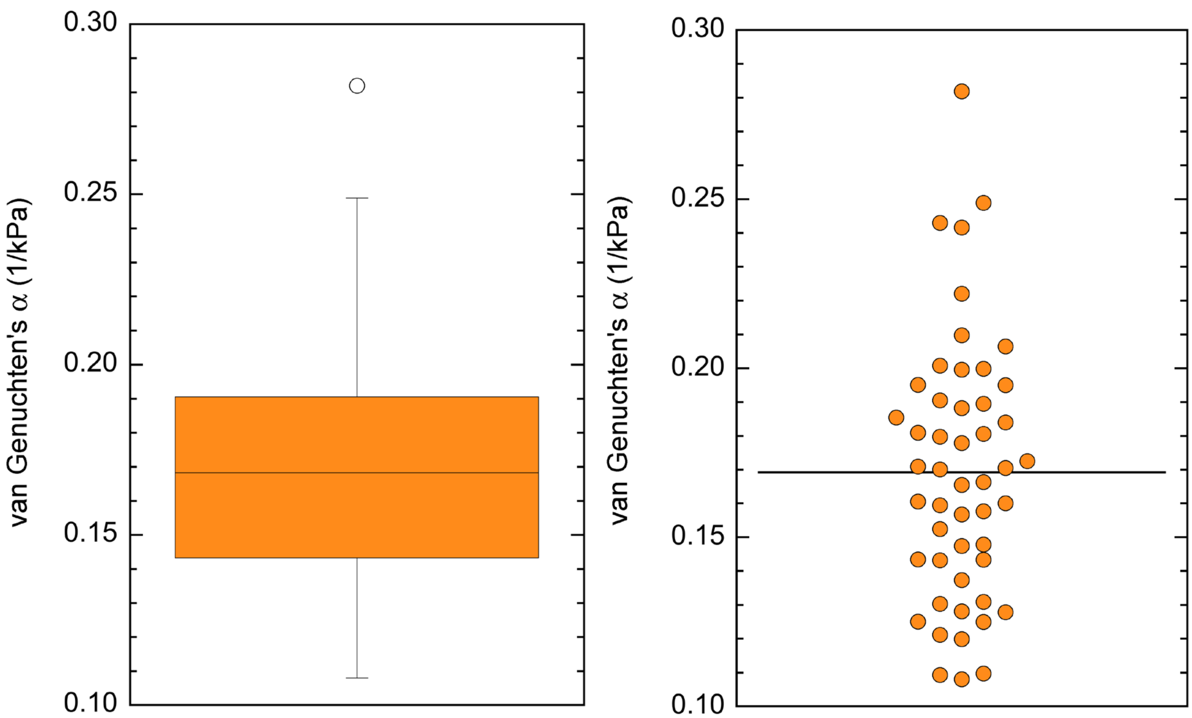


Figure 30. van Genuchten's α

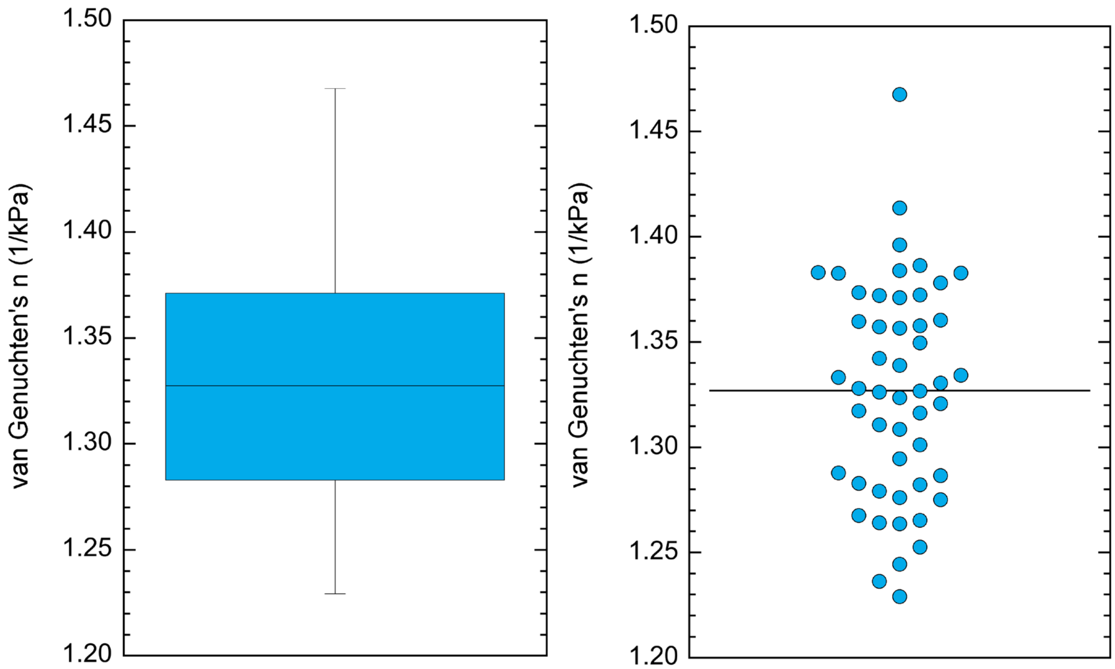


Figure 31. van Genuchten's n

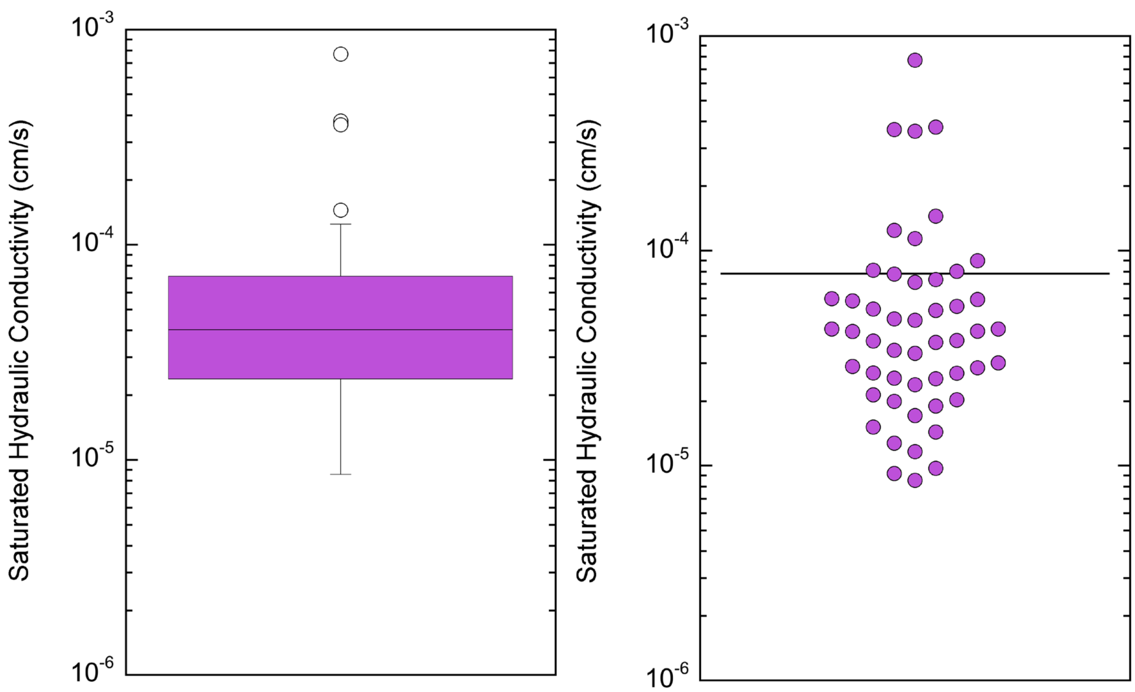


Figure 32. Saturated hydraulic conductivity

4.1.3 Supplemental Interrogatory Comment 3 – Insensitivity to K_{sat} and Lack of Water Balance Information

3) NUREG/CR-7028 (Benson et al. 2011) gives the "in-service hydraulic conductivity" as ranging from 7.5×10^{-8} to 6.0×10^{-6} meters per second (m/s) (0.7 to 52 cm/day), with a mean of 4.4×10^{-7} m/s (3.8 cm/day). Instead of using the provided distribution (i.e., log-triangular with a minimum, maximum, and most likely), Energy*Solutions*/Neptune constructed a lognormal distribution with a mean and standard deviation of 0.691 and 6.396 cm/day, respectively. Provide the justification for this approach. For example, the selection of 0.0043 cm/day as the lower end of the K_{sat} distribution requires justification (Neptune 2015e, p. 39). It is not clear why a design parameter value should be used when adequate field data are available. The number chosen by the Licensee for the lower end of the distribution range in the GoldSim implementation is 163 times lower than the lowest value in the range specified within the NUREG guidance (see Section 13.0 of Neptune 2015e). We believe that use of the design parameter biases the K_{sat} distribution in a nonconservative manner.

