Department of Energy
Washington, DC 20585

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U.S. Nuclear Regulatory Commission
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WM-00073

Subject: U.S. Department of Energy Office of Legacy Management Response to U.S. Nuclear Regulatory Commission (NRC) Letter dated March 28, 2016, "U.S. Nuclear Regulatory Commission Staff Review of U.S. Department of Energy *Draft Groundwater Flow Model for the Tuba City, Arizona, Disposal Site*" (LMS/TUB/S12512)

To Whom It May Concern:

The U.S. Department of Energy Office of Legacy Management (DOE-LM) has received the U.S. Nuclear Regulatory Commission's (NRC) comments on DOE-LM's *Draft Groundwater Flow Model for the Tuba City, Arizona, Disposal Site* (LMS/TUB/S12512). In overview, two recurring themes were noted throughout NRC's specific comments: currently available data provide insufficient support for some of the conclusions drawn from model output and sensitivity analyses should be performed. While DOE-LM considers the model architecture and its results to be sound, the value of additional data to address data gaps, to bolster support for assumptions, and to allow for further refinement of critical input parameters through sensitivity analyses is acknowledged.

With regard to data sufficiency, DOE-LM is developing plans for additional data collection that include:

- Installation of additional monitoring wells to further the understanding of site hydrogeology (assess vertical groundwater flow in the Greasewood Area and aquifer discharge at Moenkopi Wash) and refine the plume delineation on its eastern boundary.
- Installation of instrumentation for continuous real-time monitoring of water levels in the vicinity of the extraction wells to refine the understanding of plume response to variations in extraction tactics.
- Performance of geochemical analyses on collected core material to assess contaminant transport characteristics and help determine controls on contaminant migration characteristics in the vicinity of the subpile area and the potential capacity for natural attenuation of contaminants within the aquifer formation.

The results of planned data collection and analytical activities will be used to support the next iteration of groundwater model development and will be documented in a future revision of the report.

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DOE-LM's responses to NRC's general and specific comments are as follows.

NRC General Comment 1

The purpose of sensitivity analyses are to quantify the effect of uncertainty in the estimates of boundary conditions and of parameter values associated with features and processes on the model results. Sensitivity analyses are an essential step in all modeling applications. This is especially true for the current ground water flow model, which suffers from data deficiencies in many areas. The Nuclear Regulatory Commission (NRC) staff suggests that the Department of Energy (DOE) perform sensitivity analyses of various model parameters so as to determine which parameters significantly influence model outcomes.

DOE-LM Response

Sensitivity analysis is typically performed by systematically increasing and decreasing parameter values associated with zones of equal parameter value and assessing how the perturbations influence calibration statistics and model predictions. The model's hydraulic conductivity field, being derived from pilot points, is continuously variable and as such does not have zones of equal hydraulic conductivity. Thus, typical sensitivity analysis cannot be performed on the calibrated hydraulic conductivity field. However, a stochastic analytical travel time analysis (Section 4.2.5), a form of sensitivity analysis, was conducted to evaluate how parameter uncertainties, including hydraulic conductivity, could influence the predictions of groundwater travel time from the site to Moenkopi Wash. The results illustrated that hydraulic conductivity variability (uncertainty) yields corresponding variability in groundwater travel times from the site to Moenkopi Wash.

Recharge in the model is represented using zones of differing recharge rates and thus, is amenable to typical sensitivity analysis. Recharge sensitivity analysis will be performed by increasing and decreasing the overall recharge rates modeled by ±25% and recording the impact on model-predicted travel times to Moenkopi Wash. The use of 25% fluctuations in recharge rates will reasonably bracket variations in long-term precipitation trends and the effect of these variations on the groundwater flow velocity.

NRC General Comment 2

In addition to the data deficiencies, there are uncertainties related to future precipitation/temperature changes and to the conceptual model of flow and transport as presented in Sections 5 and 6 of the report. There may be alternative conceptual flow models that are as valid as the one presented in the report. Uncertainty analyses that evaluate possible future precipitation/temperature changes and alternative conceptual models would provide more confidence in the model's results.

DOE-LM Response

With regard to alternative conceptual models, the groundwater flow model was developed from existing data, including a site-specific study of aquifer recharge, stream flow measurements, numerous hydraulic conductivity measurements, and decades of groundwater elevation measurements. These data support the validity of the model configuration.

Models are typically developed utilizing all available and relevant data, but input assumptions based on professional judgment are almost always necessary. Assumptions are used to span data gaps when gathering sufficient data is not practically achievable due to cost or time constraints. As noted above, DOE-LM intends to obtain additional key data and will utilize new and relevant data, in combination with professional judgement, to close data gaps where possible.

With regard to future precipitation/temperature changes, long-term climate change is expected to increase temperatures and decrease rainfall in the desert southwest. A future model run with a 25% decrease in overall recharge may be considered as an alternative conceptual model for the prediction of groundwater flow effects resulting from future precipitation/temperature changes.

NRC General Comment 3a

Initial parameter values may be difficult to obtain for the less permeable zones of the aquifer vs. the zones of preferential flow. Information in previous ground water reports for the Tuba City disposal site have shown evidence of a possible fracture-dominated hydraulic connection between the disposal cell area and the lower terrace. Although such a feature could appreciably change the results of flow and transport model runs to the wash, this uncertainty was not analyzed in the 2016 ground water model report.

DOE-LM Response

The current conceptualization of groundwater flow at the Tuba City disposal site is that hydraulic conductivity heterogeneity (measured hydraulic conductivity ranges over 5 to 6 orders of magnitude at the site) is responsible for variations in measured drawdown including that observed at well 921. The 2015 groundwater flow model, which has a continuous, spatially variable calibrated hydraulic conductivity field, predicts 8 feet of drawdown at well 921, which corresponds favorably to the 2004 reported drawdown range of 7–9 feet and suggests that fracturing is not required for drawdown propagation as far south as observed.