*Summary of Energy*Solutions*' Response (August 18, 2014)*

Energy*Solutions* indicates that the lognormal distribution was not fit with the value of 0.0043 but that this value was used to truncate the distribution after fitting so that lower values could not be drawn at random. Energy*Solutions* notes that the DRC (now DWMRC) has not provided a reference to the cited log-triangular distribution, and that a log-triangular distribution with a minimum of 0.7 cm/day, a maximum of 52 cm/day, and a mean of 3.8 cm/day is not possible to formulate. Energy*Solutions* also expressed concerns about using artificially truncated distributions and distributions with noncontinuous modes.

Energy*Solutions* observed that the mean of the lognormal distribution is about 3.9 cm/day, which is very close to the value suggested in Supplemental Interrogatory Comment 3 (3.8 cm/day). Also, the range of the lognormal distribution exceeds the range of values suggested in Supplemental Interrogatory Comment 3. Energy*Solutions* further indicated that K_{sat} is not used in the regression equations for infiltration rate because this variable is not statistically significant and K_{sat} is not a sensitive parameter (variable) for any of the end points in the GoldSim model.

DEQ Critique from April 2015 SER, Appendix B

The Energy*Solutions* response to Supplemental Interrogatory Comment 3 has not demonstrated that the distribution of K_{sat} used for the HYDRUS modeling adequately represents the range of conditions that might be realized for a "naturalized" cover, i.e., one that has undergone pedogenesis as described in NUREG/CR-7028 (Benson et al. 2011). To account for the higher K_{sat} in NUREG/CR-7028, the lognormal distribution for K_{sat} was refit by the Licensee using an abnormally large $\log(\sigma)$ of 6.396. This provides an unrealistic distribution of K_{sat} that substantially overweights K_{sat} in the lower range.

This, in turn, has the general effect of artificially increasing apparent capillary barrier effects in the DU PA Model v1.2, i.e., at the interface between a relatively lower-permeability zone (the combined Surface Layer and the Evaporative Zone Layer, having a mean K_{sat} value in the DU PA Model v1.2 of 4.46 cm/day) and a relatively higher-permeability zone (the Frost Protection Layer, having a mean K_{sat} value in the DU PA Model v1.2 of 106.1 cm/day). When the Licensee assumes in HYDRUS that the K_{sat} value for the lower-permeability zone can be as small as

0.0042 cm/day, the ratio in hydraulic conductivity between the higher-permeability zone and the lower-permeability zone can thus be as large as 25,000. This creates in the model an extremely potent artificial, non-realistic capillary barrier at the Evaporative Zone Layer/Frost Protection Layer interface that, in an unrealistic way, reduces infiltration below that interface to extremely small or even negligible values.

The primary model hydraulic conductivity value for the higher-permeability zone in the DU PA Model v1.2, 106.1 cm/day, may already be unrealistic, since the assemblage of soil particles in the Frost Protection Layer is proposed to be a random, poorly-sorted mixture of grain sizes, with smaller grains being as small as clay. The Frost Protection Layer is not characterized in terms of actual grain size distribution in the DU PA Model v1.2, other than to say that particle sizes can range from 16-inch diameter to clay size. The hydraulic conductivity assigned to it is arbitrary. The assigned value is representative of a sandy loam, which is a very poor representation of the proposed Frost Protection Layer. A mixture of poorly-sorted grain sizes, as found in the Frost Protection Layer, tends to greatly diminish the hydraulic conductivity of a soil compared to a relatively well-sorted mixture. Further exacerbating the problem in the DU PA Model v1.2 is that the hydraulic conductivity values assumed in HYDRUS for the lower-permeability zone are additionally allowed to be 163 times lower than the lowest specified value in the NUREG range for in-service hydraulic conductivity (Benson et al. 2011).

The rationale for dramatically increasing log(σ) to account for the higher K_{sat} associated with pedogenesis or "naturalization" has not been provided and is counterintuitive. The log(σ) should at least be similar for as-built and naturalized covers and may, in fact, be lower for naturalized covers because pedogenic processes ameliorate hydraulic anomalies inherent in the cover from construction. NUREG/CR-7028 (Benson et al. 2011) indicates that pedogenesis tends to transform in-service hydraulic conductivity values to as-built values found in a much higher, but a more restricted, range. The mean should shift upward during naturalization as structure develops, reflecting overall increase in K_{sat} and α rather than a broader range.

As noted previously, while the Clive DU PA Model v1.2 may have illustrated that the output was not sensitive to K_{sat}, this conclusion may be the result of predictions from a cover hydrology model for which unrealistic parameters were used as input. Insensitivity of infiltration to hydraulic conductivity would be expected if inappropriate input parameter values are used so as to create in the model an unjustified, artificial capillary barrier effect. Normally, in the absence of a capillary barrier, infiltration is very sensitive to hydraulic conductivity. As stated by Alvarez-Acosta et al. (2012):

> *A soil hydraulic property that is often a required input to simulation models is the saturated hydraulic conductivity, K_s. It is one of the most important soil physical properties for determining infiltration rate and other hydrological processes…. In hydrologic models, this is a sensitive input parameter and is one of the most problematic measurements at field-scale in regard to variability and uncertainty.*

Thus, the insensitivity of deep infiltration to K_{sat} reported in the Clive DU PA is not sufficient to dismiss the need for demonstrating the efficacy of the parameters used for the HYDRUS input in Appendix 5 to the DU PA Model v1.2.

DEQ Critique of DU PA v1.4, Appendix 21

See Interrogatory 21 for a description of the Energy*Solutions* assumptions regarding the in-service versus naturalized parameters.

DEQ Discussion of NAC-0106_R0 – July 2019

The following discussion pertains to the layered HYDRUS modeling without naturalization. The sensitivity of saturated hydraulic conductivity to the HYDRUS abstraction modeling with naturalized parameters was not presented by Energy*Solutions*/Neptune.

The lack of significance of saturated hydraulic conductivity in the absence of saturated hydraulic conductivity in the linear model remains a concern, as saturated hydraulic conductivity is known to be a key factor affecting the percolation rate from water balance covers (e.g., Bohnhoff et al. 2009). The unsaturated hydraulic conductivity used in HYDRUS scales linearly with the saturated hydraulic conductivity that is input to the model. Consequently, fluxes should scale directly with saturated hydraulic conductivity. Adequate explanation and documentation are needed for this outcome, which is inconsistent with expectations and the literature. This issue can be resolved by presenting parametric simulations with the unsaturated flow model that illustrate mechanistically why the saturated hydraulic conductivity is not important. Water balance graphs, based on daily outputs, as requested previously, and other graphs showing hydrologic behavior (e.g., temporal evolution of water content profiles) could provide the documentation needed to demonstrate that the unsaturated flow model is not flawed, and that the saturated hydraulic conductivity is not significant.

Water balance graphs and other graphs of hydrologic behavior would also resolve queries regarding the saturated hydraulic conductivity assumed for the Surface Layer and the propensity for a modeled capillary break between the Surface Layer and the Frost Protection Layer. These graphs can be prepared using daily output from the unsaturated flow model for several one-year periods to illustrate the hydrologic behavior.

These graphs and other reporting at shorter time scales may not be necessary as high-level output for a performance assessment, but they are necessary to build confidence in the model and to identify model shortcomings. Without confidence in the model, the high-level output cannot be evaluated. Until the sensitivity of the saturated hydraulic conductivity to the naturalized HYDRUS abstraction modeling is provided, in conjunction with sufficient backup material (e.g., water balance graphs) that adequately explain any anomalous behavior, this interrogatory will remain open.

4.1.4 Supplemental Interrogatory Comment 4 – Justification for Rosetta Database

4) Provide justification for using the Rosetta database, as appropriate for an engineering earthen cover.

*Summary of Energy*Solutions*' Response (August 18, 2014)*

Energy*Solutions* indicates that the class average values of soil hydraulic function parameters for the 12 soil textural classifications in Rosetta were developed from 2,134 soil samples for water retention and 1,306 soil samples for saturated hydraulic conductivity that were based primarily on agricultural land.

Energy*Solutions* notes that the Rosetta database is widely used and has been successful in many applications, in some cases performing better than the Carsel and Parrish (1988) database. Energy*Solutions* further indicates that the soil hydraulic properties from both databases are provided in the HYDRUS software platforms, and the choice of one over the other by the modeler is considered a matter of preference. Energy*Solutions* provides additional justification by citing the origin of the data, results of infiltration studies, and extensive use of the database by other researchers.

Energy*Solutions* also provides additional discussion and explanation of the origin of the hydraulic parameters and distributions used for the ET cover system

DEQ Critique from April 2015 SER, Appendix B

This interrogatory asked for justification for using the Rosetta database for an *engineered earthen cover*. The response goes to great length comparing the attributes of the Rosetta database to other databases, none of which are populated with data for engineered earthen covers. Most of the databases are for agricultural soils, many of which have been tilled. Their relevance to an engineered earthen cover has not been demonstrated. The response has shown, however, that many of the mean values of hydraulic properties used as input are, to some extent, in reasonable agreement with those associated with engineered earthen covers, as described in NUREG/CR-7028 (Benson et al. 2011). On the other hand, as discussed in the Supplemental Interrogatory Comment 3 (see Section 4.3), the low-end value in the range of hydraulic conductivity used in the GoldSim model is 163 times lower than the lowest specified value in NUREG/CR-7028 for in-service hydraulic conductivity. The low-permeability tail of the distribution is overweighted, and variability is not properly accounted for.

One response to the interrogatory, if it could be substantiated using data, would be that the Rosetta database is not based on engineered earthen cover soils and should not be assumed to be representative, but point-wise comparisons between hydraulic recommended properties in Rosetta and those in NUREG/CR-7028 demonstrate that the mean hydraulic properties are similar in both cases. However, as pointed out above, the variability assumed in the hydraulic properties chosen to represent the soils in the DU PA Model v1.2 is not appropriately characterized, and this limitation in the model biases the modeling results greatly.

While it is true that engineered soils undergo pedogenesis and become more like natural soils over time, it is important to follow NUREG/CR-7028 guidelines. The fact that the GoldSim model uses values for its K_{sat} distribution that, at the low end, are two orders of magnitude lower than specified in NUREG/CR-7028, and that the low-permeability range of values is overweighted, does not lead to confidence that the GoldSim model is set up appropriately.

Furthermore, in the GoldSim model, as implemented, it is assumed for the input parameter values that there is no correlation between $\log(\alpha)$ and $\log(K_{sat})$. When databases based on natural soils are used, it is important to account for correlation between these two parameters. Strong correlation between $\log(\alpha)$ and $\log(K_{sat})$ (with $R^2 = 0.9$) has been established for the largest database in North America, as well as for the largest database in Europe (see Sections 4.1.1.1 and 4.4.1 of the April 2015 SER). The two correlation equations are quite similar. Furthermore, a mathematical relationship similar to the correlation equations has been developed from fundamental soil physics theory by Guarracino (2007).

Failure to account for this correlation, or other significant correlations (e.g., correlation in individual parameter values between different cover-system soil layers), leads to unrealistic modeling. As stated in GoldSim's User Manual, Appendix A: Introduction to Probabilistic Simulation (GTG 2013):

> *Ignoring correlations, particularly if they are very strong (i.e., the absolute value of the correlation coefficient is close to 1) can lead to physically unrealistic simulations. In the above example, if the solubilities of the two contaminants were positively correlated (e.g., due to a pH dependence), it would be physically inconsistent for one contaminant's solubility to be selected from the high end of its possible range while the other's was selected from the low end of its possible range. Hence, when defining probability distributions, it is critical that the analyst determine whether correlations need to be represented.*

The response has also clarified that the Surface Layer and Evaporative Zone Layer were each assigned a geometric mean hydraulic conductivity of 5×10^{-7} m/s. This hydraulic conductivity is considered unrealistically low for in-service near-surface layers (e.g., <10 feet deep) that will be densely structured due to wet-dry cycling, freeze-thaw cycling, and biota intrusion by roots, insects, etc. This unrealistically low K_{sat} at or near the surface may have choked off infiltration in the HYDRUS model and exacerbated runoff, thereby limiting deeper ingress of meteoric water in the profile and underpredicting percolation. As discussed in Section 4.1.1.1 of the April 2015 SER, the unrealistically low near-surface K_{sat} value, combined with the unrealistically high Frost Protection Layer K_{sat} value, which is input into the model, would tend to create in the model an unrealistic, artificial capillary barrier at the top of the higher-permeability layer that would inappropriately render modeled values of infiltration extremely low. Soils at the surface develop significant structure and generally are much more permeable than those much deeper in the profile. Energy*Solutions* will need to provide additional evidence that this assumed hydraulic conductivity did not artificially bias the HYDRUS modeling.

The response to Supplemental Interrogatory Comment 4 also indicates that NUREG/CR-7028 recommends using a single measurement from a single site to define α. This is an incorrect interpretation of the design recommendations in NUREG/CR-7028. The recommendation in NUREG/CR-7028 to use $\alpha = 0.2$ 1/kilopascal applies when reliable site-specific information is not available and when a single typical value (not a range of values) is desired. It is based on an interpretation of the dataset presented in NUREG/CR-7028 as accounting for scale-dependent hydraulic properties. The HYDRUS modeling in Appendix 5 (Neptune 2014b) used an α that is approximately one order of magnitude lower than the recommendation in NUREG/CR-7028. This α is based in part on historic measurements made at Colorado State University on core samples obtained at the Clive site by Bingham Environmental (1991), which are known to be too small and too disturbed to adequately represent in-service conditions. The relevancy of this historic data from Bingham Environmental is dubious, at best.

DEQ Critique of DU PA v1.4, Appendix 21

See Interrogatory 21 in Section 2.1.5 for a description of the Energy*Solutions* assumptions regarding the in-service versus naturalized parameters.

DEQ Discussion of NAC-0106_R0 – July 2019

In addition to the non-naturalized HYDRUS simulations, Energy*Solutions*/Neptune have also used the ranges of recommended naturalized parameters in HYDRUS. However, until the ambiguities and other concerns that are described in Section 4.1.2 are resolved, this interrogatory will remain open (see Supplemental Interrogatory Comment 2).

4.1.5 Supplemental Interrogatory Comment 5 – Surface Boundary Conditions and Applicability of Linear Model

5) a) Provide additional explanation/justification for the assumed surface boundary condition and the sensitivity of the HYDRUS results to the boundary conditions.

   b) Also, why is a linear regression the optimal surface response for the design?