DOE-LM has and continues to evaluate the potential for fracturing between the disposal cell area and Moenkopi Wash, especially in light of the 2012 U.S. Geological Survey (USGS) report *Characterization of Subsurface Geologic Structure for Potential Water Resources Near the Villages of Moenkopi, Arizona* (USGS 2012). Based on a geophysical survey conducted near the Villages of Moenkopi in 2016 (about 6 miles from the Tuba City site), USGS concluded that "fractures are present in the Navajo Sandstone, primarily in a north to south orientation" and "these fractures could hold potential water resources". USGS performed no hydraulic confirmation studies to verify the existence or connectivity of the hypothesized fracture network. In addition to geophysical mapping in 2016, USGS identified fractures in outcrops in the vicinity of the area of the Villages of Moenkopi and Tuba City. The USGS report prompted DOE-LM in 2016 to visit the same outcrops where the USGS reported fracturing. DOE-LM confirmed the presence of fracturing, which prompted reconnaissance of the prominent sandstone outcrop towering over Moenkopi Wash, to see if the same fractures are present downgradient of the disposal cell site. The visual evaluation found no evidence of macroscopic, vertically oriented fractures along the east-to-west-trending cliff face. Fractures, if present, would transmit water infiltrating into the ground above the cliff. Any water in the fractures exposed along the cliff face would be susceptible to freeze–thaw cycles, cracking the rock and resulting, over time, in a hummocky cliff face. The sheer-wall cliff face itself indicates an absence of fractures.

USGS also reported that fractures in the Navajo Sandstone near the Villages of Moenkopi could produce "large amounts of water and provide a good source of drinking water" (USGS 2012; citing Truini, Margot, 1999, *Geohydrology of Pipe Spring National Monument Area, Northern Arizona: U.S. Geological Survey Water-Resources Investigations Report 98–4263*). In contrast to this conclusion, wells tested during an extensive aquifer property characterization program at the Tuba City site (consisting of 10 single well pumping/recovery tests and a four-well long-term pumping test) could not sustain pumping rates over 4.4 gallon per minute (gpm) (DOE 1997). Similar yields are associated with the 33 onsite extraction wells; the maximum individual extraction well sustainable pumping rate is 6.5 gpm (DOE 2016). The onsite extraction wells do not "produce large amounts" of water as USGS expects in the presence of an extensive, connected fracture network.

If fractures are providing continuous connectivity between the disposal site and Moenkopi Wash, springs and seepage zones should be prevalent in Moenkopi Wash downgradient of the disposal site. The only seepage (cumulatively less than 1 gpm) emanating from the sandstone cliff face above Moenkopi Wash occurs just above the discontinuous limestone layers exposed in the cliff face (DOE 2016). The low flow volumes do not support the presence of an extensive, continuous fracture network extending from the disposal site and Moenkopi Wash. A pair of springs (Shonto well and Jimmy Spring) are located approximately 0.5 and 0.75 miles up Moenkopi Wash, east of the point where the wash is closest to the disposal cell. Given the location of the springs compared to the disposal site it is unlikely groundwater discharging from the spring originated beneath the disposal site. No pooling water is observed at the spring sites; rather, at both sites water is conveyed to livestock troughs through a steel pipe that has been driven into the sandstone at the contact with the alluvium. Technically, these features are more properly referred to as drive point wells as opposed to springs. Generously, the volumes of water associated with the livestock watering systems are trickles. There are no other documented springs in the vicinity of the disposal site. The absence of springs and the low flow rate at the drive point livestock watering locations do not support the presence of an extensive, connected fracture network extending from the disposal site to Moenkopi Wash.

In summary, taken together, the absence of observable vertical fractures in the sandstone cliff adjacent to Moenkopi Wash, the low sustainable yields of onsite extraction wells, and the absence of springs and seeps in Moenkopi Wash downgradient of the disposal site do not support the presence of an extensive, connected fracture network. Rather, the information suggests that groundwater flow patterns (and drawdown) are controlled by hydraulic conductivity heterogeneity; measured hydraulic conductivity ranges over 5 to 6 orders of magnitude at the site (DOE 2016). This conceptualization is consistent with the 1994 evaluation of historical drawdown data that concluded that "none of the pumping test data from the UMTRA Project site show any of the behavior associated with any kind of fracture flow conditions."

The uncertainty in groundwater travel times was addressed. To address the uncertainty in groundwater travel times from the Tuba City site to Moenkopi Wash resulting from 5 to 6 orders of hydraulic conductivity variability, DOE-LM conducted a stochastic groundwater travel time evaluation as part of the modeling exercise (DOE 2016). Using observed ranges of hydraulic conductivity and horizontal hydraulic gradient, the evaluation concluded that groundwater travel times from the site to the wash likely range between 100 and 1000 years with a median travel time of 463 years. The calibrated groundwater flow model reproduced the calculated groundwater travel time variability, suggesting that the model is replicating the expected variability in groundwater travel times from the disposal site to the wash.

DOE-LM is currently installing additional monitoring wells around and downgradient of the disposal site. Cores are being collected from select locations and will be visually evaluated for the presence of fractures. Hydraulic testing is planned for one of the boreholes to characterize the vertical flow characteristics of the penetrated sandstone and potentially help further discern how fractures (if present) or hydraulic conductivity heterogeneity influences groundwater flow. The information gleaned from the well installation and hydraulic testing program will be evaluated and incorporated into the groundwater flow system conceptual model.

Documentation referred to in this response includes:

USGS 2012. *Characterization of Subsurface Geologic Structure for Potential Water Resources Near the Villages of Moenkopi, Arizona, 2009–2010*, Scientific Investigations Report 2012-5180.

DOE 2016. *Draft Groundwater Flow Model for the Tuba City, Arizona, Disposal Site*, LMS/TUB/S12512.

DOE 1997. *Tuba City Interim Action*, Project Number 10943.003.114.0100.02, Calculation Number U00178AA.

DOE 1994. *Integrated Hydrogeologic Conceptual Model Tuba City*, Arizona UMTRA Project Site, unpublished.

NRC General Comment 3b

Ground water inflow at the model's northern boundary parameter values may be difficult to obtain since the hydraulic conductivity may be unknown in the Kayenta-Navajo Transition Zone (KNTZ). The 2016 ground water model report stated that, "A remedial investigation in 2013 determined that local groundwater flow north and west of the site converges to Pasture Canyon (AMEC 2013). This observation supports the concept that a local groundwater divide coincides with the surface water divide north of the site." The NRC staff were not able to obtain or review this report to confirm this assumption.