*Summary of Energy*Solutions*' Response (August 18, 2014)*

a) Energy*Solutions* indicates that the surface boundary conditions for the HYDRUS cover model consisted of 100 years of daily values of precipitation, potential evaporation, and potential transpiration, and that these boundary conditions were repeated 10 times for a 1,000-year (ky) simulation. Energy*Solutions* notes that sensitivity under different climate scenarios was not evaluated because there is no scientific evidence suggesting climate change in the next 10,000 years (10 ky) and that current science suggests that the future climate is likely to be drier in the next 10 ky. Furthermore, Energy*Solutions* contends that the probabilistic bounds are reflected within the variability contained in the historical data record and the small probability of significant changes in future climate over the next 10 ky.

b) Extensive statistical analysis has been conducted to evaluate possible model abstraction from HYDRUS to GoldSim for water content in each of the five upper layers of the ET cover, and for infiltration into the waste. Energy*Solutions* described how van Genuchten's α and n in the surface and evaporative zone soil layers and saturated hydraulic conductivity (K_{sat}) in the two lower radon barriers were varied in HYDRUS, to form the basis for the regression modeling (i.e., model abstraction). After creating a set of 20 observations that contained both inputs (i.e., explanatory or independent variables in a regression) and outputs (i.e., outputs of interest from the HYDRUS runs, which included water content in the upper five layers and infiltration into the waste layer), Energy*Solutions* ran linear and quadratic regression models and found that the results were not very sensitive to K_{sat}. Energy*Solutions* (2014d, p. 12) concluded that,

> *Despite the r-squared values, which are decent for at least the top two layers, the models are very weak. The dominant factors are the intercept term for all water content endpoints, a negative value of* n *for water content in the top two layers, and positive values of alpha for the other layers and the infiltration rate.*

Energy*Solutions* (2014d, p. 13) also concluded that,

> *Overall, the regression models are not very good. Although the r-squared values look reasonable for some of these regression models, explanations of the regression models are difficult to provide. That is, statistical fits are reasonable, but practical explanation is difficult. Consequently, the linear regressions were used for simplicity.*

The linear regressions for all water content endpoints show the same effect that the predicted values are greater than for the quadratic regressions. For infiltration, the linear regression indicated considerably greater values of infiltration flux than the quadratic regression, and the quadratic regression implied a large proportion of negative values. For these reasons, Energy*Solutions* used the linear regression models over the quadratic regression models.

DEQ Critique from April 2015 SER, Appendix B

The interrogatory asked for additional justification for the assumed surface boundary condition. Energy*Solutions*' response explains how the boundary condition was created but does not provide justification for the boundary condition. Two shortcomings need to be addressed explicitly.

First, the repetition of the same 100-year periods 10 times to represent the climatic conditions over a 1,000-year period of climatic input will need to be justified quantitatively. For all practical purposes, this simulation strategy will provide essentially the same output for each 100-year period in the record. This demonstration should show that the meteorological conditions over a 1,000-year period, including extreme events expected over a 1,000-year period, can be represented adequately using a sequence of repeated 100-year records. Normally, longer periods of time involve greater variability in the data. This requested demonstration should also show that the impacts of these extremes on the hydrological response of the cover are adequately represented.

Second, the justification should show that the hydrological behavior at the upper boundary (i.e., surface of the cover) is reasonable and within expected norms. This has not been demonstrated in Appendix 5 (Neptune 2014b, 2015e), and the unrealistically low K_{sat} assigned to the Surface Layer (see Supplemental Interrogatory Comment 4) in combination with likely capillary-barrier effect artifacts in the model may have choked off infiltration into the cover profile. At a minimum, water balance graphs should be presented for typical and wet years showing the temporal behavior of each of the primary cumulative water balance variables for the cover (e.g., precipitation, runoff, soil water storage, evapotranspiration, percolation). These graphs, and their associated discussion, should demonstrate that the surface boundary is represented adequately and that predictions are within expected norms.

The absence of climate change considerations should also be presented in the context of the most recent climate science, which does show systematic shifts in climate throughout North America within the next 10,000 years, if not sooner. An explanation should also be provided as to why climate change is not relevant at the Clive site when it has been considered in performance assessments for other disposal facilities in the region (e.g., the Monticello uranium mill tailings disposal facility).

Energy*Solutions*' response also provides an extensive discussion to justify the efficacy of Equations 39 and 40 in Appendix 5 (Neptune 2014b). However, these outcomes may have been biased by the unrealistically low K_{sat} assigned to the Surface Layer and Evaporative Zone Layer (see Supplemental Interrogatory Comment 4), which, in combination with likely capillary-barrier effect artifacts in the model, may have choked off infiltration into the cover profile. The efficacy of Equations 39 and 40 should be revisited once the impacts of the unrealistically low K_{sat}

assigned to the Surface Layer and Evaporative Zone Layer (see Supplemental Interrogatory Comment 4) have been investigated.

As an alternative to the linear regression, DEQ/SC&A fit an exponential equation to the van Genuchten α, *n*, and K_{sat} input data and the HYDRUS-calculated fluxes (Figure 33). The triangles shown in Figure 33 are the fluxes calculated using the following exponential fit: Flux = $45.465 \times \alpha^{1.4408} \times n^{-1.332} \times K_{sat}^{-0.445}$. For large fluxes, the exponential fit does not appear to be much better than the linear fit, but for small fluxes (which tend to result when the van Genuchten α is small), the exponential fit is much better than the linear fit.

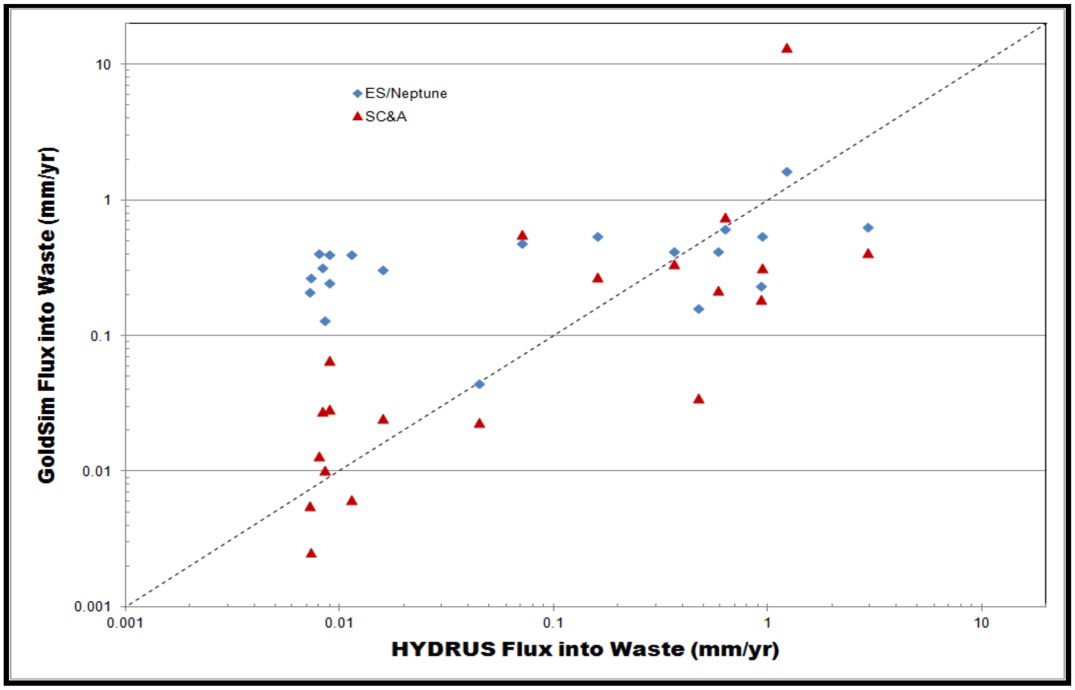


Figure 33. GoldSim versus HYDRUS infiltration flux

DEQ Critique of DU PA v1.4

See Interrogatory 21 in Section 2.1.5 for a description of the Energy*Solutions* assumptions regarding the linear regression of the GoldSim versus HYDRUS infiltration rates.

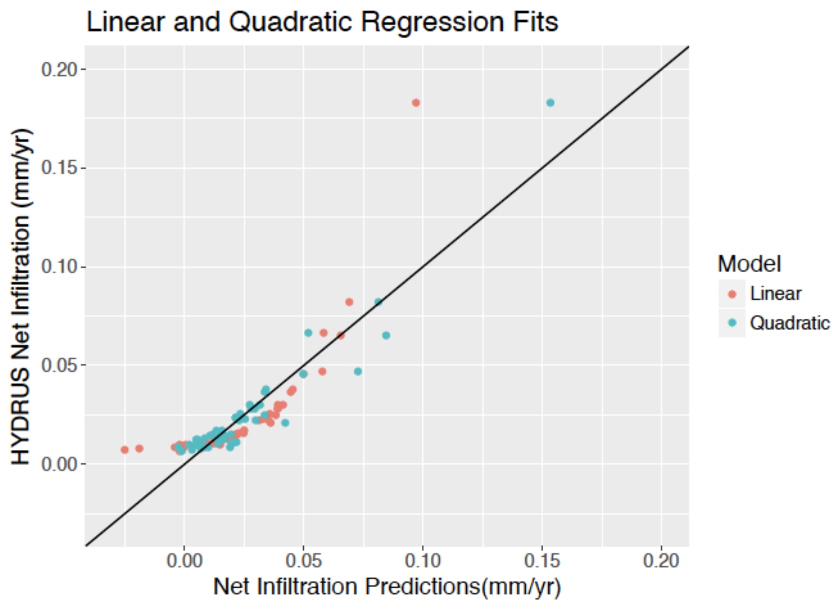
DEQ Critique of DU PA V1.4, Appendix 21

No changes have been made with respect to the treatment of the surface boundary conditions.

DEQ Discussion of NAC-0106_R0 – July 2019

The rationale for representing a 1,000-year meteorological record using 10 sequential runs with the same 100-year record has not been clarified if the performance assessment is to represent a 1,000-year scenario. If the objective is solely to provide a prediction for 100 years that is independent of the assumed initial condition, then this approach can be acceptable provided that metrics are provided showing that 10 repetitions is acceptable to eliminate the effects of the initial condition. However, if the objective is to provide predictions for a 1,000-year scenario, then this approach will not represent extreme conditions adequately. For example, a 1,000-year storm event is much different from a 100-year storm event. These issues need to be clarified.

The linear model used in GoldSim for percolation rates has been shown to provide a reasonable prediction of percolation rates predicted by the non-naturalized HYDRUS model, except at the extreme case where the linear model underpredicts the percolation rate by approximately a factor of 2 (see Figure 20 in Neptune (2018f) responses, reproduced as Figure 34 below). The prediction with the quadratic model is in closer agreement but is still an underprediction. Given the limited number of realizations used in the HYDRUS model (50), the tails of the distribution likely are underrepresented, and a much greater deviation may exist for higher percolation rates. The significance of underprediction in the tails needs greater documentation and the impact of this underprediction needs to be quantified. Furthermore, an analogous analysis needs to be performed using the naturalized HYDRUS net infiltration rates. Therefore, this interrogatory remains open.



Source: Neptune (2018f)

Figure 34. Comparison of percolation predicted by unsaturated flow model vs. prediction with linear or quadratic abstraction models

4.1.6 Supplemental Interrogatory Comment 6 – HYDRUS Infiltration Results

(6) To summarize the 20 HYDRUS results, Appendix 5, Section 12.9 (Neptune 2014b) states: “Infiltration flux into the waste zone ranged from 0.007 to 2.9 mm/yr, with an average of 0.42 mm/yr, and a log mean of 0.076 mm/yr for the 20 replicates.” In addition to this statement, provide the results for each HYDRUS run so that the results can be matched to the input data.

*Summary of Energy*Solutions*’ Response (August 18, 2014)*

Energy*Solutions* refers to a Microsoft Excel file provided to DEQ (i.e., “CHB#6, Hydrus params and results.xlsx”) for infiltration and water content results matched with input data for the 20 replicates. This file includes the 20 replicate values of van Genuchten α and *n* for the surface and evaporative zone layers, and K_{sat} for the radon barriers. Infiltration and water content data are calculated as averages over the last 100 years of a 1,000-year simulation (i.e., from 900 to 1,000 years). Energy*Solutions* also presents several figures plotting volumetric water content and infiltration versus log(α), and versus log(K_{sat}). Based upon these figures, Energy*Solutions* concludes that there is no correlation between infiltration and the K_{sat} of the radon barriers for the 20 HYDRUS-1D replicates, but there is a correlation between infiltration and α of the two uppermost surface layers. Energy*Solutions* also indicates that there is no apparent correlation between infiltration and *n* of the two uppermost surface layers but that there is a correlation between infiltration and α as well as a correlation between volumetric water content in the lower layers (frost protection and radon barriers) and α of the two uppermost surface layers.

The Excel file also includes calculations of mean, log mean, min, and max of the 20 replicate input and output values.

DEQ Critique from April 2015 SER, Appendix B

This interrogatory requested that the results be provided for each HYDRUS run so that the results can be matched to the input data. The response included a spreadsheet summarizing percolation from the base of the cover and water contents from the HYDRUS analysis. However, the output from HYDRUS was not provided.

The output from HYDRUS should be included in the report and presented in a manner consistent with the practice associated with design and evaluation of water balance covers (i.e., ET covers). Water balance graphs should be reported showing the key water balance quantities, and discussion should be provided that demonstrates that the predictions are within expected norms for water balance covers. This type of presentation and discussion has not been provided in Appendix 5 (Neptune 2014b) or in subsequent responses to interrogatories.

Energy*Solutions*' response also discusses graphs in an attached spreadsheet and indicates that these graphs demonstrate that there is no relationship between percolation from the base of the cover and K_{sat} of the radon barrier. This finding may have been biased by the unrealistically low K_{sat} assigned to the Surface Layer and Evaporative Zone Layer (see Supplemental Interrogatory Comment 4), which, in combination with likely capillary-barrier effect artifacts in the model, may have choked off infiltration into the cover profile. This issue needs to be reevaluated once the impact of the K_{sat} assigned to the near-surface layers has been addressed.

DEQ Critique of DU PA v1.4, Appendix 21

See Interrogatory 21 in Section 2.1.5 for a description of the adequacy of the HYDRUS model output.

DEQ Discussion of NAC-0106_R0 – July 2019

Energy*Solutions*/Neptune have provided the non-naturalized HYDRUS input and output for the 50 simulations; however, Energy*Solutions*/Neptune have not provided the naturalized HYDRUS input and output for the 50 simulations.

Therefore, this interrogatory remains open.

4.1.7 Supplemental Interrogatory Comment 7 – HYDRUS and GoldSim Infiltration Rate Output

(7) The HYDRUS and GoldSim calculated infiltration rates (and perhaps other intermediary results) need to be provided in the report, so that the reviewers do not have to delve into the

code's output files. For example, provide dot plots of the infiltration rates through the surface layer and/or provide a statistical summary of the infiltration rates that were sampled in GoldSim.

*Summary of Energy*Solutions*' Response (August 18, 2014)*

Energy*Solutions* (2014d) provided Figure 2-4, which shows the sorted infiltration through each layer of the ET cover and into the waste zone for the 20 HYDRUS-1D replicates where infiltration is the average infiltration over the last 100 years of a 1,000-year simulation. Figure 2-5 in that document shows the same result for HYDRUS-1D flux into waste presented in the first figure, along with the infiltration into waste calculated by the GoldSim DU PA Model v1.2 for 1,000 replicates using the linear regression equation where infiltration is based on van Genuchten α and n. Energy*Solutions* concludes that GoldSim infiltration has a smaller range than the HYDRUS-1D results.

Energy*Solutions* provides additional discussion pertaining to the inputs and distributions in HYDRUS and GoldSim, as well as the scaling assumptions assumed in GoldSim. Energy*Solutions* also presents infiltration statistics for the HYDRUS-1D and GoldSim model results and concludes that the mean infiltration values are similar (0.422 mm/yr for HYDRUS and 0.344 mm/yr for GoldSim).

DEQ Critique from April 2015 SER, Appendix B

This interrogatory requested that the percolation rates reported by HYDRUS be presented directly in the report. The response includes Energy*Solutions* (2014d), Figure 4, which shows "infiltration" in mm/yr for various layers in the cover and Figure 5, which shows "infiltration" (interpreted as percolation from the base of the cover) from HYDRUS and predicted with the regression equation, i.e., Equation 38 in Appendix 5 (Neptune 2014b).