DOE-LM Response

The northern model boundary corresponds to a surface-water divide that supports the current conceptualization, that there is no groundwater inflow into the model domain across its northern boundary. Thus, the hydraulic conductivity in the KNTZ is irrelevant to the definition of the northern model boundary. The referenced study (AMEC 2013) is a draft report that was completed in 2015 but was not yet available. DOE-LM can provide NRC with an electronic version of the report upon request.

NRC General Comment 3c

The base of the N-aquifer, (i.e., both the Navajo Sandstone and the KNTZ), is unknown, especially near the Moenkopi Wash so that it is unclear if all the ground water discharges at or near the wash.

DOE-LM Response

The model's current conceptual basis for aquifer recharge and discharge is that the site lies within a localized basin, and all groundwater within the basin discharges to Moenkopi Wash. Agreement between the volumes of basin recharge (evapotranspiration [ET]/recharge study as cited in the Groundwater Flow Model) and discharge (stream gaging) support this concept.

The base of the aquifer cannot be precisely defined due to the depositional heterogeneity and lack of discrete marker beds. The position of the base of the aquifer is considered to be more certain near Moenkopi Wash because of direct observation of local outcrops that span the transitional interval. Field observations suggesting that the base of the aquifer coincides with the top of the Kayenta Formation are particularly evident along Highway 264 near the village of Moenkopi. Water is expressed in discrete horizontal bedding planes above the top of the Kayenta. No water is expressed from the Kayenta Formation or from the underlying Moenave Formation.

The assumption that all site (local, not regional) groundwater discharge occurs at Moenkopi Wash is also supported by recognition of land surface topography and drainage features. Topography and drainage east of Moenkopi Wash show a westward trend. There are no major or regional groundwater discharge features farther east of Moenkopi Wash.

NRC Specific Comment(s) 1

Appendix B, Table B-1; Section 3.1, Page 10, and Figure 6, Page 15:

Very little information is known about the KNTZ and even less is known about the Kayenta Formation. Five wells (well numbers 253-257) that were decommissioned in 2005 were deeper than all other wells. Well numbers 253, 255, and 257 were deeper than aquifer Horizon M and reached the Kayenta Formation. Any additional information on the KNTZ and the Kayenta Formation obtained from these wells on stratigraphic composition, hydraulic properties, water chemistry, or water table levels measured within the screened interval could be valuable data for the ground water flow model and should be included in the model report. If information concerning these wells is no longer available or useful, that should also be briefly discussed in the report.

Appendix B, Table B-1; Section 3.1, Page 10, and Figure 6, Page 15:

In addition, Figure 6 (Page15) shows well numbers 968 and 971 with screen intervals from aquifer Horizon B down to greater than Horizon M. These deep wells, with potentially valuable information, are not discussed nor are they included in Tables B-1 and B-2 in the current report.

DOE-LM Responses

Wells 254, 255, 256, and 257 were decommissioned in August 2005 because by that time there was sufficient evidence to indicate that the integrity of the annular seals was compromised. The water-level data and water quality are not representative of discrete depths of the aquifer, and so the data were not used to calibrate the groundwater flow model. Although the monitoring data for these wells were of questionable quality, the stratigraphic information obtained during installation of these wells was used to develop the hydrogeologic conceptual model. (Well 251 was abandoned in 2001; however, the rationale for its decommissioning is not documented).

Wells 968 and 971 are former supply wells for mill operation. Well 971 is currently used as a Navajo Tribal Utility Agency domestic supply well. Well 968 is not in use. Neither well is owned or maintained by DOE-LM. Historical water-level information and production information for these wells is viewed with considerable uncertainty, and given the long screen lengths (>500 ft), the information related to these wells was generally excluded from the model. However, the available geologic logs proved useful in identifying the approximate positions of the KNTZ and top of the Kayenta Formation, as depicted in Figure 15, and originally documented in the Site Observational Work Plan (DOE 1998). This information provided rationale for selecting the base of the groundwater flow model.

NRC Specific Comment 2

Section 3.2.1, Page 15; Section 7.3.1, Page 65, and Plate 1:

This section states that, "East of the topographical divide, a portion of the watershed slopes toward a dry lake bed referred to as Greasewood Lake. Surface water runoff occasionally collects temporarily in this closed basin in wet seasons. There is no perennial inflow to or outflow from Greasewood Lake." The majority of the Greasewood Lake watershed that lies outside of the model domain appears to flow into the Greasewood Lake and since this depression has no outflow, and no vegetation (see Section 7.3.1, Page 66), it is very probable that standing water would enter the model domain as recharge and increase the current water budget of the model." Section 7.3.1 states that, "Infiltration of runoff received by this depression is expected to flow southeast toward Moenkopi Wash." Therefore, there may be an impact to the water budget and this should be evaluated.

DOE-LM Response

Net recharge was estimated for the area (ET Zone 1) encompassing a portion of Greasewood Lake, which lies within the model domain. Greasewood Lake is a relatively small localized basin, and the occurrence of standing water is likely infrequent and short-lived. The model utilizes long-term average conditions to achieve the primary objective of determining the time required for groundwater to travel from the site to Moenkopi Wash. The occurrence of ephemeral standing water and subsequent infiltration would pose minimal, if any, impact and therefore is not included as an input to the model.

NRC Specific Comment 3

Section 3.2.1, Page 15; Section 7.3.1, Page 65, and Plate 1:

Plate 1 indicates that there is a topographical divide between the Greasewood Lake and Moenkopi Wash watersheds and it is not clear why the surface water divide between these two watersheds does not have the same effect on the ground water as the surface water divide between the Greasewood Lake watershed and the Pasture Canyon watershed. It is not clear why the report does not discuss the impacts of a ground water divide separating the Greasewood Lake and the Moenkopi Wash areas.

DOE-LM Response

Groundwater within the Pasture Canyon watershed has two routes of discharge: to perennial springs that form a creek in the canyon, and through transpiration by vegetation within the canyon. Therefore, the surface divide can logically be interpreted as a groundwater divide.