The quantities shown in Figure 4 (ES 2014d) need more explanation. Infiltration is defined as the flux of water across the atmosphere-soil interface in response to precipitation. Water movement below the surface is a volumetric flux, and the flux from the base of the cover and into the waste is the percolation rate for the cover. Do these quantities represent the net flux from the base of each layer in the cover? The "infiltration" for the surface layer report in Figure 4 also raises concern, as the results indicate that the unrealistically low K_{sat} assigned to the Surface Layer and Evaporative Zone Layer (see Supplemental Interrogatory Comment 4), in combination with likely capillary-barrier effect artifacts in the model, may have choked off infiltration into the cover profile and unrealistically limited downward movement of water. A discussion of the HYDRUS predictions in the context of cumulative water balance quantities and expected norms for water balance covers could address this issue.

As indicated in the discussion associated with Supplemental Interrogatory Comment 1, the predictions shown in Figure 5 (ES 2014d) illustrate that the percolation rate from the regression used in GoldSim is considerably different from the predictions made with HYDRUS and is essentially insensitive to the hydraulic properties used as input. The lack of sensitivity is attributed to the reduction in log-variance to address spatial averaging, but another plausible explanation is that Equation 38 (Neptune 2014b) reflects central conditions adequately but extreme conditions in the tailings inadequately. Yet another plausible explanation is the likely capillary-barrier effect artifacts in the model, which would minimize or possibly even exclude infiltration of water to greater depths, so long as evaporation could remove it from the upper two soil layers. Furthermore, evapotranspiration rates in the model are likely too high, since they do not account for accumulation of gravel at the surface over time, which would tend to greatly diminish evaporation. A quantitative demonstration and explanation are needed to address this issue.

The response should also indicate how and why temporal scaling was incorporated into the hydraulic properties, as indicated by the term "spatio-temporal" used in the response to the interrogatory. Temporal scaling should account explicitly for the temporal evolution of the distribution of hydraulic properties due to pedogenic effects. No discussion has been provided regarding a temporal evolution of hydraulic properties. If temporal scaling has not been incorporated, then scale matching should be described as spatial rather than spatio-temporal.

Energy*Solutions*' response should also indicate why conventional spatial averaging procedures for correlated hydraulic properties were not used in the spatial scaling process from point scale measurements in the Rosetta database to grid scale in the model. Spatial scaling from a point measurement to model grid scale will need to account for upscaling of the mean to address measurement bias as well as downscaling of the log-variance in a manner consistent with the spatial correlation structure of engineered but degraded-over-time in-service earthen cover soils. The response should indicate how these factors are addressed by reducing the log-variance by the square root of the sample size in the Rosetta database.

The discussion below illustrates DEQ's mathematical (as opposed to hydrogeologic) concerns with the way infiltration is being abstracted into GoldSim from the HYDRUS results.

(1) The linear regression equation that has been programmed into GoldSim does not give results that are consistent with what is calculated by HYDRUS (i.e., for a given pair of α and *n*, the regression equation result in GoldSim does not approximate the HYDRUS result). This is demonstrated by Figure 33 (See DEQ Critique to Supplemental Interrogatory Comment 5).

(2) As acknowledged by Energy*Solutions* in its responses to Supplemental Interrogatories 1 and 2, due to scaling effects the ranges for α and *n* that have been programmed into GoldSim are more narrow than those in HYDRUS (i.e., in HYDRUS, α ranges from 0.001883 to 0.3021, but in GoldSim, α only ranges from 0.005 to 0.0493; likewise, in HYDRUS, *n* ranges from 1.029 to 1.883, but in GoldSim *n* only ranges from 1.060 to 1.540). See Figure 35 and Figure 36 for complementary cumulative distribution (CCD) comparisons that were prepared by SC&A utilizing Energy*Solutions* HYDRUS results and the Neptune (2014b), Table 1, GoldSim α and *n* distributions.

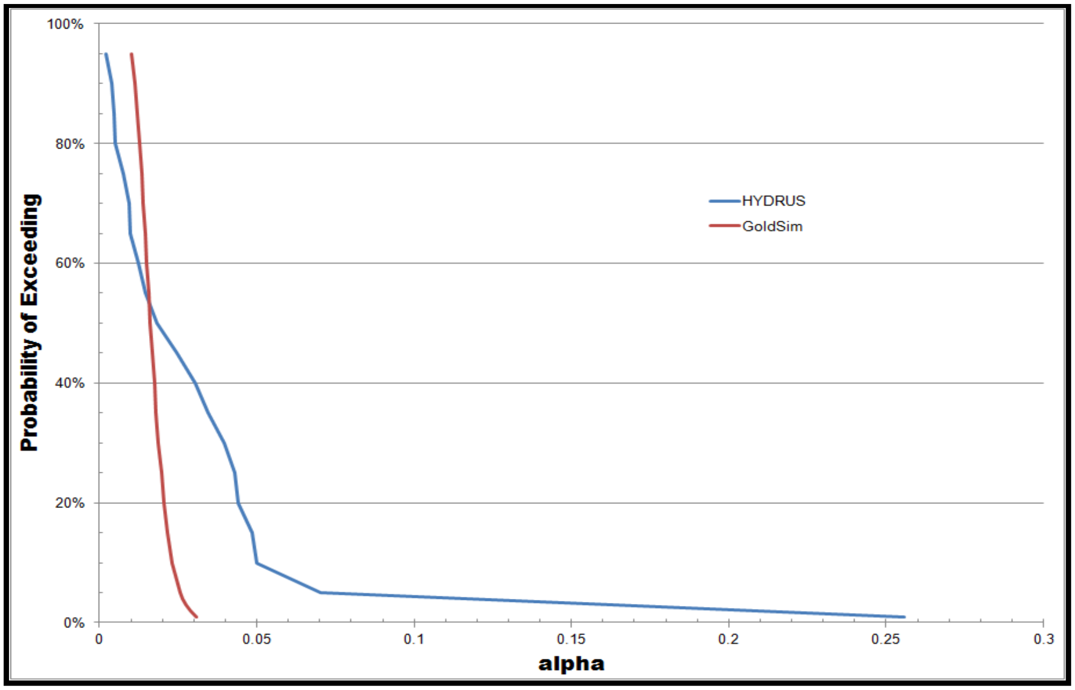


Figure 35. Complementary cumulative distribution of HYDRUS and GoldSim α parameters

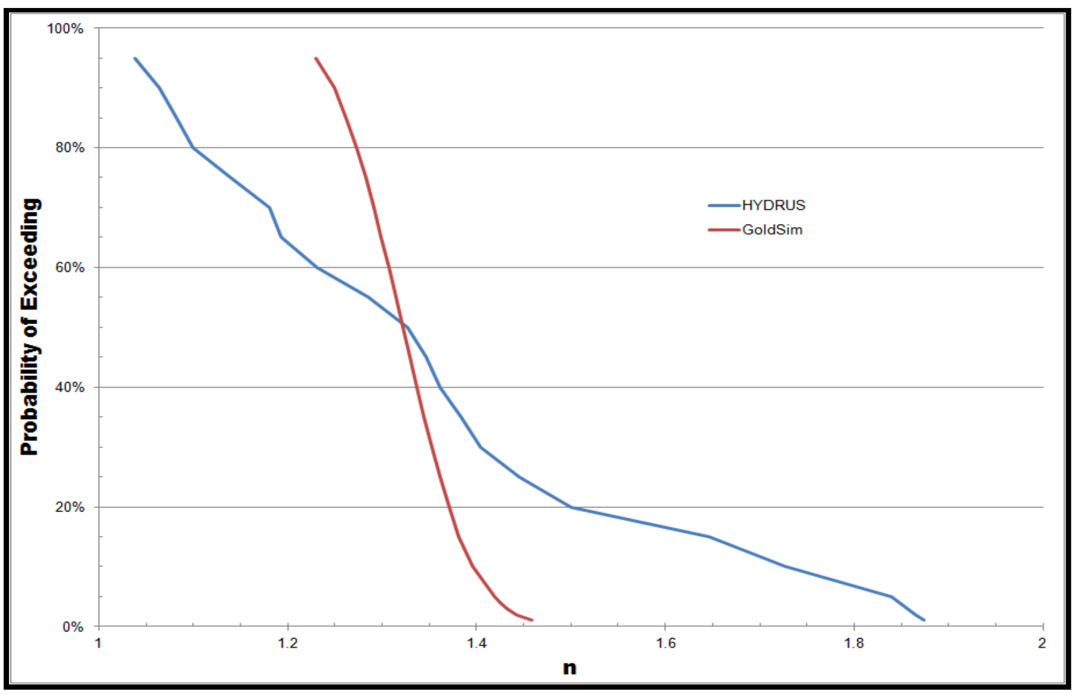


Figure 36. Complementary cumulative distribution of HYDRUS and GoldSim n parameters

The CCD comparison in Figure 37 shows the effect of these two mathematical considerations on the resulting GoldSim infiltration rate. This infiltration CCD is very similar to Figure 5 of the Energy*Solutions* response to supplemental interrogatories (ES 2014d), except that it is rotated 90 degrees.