However, the closest and only local boundary for discharge of groundwater from the closed basin (from a topographic perspective) that includes Greasewood Lake is Moenkopi Wash. Therefore (and unlike Pasture Canyon), the surface divide between Greasewood Lake and Moenkopi Wash is not interpreted as a groundwater divide. And as noted above, the contribution to groundwater via the occurrence of standing water and infiltration in Greasewood Lake would be a minimal component of the net recharge estimated for ET Zone 1. Accordingly, no change to the report text is proposed.

NRC Specific Comment 4

Section 3.0, Page 9; Section 4.2.1, Page 32, and Table 6, Page 33:

Section 3 on Page 9 states that within the KNTZ, the classic Navajo Sandstone dune deposits become interbedded at depth with fine-grained, horizontally bedded alluvium more typical of the deeper Kayenta Formation. The Kayenta formation is considered to be an aquiclude. This would indicate that hydraulic conductivities should be less for the KNTZ than it would be for the Navajo Sandstone and Table 6 appears to show that this is the case. However, it does not appear that an effort was made to match the properties of the model with this hydrogeological insight and it was not considered during the model calibration process.

DOE-LM Response

Hydraulic conductivity measurements in the Navajo Sandstone at the site span 6 orders of magnitude. It is likely that the hydraulic conductivity of the KNTZ, which is similarly composed of interbedded fine sands and silts, falls within the measured range. Thus, the hydraulic conductivities of the KNTZ and the Navajo Sandstone are not expected to be significantly different.

NRC Specific Comment 5

Section 4.3.2, Page 40:

This section states that, "Recharge to the aquifer in the model domain is estimated as the difference between average annual precipitation, applied uniformly over the model domain, and estimated ET within the various delineated vegetation zones." Average annual precipitation rates are important parameter values since this is the most significant contributor to inflow for *the model. However, no references or source materials are discussed when presenting the precipitation rates used for the model domain nor are seasonal or annual variabilities discussed that may influence recharge.*

DOE-LM Response
Section 4.3.2 "Precipitation Recharge" provides a reference ("*Evapotranspiration Within the Groundwater Model Domain of the Tuba City, Arizona, Disposal Site, Interim Report*" DOE 2015) for information presented in that section. A thorough technical basis for estimating recharge is described in that report. The annual average precipitation for the site area (129 millimeters per year) was obtained from NOAA Cooperative Station 028792 via the Western Regional Climate Center (http://www.wrcc.dri.edu).

The model was developed for long-term predictions, primarily groundwater flow path and travel time from the site to Moenkopi Wash, over a duration of hundreds of years. Seasonal or annual variabilities are not relevant as input parameters, as they become averaged out over the long-term.

NRC Specific Comment 6
Section 4.3.2.3, Page 41 and Table 20, Page 95:
Table 20 on Page 95 shows that the calculated recharge to Zone 1 (upland north of Highway 160) represents almost 50 percent of the water budget input, yet there is no discussion of this significant vegetation zone in Section 4.3.2.3. Such a discussion is especially important considering that Zone 1 was apparently not included in the original February 2015 evapotranspiration study "Evapotranspiration Within the Groundwater Model Domain of the Tuba City, Arizona, Disposal Site, Interim Report", LMS/TUB/S12694, Office of Legacy Management, Grand Junction, Colorado)

DOE-LM Response
The section summarizes information presented in the February 2015 evapotranspiration study. Zone 1 was not specifically called out in the report text; nor were Zones 2, 3, and 7. All zones are listed in the accompanying Table 10, "Vegetation Zones in the Model Domain" and are shown in Figure 21. Expected recharge rates to Zone 1 are discussed on page 12 of the Evapotranspiration Report (LMS/TUB/S12694). A site reconnaissance walkover was performed to confirm the representativeness of Zone 1 vegetation effects on the model from the area north of Highway 160.

Zone 1 was included in the initial February 2015 evapotranspiration study but was not as extensive as the model domain. Additional field reconnaissance that covered the entire northern portion of the model domain was performed after the February 2015 study. It was concluded that the same plant communities of comparable health were present throughout the northern portion of the model domain and the initial Zone 1 recharge estimates were representative of the larger domain.

A more thorough discussion of the additional field reconnaissance effort related to confirming the representativeness of ET Zone 1 in the northern half of the model domain will be included in the next modeling report documenting the next modeling effort.

NRC Specific Comment 7

Section 4.4.2.1, Page 45 and Table 13, Page 48:

The precipitation and evapotranspiration rates used in the water budget presented in Table 13 on Page 48 are mean annual rates, presumably taken over an entire year and multiple years, while the information on aquifer discharge to the wash appears to be based on three measurements and thus is not a mean annual rate. Due to the variability during the growing vs. non-growing season and of the regional meteorology, the amount of water discharging could vary depending on the season of the year and the weather pattern over a range of years. Therefore, a sensitivity analysis, or more data on the discharge to the wash, would improve the model output.

DOE-LM Response

Additional stream gaging measurements would be useful in characterizing long-term average groundwater discharge to the Moenkopi Wash from the model domain, and collection of additional measurements is planned. However, it is important to recognize that the stream flow measurements were not used as calibration targets; the values did not directly constrain the model. Rather, the measurements were used to check the representativeness of the model by comparing whether the modeled values were similar to the measured values. The model-predicted interaction between the basin aquifer and surface stream flow also compares favorably to long-term flow measurement recorded by the U.S. Geological Survey at the gaging station on Moenkopi Wash approximately 5 miles downstream of the site (there are no perennial tributaries to the Wash through that reach).

NRC Specific Comment(s) 8

Section 4.4.2.1, Page 45:

Section 4.4.2.1 states, "The stream gain is attributed to groundwater discharge from the Navajo Sandstone aquifer because no tributary sources are observed, and is assumed to occur from both sides of the wash in equal proportion."

a. *No hydrogeological information is presented on the upland area south of the Moenkopi Wash. Therefore, the assumption that ground water discharge is occurring equally from both sides of the banks of the Moenkopi Wash is not justified. A sensitivity analysis would help to determine if additional justification is needed to support this assumption.*

b. *The KNTZ is not discussed although this is the unit that probably was meant instead of the "Navajo Sandstone aquifer." It is not clear that all the regional ground water empties into the Moenkopi Wash. If regional ground water continues to flow under, or bypasses, the wash, this would affect the water budget of the model. Relevant information supporting the current conceptual model of outflow to the wash should be discussed.*

DOE-LM Responses

a. Stream flow information was not used to directly constrain the model; it was used to check the representativeness of the model output. The measured stream flow and model-predicted groundwater discharge volumes are similar, which supports the reasonableness of the model input assumption (discharge from both sides of Moenkopi Wash in approximately equal proportion) and the resultant model output predictions. Sensitivity analysis would neither lend support to the assumption nor indicate a need for further justification. The conclusion that the modeled discharge volume is reasonable would remain even if it was assumed that 100% of groundwater discharge came from the north side of Moenkopi Wash. The measured and modeled volumes would still be within a factor of 2, which is a reasonable match for hydrologic evaluations.

b. The reference to the Navajo Sandstone aquifer is correct, as the KNTZ is a part of this aquifer. Regional groundwater does not discharge to Moenkopi Wash in significant quantities, if at all. If regional groundwater was discharging to Moenkopi Wash, creek flows would be considerably higher than 1000 gpm. For reference, the Little Colorado River is a regional discharge feature and has typical flows of about 50,000 gpm. The current concept is that the site is located within a local groundwater basin. Recharge is derived from precipitation that falls within the basin. Discharge is to Moenkopi Wash. The saturated thickness of the aquifer (to the top of the Kayenta Formation) is thought to be fully or nearly fully penetrated by the Wash, and there is no expression of groundwater discharge farther to the east of the Wash.

   Furthermore, stream flow measurements were made during times of the year when significant plant transpiration on the floodplain to the north (site side) of Moenkopi Wash was not likely. The geology and drainage patterns are similar on both sides of the Wash, supporting the assumption of equal rates of groundwater discharge.

   Nested monitoring wells have been installed in the floodplain of Moenkopi Wash. Water level data obtained from these wells will be used to further validate the current concept of outflow to the wash. If groundwater data evaluation results in changes to the conceptual basis, the groundwater flow model will be refined accordingly. Discussion of the data collected from the new wells will be addressed in future groundwater modeling reports.

NRC Specific Comment 9

Section 4.5, Page 47:

Section 4.5 states that, "The analysis indicates that the total rate of groundwater flow through the model domain is about 150 gallons per minute (gpm). This volumetric rate is approximately one-half of that presented in the [Site Observational Work Plan] SOWP (DOE 1998)." It is not clear why the current water budget is 50 percent less than that presented in the SOWP and an explanation of this difference would be useful.

DOE-LM Response

The site conceptual model was revised based on additional evaluation of existing and new data. The original conceptualization had evapotranspiration occurring on the Lower Terrace and Moenkopi Wash cliff face. The original conceptualization also assumed a quantity of upgradient inflow that could not be supported by direct measurement or physical boundary. Data evaluation showed that inflow is almost entirely attributable to precipitation and that significant ET discharge does not occur on the lower terrace (as was hypothesized in the original conceptualization). The updated site water budget and conceptual model benefit from site-specific study of ET, stream flow measurement, and additional field reconnaissance and groundwater monitoring information that was not available when the SOWP was prepared.

Historic hydrogeologic cross sections showed a regional groundwater flow component contributing to the local flow system. The cross-section contained in this report (Figure 6) shows localized flow patterns. In the future, based on the updated conceptual model, local (not regional) groundwater flow patterns will be consistently shown on hydrogeologic cross sections. The history of model development (a record of changes made to the model, when new data became available) can be documented in an addendum to the report. DOE-LM's planned path forward is to revisit the model's architecture when results are available from the expanded data collection effort (new monitoring wells and geochemical testing). The addendum will provide resolutions to NRC's review comments.

NRC Specific Comment(s) 10

Section 5.0, Page 57:

Major assumptions are associated with several components of the conceptual model but supporting data is lacking. These components include:

a. *The site is located in a local hydrologic basin that is bounded by an up gradient ground water flow divide. (See comment general 2.b);*

b. *Ground water flow from north of the divide is discharged westward to Pasture Canyon. (See general comment 2.b)*

c. *The hydrologic basin is bounded downgradient by Moenkopi Wash. There is no ground water flow beneath the wash. (See specific comment 10.b)*

d. *The local flow system does not extend into the Kayenta Formation.*

e. *All ground water within the hydrologic basin originates from precipitation within the basin. (See specific comment 2)*

DOE-LM Responses

a. The northern boundary of the model domain corresponds to a topographic high. The assumption is that groundwater is a subdued reflection of topography. This is a common assumption for unconfined aquifers. Inflow, calculated by multiplying ET/recharge estimated infiltration rates by areas within the model domain, is approximately equal to the measured creek flow plus ET within Moenkopi Wash. The convergence of calculated recharge and measured discharge volumes suggests that the local hydrologic basin and model domain are bounded appropriately.

b. North of the topographic divide, the land surface slopes towards Pasture Canyon. Assuming groundwater is a subdued reflection of topography, groundwater will flow toward Pasture Canyon. Pasture Canyon is an obvious location of aquifer discharge and as cited previously, hydrogeologic study near the site *Final Remedial Investigation Report, Tuba City Dump Site, Tuba City, Arizona* (AMEC 2015) indicates converging groundwater flow in Pasture Canyon from the east.

c. The current concept is that the site lies within a localized basin and that the basin discharges to Moenkopi Wash. Agreement in basin recharge (ET/recharge study) and discharge (stream gaging) volumes support this conceptual basis. Deeper regional groundwater flow, if present, is assumed to be disconnected from the confined basin aquifer at the site and would discharge at a more prominent boundary than that observed at Moenkopi Wash.

d. The top of the Kayenta Formation is assumed to be the bottom of the localized flow system. This assumption is supported by the presence of many springs and seeps at the contact between the Navajo Sandstone and the Kayenta Sandstone. The seep zone at the base of the aquifer is apparent for many miles in outcrops extending from the village of Moenkopi at least to the village of Moenave, north and west of Tuba City. This interpretation is supported in the work of Cooley et al. (*Regional Hydrogeology of the Navajo and Hopi Reservations, Arizona, New Mexico, and Utah*, Geological Survey Professional Paper 521-A, 1969).

e. The current base concepts for model architecture are as follows: the aquifer at the site is a localized basin; the vast majority of recharge is from precipitation; and the vast majority of discharge is to Moenkopi Wash. The model domain's eastern and western boundaries present constraints to groundwater flow, so any additional inflow from upgradient (i.e., sources other than precipitation) would have to discharge to the Wash. If an additional inflow was significant, it would be measureable at USGS stream gages. Recorded surface-water flow in Moenkopi Wash would then have been in conflict with the model's projected water budget and would have led to reconsideration of the model's base concepts. The convergence of independent analyses, used for the model's input parameters for recharge and discharge, lends support to the model's basic concepts.