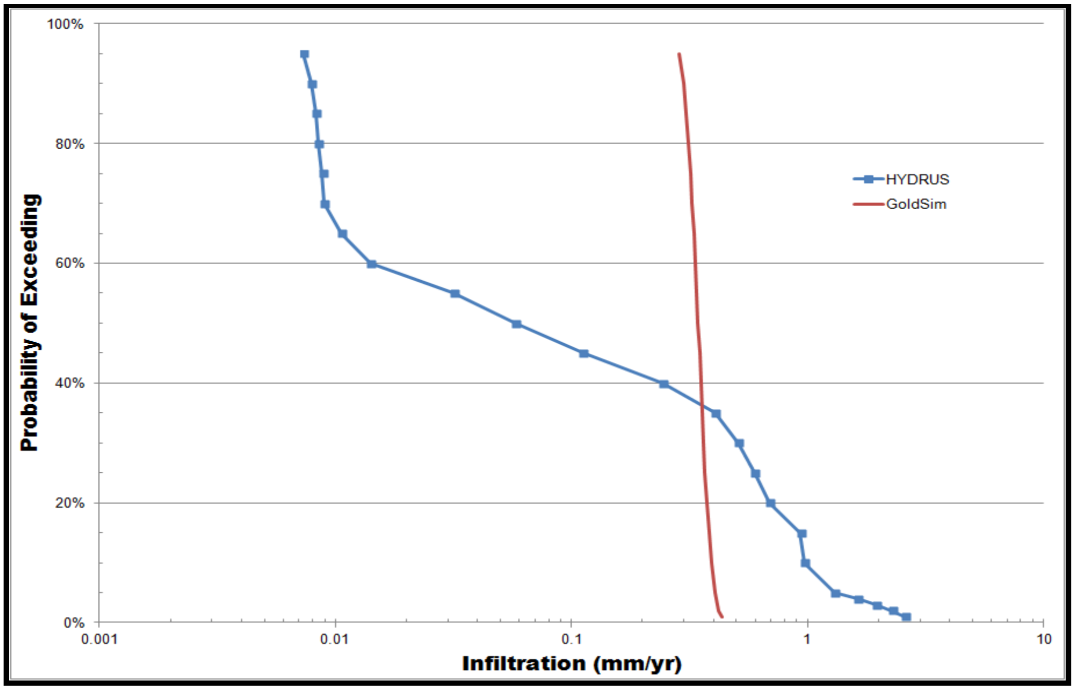


Figure 37. Complementary cumulative distribution of HYDRUS and GoldSim infiltration fluxes

Note that GoldSim was not rerun for these analyses. Instead, the GoldSim equations were programmed into an Excel Crystal Ball file, and 10,000 realizations were run. Also, the reason the GoldSim CCDs are smoother than the HYDRUS CCDs is that the GoldSim CCDs have 10,000 points, whereas the HYDRUS CCDs have only 20.

DEQ Critique of DU PA v1.4, Appendix 21

See Interrogatory 21 in Section 2.1.5 for a description of the adequacy of the GoldSim and HYDRUS model output.

DEQ Discussion of NAC-0106_R0 – July 2019

In response to this interrogatory, Energy*Solutions*/Neptune explain their use of spatial scaling and long-term averaging, and normal distribution of data in the Rosetta data base. As discussed in Supplementary Interrogatory Comment 2, considerable ambiguity remains regarding which hydraulic properties are the basis for the current water fluxes employed in the performance assessment. As indicated previously, naturalized hydraulic properties should be used for all layers in the cover, and those properties should be consistent with recommendations in NUREG/CR-7028 (Benson et al. 2011). The graphs provided by Energy*Solutions*/Neptune in response to this interrogatory do not provide the intermediate results requested in order to better evaluate the consistency between the GoldSim and HYDRUS results.

Therefore, this interrogatory remains open.

4.1.8 Supplemental Interrogatory Comment 8 – Underrepresentation of the Tails of the Distributions and Daily Water Balance Graphs

(8) a) Demonstrate that the fitted equations for water content and infiltration (DU PA v1.2, Appendix 5, Equations 39 and 40, and Table 10) give "reasonable" results when compared to HYDRUS.

b) For example, provide an explanation for why K_{sat} is insensitive to the infiltration rates.

*Summary of Energy*Solutions*' Response (August 18, 2014)*

a) Energy*Solutions* notes that the DU PA Model v1.2 was used to generate 1,000 realizations of the net infiltration rate and the cover layer volumetric water contents. Energy*Solutions* provides a table that compares the maximum, minimum, means, and standard deviations with the 20 HYDRUS simulation results. Energy*Solutions* also presents a number of histogram plots that compare results between the Clive DU PA Model v1.2 and the 20 HYDRUS simulations (H1D). Energy*Solutions* concludes that, for all parameters, the means are comparable and the standard deviations are larger for the HYDRUS results.

b) Energy*Solutions* provides two flux-versus-time plots. Energy*Solutions* hypothesizes that the reason that the net infiltration rates simulated by HYDRUS are likely not sensitive to the saturated hydraulic conductivity is because of the high evaporation rates from the surface layer and because the radon barriers do not have a large influence on the water balance of the cover system.

DEQ Critique from April 2015 SER, Appendix B

This interrogatory asked for demonstration that Equations 39 and 40 of Appendix 5, DU PA v1.2 (Neptune 2014b) provide realistic predictions relative to the predictions from HYDRUS. Energy*Solutions*' response provides a number of graphs showing that the predictions in the Clive DU PA Model v1.2 using Equations 39 and 40 are similar to those from HYDRUS in the sense of the mean but exhibit less variability than the predictions in HYDRUS. The reduced variability in the percolation predicted by Equation 39 is attributed to the reduction in log-variance to address spatial averaging, but another plausible explanation is that Equation 39 reflects central conditions adequately, but extreme conditions in the tailings inadequately. A quantitative demonstration and explanation are needed to resolve this issue.

This interrogatory also asked for an explanation of the lack of sensitivity of percolation rate to K_{sat}. The response on pages 25 and 26 (un-numbered figures) shows that water is isolated in the surface layer. However, using an unrealistically low K_{sat} for the Surface Layer and Evaporative Zone Layer, in combination with likely capillary-barrier effect artifacts in the model (see Supplemental Interrogatory Comment 4), may have choked off infiltration into the cover profile and trapped water at the surface, thereby limiting downward movement of water unrealistically and artificially impacting the significance of K_{sat} of the radon barrier. A discussion of the HYDRUS predictions in the context of cumulative water balance quantities and expected norms for water balance covers could address this issue.

DEQ Critique of DU PA v1.4, Appendix 21

See Interrogatory 21in Section 2.1.5 for a description of the verification of the HYDRUS results.

DEQ Discussion of NAC-0106_R0 – July 2019

The linear model used in GoldSim for percolation rates has been shown to provide a reasonable prediction of percolation rates, except at the extreme case where the linear model underpredicts the percolation rate by approximately a factor of 2 (see Figure 20 in the Neptune (2018f) responses, reproduced as Figure 34 above). The prediction with the quadratic model is in closer agreement but is still an underprediction. Given the limited number of realizations used in the HYDRUS model (50), the tails of the distribution likely are underrepresented, and a much greater deviation may exist for higher percolation rates. The significance of underprediction in the tails needs greater documentation, and the impact of this underprediction needs to be quantified.