NRC Specific Comment 11
Section 6.0, Page 59:
Section 6.0 states that, "LM is evaluating how these processes may affect contaminant transport at the site." These evaluations could have important ramifications on the results of future iterations of the model, and LM should discuss how the results of the evaluations will be incorporated into the final ground water flow model.

DOE-LM Response
In concert with the planned installation of new monitoring wells and additional data collection (FYs 2016–2017), new core material will be collected for use in geochemical studies. The objectives of geochemical studies will be to determine the adsorptive and desorptive characteristics of the contaminants and the aquifer formation for better understanding of contaminant fate and transport, and as input to remediation strategy.

The ramifications of contaminant source and plume stability evaluation for future iterations of the model are not known at this time and cannot be meaningfully discussed beyond "hypotheticals." NRC will be kept informed as the plans for these expanded efforts mature. When data that will have an impact on groundwater flow modeling become available, the architecture of the groundwater flow model will be refined.

NRC Specific Comment 12
Section 7.2.2, Page 59; Figure 30, Page 65 and Figure 6, Page 15:
Although no data was presented to support the location of the KNTZ/Kayenta interface, Figure 6 on Page 15 shows the interface rising several hundred feet from one end of the model domain north of Highway 160 to the other end of the model domain at the Moenkopi Wash. However, Figure 30 indicates that the model was constructed using a horizontal line to represent that interface. A sensitivity analysis may be needed to demonstrate how the difference in the bottom boundary condition might influence the output of the model.

DOE-LM Response
The referenced surface dips at a rate of approximately 1 foot per 1000 foot run. For all practical purposes, the surface is flat. Figure 6 implies that the KNTZ–Kayenta interface rises 200 feet in the direction of the cross section. DOE-LM recognizes that the position of the base of the aquifer is uncertain. However, as currently conceptualized and represented in the numerical model, it is consistent with field observations and flow measurement data. Sensitivity analysis for this aspect of the model is, therefore, not considered warranted.

NRC Specific Comment 13
Section 7.3.2, Page 66:
It would be helpful if a flownet is presented to demonstrate that the "model domain is oriented such that the eastern and western boundaries are parallel to the predominant direction of ground water flow that occurs southeast of the flow divide."

DOE-LM Response
Flow direction was determined using a three-point analysis (summarized in Section 4.1.2 and Table 4). The dominant groundwater flow direction was found to be about 170 degrees east of north. The model was oriented so that "long sides" run parallel to the calculated groundwater flow direction. The model orientation is also consistent with the general direction of groundwater flow implied in the baseline water-table contour map (Figure 9). Groundwater flow paths and equipotential lines within the model-predicted flow field, which effectively comprise a sophisticated three-dimensional flownet, confirm that the model orientation is appropriate.

NRC Specific Comment 14
Section 7.4.2, Page 73 and Figure 36, Page 79:
Figure 36 on Page 79 shows the dearth of calibration points for this model south of the Greasewood area. The area around the disposal site appears to be well represented. However, this cannot be said for the area between the disposal site and Moenkopi Wash. This may pose a problem for meeting the stated objective of estimating the ground water travel times from the Tuba City disposal site to Moenkopi Wash. As Section 7.4.2 discusses, pilot points were used, however they cannot replace real data. In addition, the pilot points are assigned expected "typical" values rather than hydraulic conductivity values closer to the minimum and maximum extremes, although more water will flow within an area with interconnected maximum hydraulic conductivity values compared to an area with typical hydraulic conductivity values.

DOE-LM Response
Historically, the initial set of well locations was selected to define the horizontal and vertical extent of groundwater contamination and to broadly characterize site geology, water quality, and groundwater levels in distal areas (for example, clustered wells 917/918/919 and wells 902 and 904). Later well installations were focused on the collection of input parameters for design and subsequent performance monitoring of the groundwater remediation system.

Additional downgradient wells, south of the Greasewood Area, may not necessarily improve the ability to predict groundwater travel times. Hydraulic conductivity measurements collected across the site span 6 orders of magnitude, and site reconnaissance has revealed Navajo Sandstone outcrops in the downgradient area, similar to outcrops in other areas of the site. So it is reasonable to expect that point measurements collected from new downgradient wells would fall within the currently measured range of hydraulic conductivities. The predicted range of groundwater travel times would not be significantly different and would not necessarily be more accurate through the addition of point measurements.

Hydraulic conductivity measurements at the Tuba City open dump site located a few miles west of the disposal site (and at a lower Navajo Sandstone elevation) span the same 6 orders of magnitude of hydraulic conductivity, supporting the position that additional point measurements at the site will not have significant impact on the precision or accuracy of model output. Note that hydraulic conductivity measurements for the open dump site are reported in the *Final Remedial Investigation Report, Tuba City Dump Site, Tuba City, Arizona* (AMEC 2015). DOE-LM recognizes the uncertainty associated with travel time predictions, which is why a stochastic evaluation of travel times from the site to Moenkopi Wash was performed and presented in the groundwater flow model report.

Measured values of hydraulic conductivity were used as pilot point inputs, where data were available. For pilot points without existing hydraulic conductivity data, typical values were initially assigned. During calibration, the pilot point hydraulic conductivities were adjusted and kriged to determine the best spatially continuous hydraulic conductivity field. At insensitive pilot point locations (those which did not influence calibration statistics), the PEST calibration algorithm maintained pilot point hydraulic conductivity at the initial assigned value rather than letting hydraulic conductivity migrate to the minimum or maximum allowable values. The result is a calibrated hydraulic conductivity field that reflects the calibration data and site conditions.

NRC Specific Comment(s) 15

Section 7.4.2, Page 71, Figures 5, 6, 30, 40 and 48 (numerous pages) and Section 3.2, Page 13:

a. *Figures 40 and 48 show that model layer 1 was assigned higher hydraulic conductivity values in the floodplain and riparian zone along the Moenkopi Wash. Figures 5 and 6 indicate that the terrace alluvium is relatively thin and that model layer 1 in this area is basically representing the Navajo Sandstone (Aquifer Horizons A, B, and C) as shown in Figure 30. It is not clear why the sandstone should have such a high hydraulic conductivity value.*

b. *Section 7.4.2, Page 74 states that, "Pilot points were not used to constrain the spatial distribution of hydraulic conductivity of the Moenkopi Wash floodplain alluvium. These sediments were assigned a homogeneous hydraulic conductivity of 100 ft/day."*

   However, Section 3.2 states that, "terrace alluvium and dune deposits are not saturated." It is not clear why the high hydraulic conductivity values were assigned to a unit that is basically dry (and very thin).

DOE-LM Response

a. Terrace alluvium and sand dune deposits should not be confused with the Moenkopi Wash floodplain alluvium. While geologically similar, hydrologically the difference between the two is that the Moenkopi Wash floodplain alluvium is saturated while the terrace alluvium and sand dune deposits are unsaturated. The reason for the different degree of saturation is that the terrace alluvium and sand dune deposits are located vertically, hundreds of feet above Moenkopi Wash. At these elevations, the water table occurs within the underlying Navajo Sandstone and groundwater doesn't contact the overlying terrace alluvium and sand dune deposits. Because the terrace alluvium and sand dune deposits are unsaturated, these deposits, although discussed in Section 3.2 of the report, are not included in the groundwater flow model.

b. The Moenkopi Wash floodplain alluvium, present within Moenkopi Wash at the lower elevations of the local groundwater flow system, contains the water table. Because the Moenkopi Wash floodplain alluvium is saturated, the alluvium, consisting primarily of sand, is included in the groundwater flow model. The assigned hydraulic conductivity of 100 feet/day (~0.04 centimeter per second) is within the expected range of hydraulic conductivity for sand. Groundwater within the saturated Moenkopi Wash floodplain alluvium ultimately is consumed by the local plant community and discharges to Moenkopi Creek.

NRC Specific Comment 16
Section 8.1.3, Page 78:
The use of censor targets as shown in Figure 38 may be indicative of a calibration problem. If so, a discussion would be helpful on why this would not significantly affect the outcome of the model's results.

DOE-LM Response
Censor targets allow soft data to be included in the calibration. For example, the water table at the site is below ground surface everywhere within the model domain with the exception of the creek and springs in Moenkopi Wash. For the model to be representative, the predicted water table must be below ground surface except at the locations previously identified. The use of censor targets, equal to ground-surface elevation, ensures that the model-predicted water table is below ground surface, a known condition. Satisfying a censor target is no different than matching a water-level target, and both target types result in a better calibrated model.

NRC Specific Comment 17
Tables 16, 17 and 18, Pages 87, 92 and 93:
It is not clear why the model layer 1 hydraulic conductivity values in Table 18 are different than the model layer 1 values found in Tables 16 and 17.

DOE-LM Response
Tables 16 and 17 summarize calibrated horizontal and vertical hydraulic conductivity distributions, respectively, for each layer everywhere in the model. Table 18 is a summary of the calibrated horizontal and vertical hydraulic conductivity distributions in the vicinity of the site. The horizontal and vertical hydraulic conductivities were extracted from the model for comparison to pumping tests results (Table 18).

In future modeling reports, if such analysis is performed, a figure will be included showing the area within the model where the hydraulic conductivity measurements were extracted for comparison purposes.

NRC Specific Comment 18
Section 8.2.4, Page 95:
It is not clear why the "Disposal cell drainage" inflow (0.6 gpm) in Table 20 is different than the "Disposal Cell: 1990 to 2001" inflow component (6 gpm) in Table 13.

DOE-LM Response
Cell drainage estimates applied in the model were adopted from the SOWP. The corresponding dates and rates of transient cell drainage are listed in Table 19. The cited drainage rate listed in Table 20 (0.6 gpm) is the net drainage rate estimated for the transient period of model calibration (2002 to 2012).

NRC Specific Comment 19

Figure 60, Page 100:

Figure 60 shows the equipotential lines of the calibrated model (the assumption is that the units are in feet). However, the lines intersect the ground water divide adjoining the Pasture Canyon watershed at almost right angles. This conflicts with the assertion that this line represents a ground water divide. If it is a divide, the water table map should show ground water flowing away from the divide since the divide represents a relative high point (or water table ridge) in the area.

DOE-LM Response

The divide is not conceptualized as a groundwater ridge that results from a local recharge condition. However, it is a divide in the sense that groundwater on one side discharges to Moenkopi Wash and to Pasture Canyon on the other side. The mathematical solution of flow equations requires that the groundwater flow direction be parallel to a no-flow boundary; hence, the need for equipotentials to be at right angles to the no-flow boundary.

The groundwater divide is a feature where precipitation on one side flows to a common discharge location(s) while precipitation falling on the other side flows toward a different location(s). The distribution of recharge on either side of the divide and the location of discharge locations will control the equipotential patterns. If the majority of recharge within a basin occurs along the divide and the discharge location is parallel to the divide (such as a river running through a mountain valley) the equipotential pattern will show flow away from the divides to the discharge location.

The localized Tuba City basin is different in that recharge is from precipitation that falls across the basin. During pre-extraction system conditions, the only basin discharge location is Moenkopi Wash at the downgradient end of the flow system. The combination of basin-wide, diffuse recharge and a mostly linear discharge feature at the downgradient end of the basin results in equipotential lines that are essentially parallel to the groundwater divide.

NRC Specific Comment 20

Section 8.4.1, Page 111:

Section 8.4.1 states that, "... because of the large number of particles (9,235) used in the evaluation individual particle traces are not visible, but instead the particle traces blend together to produce a "plume" of particle traces." It is not clear why fewer particles could not be used to better show the relative contribution from each model layer. It would be useful to show how much ground water is flowing in each model layer as it makes its way to the wash.