The lack of significance of saturated hydraulic conductivity in the absence of saturated hydraulic conductivity in the linear model remains a concern, as saturated hydraulic conductivity is known to be a key factor affecting the percolation rate from water balance covers (e.g., Bohnhoff et al. 2009). The unsaturated hydraulic conductivity used in HYDRUS scales linearly with the saturated hydraulic conductivity that is input to the model. Consequently, fluxes should scale directly with saturated hydraulic conductivity. Adequate explanation and documentation are needed for this outcome, which is inconsistent with expectations and the literature. This issue can be resolved by presenting parametric simulations with the unsaturated flow model that illustrate mechanistically why the saturated hydraulic conductivity is not important. Water balance graphs, as requested previously, and other graphs showing hydrologic behavior (e.g., temporal evolution of water content profiles) could provide the documentation needed to demonstrate that the unsaturated flow model is not flawed, and that the saturated hydraulic conductivity is not significant.

Water balance graphs and other graphs of hydrologic behavior showing would also resolve queries regarding the saturated hydraulic conductivity assumed for the Surface Layer and the propensity for a capillary break between the Surface Layer and the Frost Protection Layer. These graphs can be prepared using daily output from the unsaturated flow model for several one-year periods to illustrate the hydrologic behavior.

These graphs and other reporting at shorter time scales may not be necessary as high-level output for a performance assessment, but they are necessary to build confidence in the model and to identify model shortcomings. Without confidence in the model, the high-level output cannot be evaluated.

Therefore, this interrogatory remains open.

4.1.9 Supplemental Interrogatory Comment 9 – Volumetric Water Content

(9) Compare the moisture contents calculated using the fitted equations to the Bingham (1991, Table 6 and/or Appendix B) Clive site measured Unit 4 moisture contents, and rationalize any differences.

*Summary of Energy*Solutions*' Response (August 18, 2014)*

Energy*Solutions* calculated volumetric water contents using the fitted equations extracted from the GoldSim DU PA Model v1.2. Energy*Solutions* then ran the model for 1,000 simulations to generate 1,000 values of water content for the Evaporative Zone Layer (Unit 4 soil).

Gravimetric water contents for Unit 4 soils, at depths less than or equal to 2 feet (near the depth of the Evaporative Zone Layer (0.5 to 1.5 feet)), were obtained from Bingham Environmental (1991, Table 6) and converted to volumetric values.

Volumetric water contents from GoldSim (1,000 replicates), from HYDRUS-1D (20 replicates), and the six measured values from Table 6 are plotted in a figure, and Energy*Solutions* concludes that the volumetric water contents calculated with the fitted equation in GoldSim are well bounded by the Bingham Environmental (1991) data from Table 6. Energy*Solutions* indicates further agreement in that the mean volumetric water content value in Table 6 is 0.285, while the mean from the 1,000 GoldSim model replicates is slightly higher at 0.294, and the mean value of the 20 HYDRUS-1D replicates is 0.286, nearly identical to the Bingham Environmental (1991) samples.

DEQ Critique from April 2015 SER, Appendix B

The comparison with HYDRUS is remarkably good. However, the comparison with Equation 39 (Neptune 2014b) is not good. Equation 39 seems to predict θ between 0.27 and 0.31 for nearly all cases, whereas the data are over a much broader range.

DEQ Critique of DU PA v1.4, Appendix 21

See Interrogatory 21 (Section 2.1.5) for a description of the adequacy of the goodness of fit against the Bingham (1991) data.

DEQ Discussion of NAC-0106_R0 – July 2019

The volumetric water content provided in Bingham Environmental (1991) appears too high, based on data from other similar sites. An unreasonably high volumetric water content leads to infiltration being underestimated.

Therefore, this interrogatory remains open.

4.1.10 Supplemental Interrogatory Comment 11 – Use of Naturalized Parameters

DEQ provided Energy*Solutions* with an Excel file, “Clive Hydrus Sensitivity Recommend REV2.xlsx,” which contains suggested or proposed combinations of input values for the HYDRUS runs used to support the Clive DU PA.

*Summary of Energy*Solutions*’ Response (August 18, 2014)*

Energy*Solutions* provides a lengthy discussion of the fallacy of conducting and drawing conclusions from this type of deterministic analysis. Energy*Solutions* expresses further concerns related to the parameter input values as well as the “warm up” simulations.

Energy*Solutions* ran the nine HYDRUS-1D simulations requested by DWMRC, and results showing the range from minimum to maximum infiltration (into waste zone), along with the results from the original 20 HYDRUS-1D simulations, were shown in a figure. Energy*Solutions* (2014d, p. 33) concludes that,

> *Despite the implementation of the high K_s values requested by the Division, infiltration in the new 9 simulations is generally lower than for the original 20 HYDRUS-1D simulations. This is largely due to setting residual water content to zero, which effectively increases the water holding capacity of each soil layer.*

> *Overall, the Clive DU PA model provides a reasonable range for the input parameters for the hydraulic properties given the currently available data and information, and the HYDRUS runs for the nine additional combinations of single values for inputs adds no further insight.*

DEQ Critique from April 2015 SER, Appendix B

DEQ requested a sensitivity analysis for a reasonable range of parameters to evaluate whether the model responds within expected norms for a water balance cover. DEQ made this request, in part, because Appendix 5 of DU PA v 1.2 (Neptune 2014b) provides inadequate documentation to demonstrate the efficacy of the HYDRUS model and its realism relative to expected norms for a water balance cover. Moreover, Appendix 5 indicates that predictions made by the model are insensitive to hydraulic parameters (notably K_{sat}) generally known to have a strong influence on predictions made by HYDRUS and similar models. For example, the unrealistically low K_{sat} for the Surface Layer and Evaporative Zone Layer (see Supplemental Interrogatory Comment 4) may have choked off infiltration into the cover profile and trapped water at the surface, thereby limiting downward movement of water unrealistically and artificially impacting the significance of K_{sat} of the radon barrier. As explained throughout this document, there are significant concerns that the HYDRUS model may not be realistic and may be biasing the analyses in the performance assessment. An assessment of the efficacy of the HYDRUS model in the context of expected norms is essential to resolve this issue.

Energy*Solutions*' response goes to great length to dismiss the requested sensitivity analysis as not based on reasonable soil properties and as being inconsistent with a performance assessment approach. The response justifies the criticism of the soil properties by citing databases for soil properties unrelated to engineered earthen covers (e.g., the National Resource Conservation Service database) or data reports known to contain measurements on samples that are too small to represent in-service conditions and collected with antiquated techniques that are known to cause disturbance of soil structure (e.g., Bingham Environmental 1991).

Despite these criticisms, the requested analyses apparently were conducted, but the output was not included or presented comprehensively in the responses. The findings from these simulations should be tabulated and reported, and water balance graphs should be prepared and discussed in the context of the mechanisms known to influence the hydrology of water balance covers. A thoughtful discussion would help justify the use of the HYDRUS model and build confidence in the output.

DEQ Critique of DU PA v1.4, Appendix 21

See Interrogatory 21 in Section 2.1.5 for a description of the adequacy of the range, distribution, and bounds on the HYDRUS input data. The type of output that should be provided is also presented as described in Supplemental Interrogatory Comment 8.

DEQ Discussion of NAC-0106_R0 – July 2019

As described in Supplemental Interrogatory Comment 2, Energy*Solutions*/Neptune have used naturalized parameters in one set of HYDRUS simulations. However, the results and other relevant information have not been presented. Furthermore, water balance and other hydrologic information is requested in Supplemental Interrogatory Comment 11; this information is also required to close Supplemental Interrogatory Comment 8. Therefore, this supplemental interrogatory will remain open until these other supplemental interrogatories are closed.

4.1.11 Supplemental Interrogatory Comment 12 – Huntsman Agreement

This comment dealt with available disposable volumes under the "Huntsman Agreement." The discussion is not relevant to the ET cover.

4.2 Closed Supplemental Interrogatories

All supplemental interrogatories remain open as of July 2019.

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