DOE-LM Response

Particles represent groundwater flow paths and not flow contributions. Because of hydraulic conductivity heterogeneities, groundwater flow paths from different locations within the site to Moenkopi Wash are highly variable. Thus, placing particles at only a few locations could lead to erroneous interpretations of migration patterns and travel times to Moenkopi Wash. Additionally, because of the complexity of flow patterns, groundwater flow volumes within each model layer will increase and decrease with distance from the site. Because all of the groundwater within the model domain discharges to the Wash, the total volume is the only number reported.

NRC Specific Comment 21
Section 9.0, Page 115:
This section states that, "With regard to modeling objectives, the calibrated model can be used to evaluate groundwater flow patterns, to estimate travel times from the Tuba City disposal site to Moenkopi Wash, and to simulate extraction system pumping with and without injection of treated groundwater." The NRC staff agrees that the calibrated model could possibly be used to simulate extraction system pumping with and without injection of treated ground water, however the staff does not agree with the other two statements. Only the information around the disposal site is sufficient to be able to use this model for prediction of ground water flow because very little hydrogeological data is present for the area north of the Highway 160 and to the area south of Well number 107 (with the exception of well numbers 904 and 902). This gap between the disposal site and Moenkopi Wash is evident in Figure 36 on Page 79 and, as such, the usefulness of any travel time predictions from the Tuba City disposal site to Moenkopi Wash would be questionable.

DOE-LM Response
The model was built utilizing all available and relevant data. In areas where data were lacking, assumptions were made based on observed site conditions and professional judgment. Groundwater travel time predictions resulting from model runs match analogous predictions generated by stochastic analysis (Section 4.2.5.1). This convergence lends support to the validity of the assumptions that were used to span data gaps and develop conclusions. Additionally, the model matches measured groundwater levels and vertical gradients and as such replicates, as much as possible, groundwater flow conditions. The model will be refined, and its architecture may be revised, if necessary, as additional data becomes available. At this time, the stated conclusions are considered by DOE-LM to be consistent with the level of model development.

NRC Specific Comment 22
Section 11.0, Page 133:
The second bullet under "Results" states, "Complex groundwater flow paths, arising from a wide range in hydraulic conductivity and vertical hydraulic gradients, account for the wide range in predicted groundwater travel time. "However, figures 40-46 and figures 49-54 do not show a wide range in hydraulic conductivities (with the exception of the disposal site area and near the wash). In addition, calibrated vertical gradients were not shown in the report.

DOE-LM Response
The greatest variability in the model-predicted hydraulic conductivity fields corresponds to the site and surroundings. This result is due to an abundance of data in this area of the model. The variability in hydraulic conductivity away from the disposal site is not as great. This is because PEST employs an algorithm (preferred value) that keeps insensitive hydraulic conductivity pilot points from moving away from the initial value. An insensitive pilot point is defined as a

location where changing the initial hydraulic conductivity value over the range of allowable values does not change the calibration metrics. Prior to implementation of the preferred value algorithm, insensitive hydraulic conductivity pilot points had a tendency to migrate to the minimum or maximum allowable value. The result was a conductivity field with unrealistic bullseyes of high and low hydraulic conductivities. The use of the preferred value algorithm leads to more representative, model-predicted hydraulic conductivity fields. Information pertaining to the model's ability to match vertical gradients is presented in Table 22 and Figure 58.

NRC Specific Comment 23
Section 11.0, Page 134:
The last sentence in Section 11.0 states "It is therefore suitable as a supporting tool for evaluating future options for the groundwater remediation strategy at the Tuba City site." The last 2 bullets in the section entitled "Conceptual Model of Solute Transport" on Page 58 state:

- *"Groundwater flow paths are expected to be highly variable because of the complex bedding structure and contrasts in hydraulic conductivity." and,*
- *"......The likeliness that fracture-controlled flow has no influence on ground water flow and solute transport at the site cannot be dismissed; however, the significance of this process has not been evaluated in detail."*

These factors can significantly speed up, or slow down, travel time to the wash. Sensitivity analyses would provide more insight as to the effect of these processes on ground water travel times from the disposal site to the wash.

DOE-LM Response
Hydraulic conductivity sensitivity analysis was accomplished by stochastic travel time evaluation conducted prior to modeling, which showed that travel times are expected to range between 100 and 1000 years. Model runs generated consistent results and were analogous to the results obtained by stochastic analysis. Sensitivity analysis involving hypothetical variations of hydraulic conductivity cannot be expected to meaningfully impact the groundwater travel time predictions. When additional data are available, the model will be refined, as necessary. Sensitivity analyses will carry more weight in validation and verification of model outputs when more input data are available.

As stated in comment response 3a, to address the uncertainty in groundwater travel times from the Tuba City site to Moenkopi Wash resulting from 5 to 6 orders of magnitude difference in hydraulic conductivity, DOE-LM conducted a stochastic groundwater travel time evaluation as part of the modeling exercise (DOE 2016). Using observed ranges of hydraulic conductivity and horizontal hydraulic gradient, the evaluation concluded that groundwater travel times from the site to the wash likely range between 100 and 1000 years with a median travel time of 463 years. The calibrated groundwater flow model reproduced the calculated groundwater travel time variability, suggesting that the model is replicating the expected variability in groundwater travel times from the disposal site to the wash. Thus, the requested sensitivity analysis is not warranted.

As presented in comment response 3a, the absence of observable vertical fractures in the sandstone cliff adjacent to Moenkopi Wash, the low sustainable yields of onsite extraction wells and the absence of springs and seeps in Moenkopi Wash downgradient of the disposal site do not support the presence of an extensive, connected fracture network. Thus, sensitivity analysis is not warranted to understand the potential effects of a fracture network on travel times on travel times to Moenkopi Wash.

Path Forward for Comment Resolution

As a path forward for the Groundwater Flow Model, DOE-LM recommends that NRC attach this comment response document to the draft report and maintain it for reference to any future modeling that is conducted. DOE-LM does not intend to revise and reissue the draft report based on the NRC comments received. Future data collection efforts and model runs will be designed to address the range of issues and concerns expressed.

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Sincerely,

Richard P. Bush
Site Manager

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File: TUB 0045.15 (Records)

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