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MEMORANDUM

TO: File PRG 2/2/2012

THROUGH: Phil Goble and John Hultquist JH 2/2/2012

FROM: David Edwards

DATE: January 9, 2012

SUBJECT: Review and Audit of the Rio Algom Mining, LLC (RAML) work plan prepared by Montgomery & Associates (M&A) entitled, "Supplemental Site Assessment to Address Out-of-Compliance Status at Trend Wells RL-1 and EF-8, Lisbon Facility," dated December 13, 2011.

1. Introduction

This is a review by the Utah Division of Radiation Control (DRC) of the Rio Algom Mining, LLC (RAML) work plan prepared by Montgomery & Associates (M&A) entitled, "Supplemental Site Assessment to Address Out-of-Compliance Status at Trend Wells RL-1 and EF-8, Lisbon Facility," dated December 13, 2011. This work plan is required under a proposed License Amendment of the Rio Algom State of Utah Radioactive Material License No. UT19000481 sent out for public comment on December 21, 2011. In the proposed License Amendment, License Condition 56 (Requirement for a Work Plan and Schedule) was added, as follows:

> *The amended License Condition 56 shall require the licensee to submit a work plan and schedule by December 16, 2011 for Executive Secretary review and approval. The purpose of this work plan and schedule is to collect additional field data in the area of the former uranium mill property and provide an analysis of the existing data to be used for subsequent technical evaluation of the Licensee's Application for Alternate Concentration Limits and Long Term Ground Water Monitoring Plan (Approved by the U.S. Nuclear Regulatory Commission May 11, 2004, License No. SUA-1119, Amendment 66).*

The RAML work plan commences with an introduction and summary of site conditions. The summary includes basic descriptions of site geology, hydrogeology, groundwater flow, and uranium concentrations. The work plan then outlines proposed supplemental site assessment tasks. After providing the summary of site conditions, the work plan specifically discusses the following tasks:

- Task 1 – conduct phase 1 groundwater modeling
- Task 2 – prepare final work plan
- Task 3 – conduct field investigations
- Task 4 – evaluate field data
- Task 5 – conduct phase 2 groundwater modeling
- Task 6 – prepare report

The work plan includes seven graphics illustrating descriptions in the text:

- Figure 1 - site overview map
- Figure 2 - uranium concentrations and groundwater levels for trend well RL-1
- Figure 3 - uranium concentrations and groundwater levels for trend well EF-8
- Figure 4 - 2010 groundwater level contours in Burro Canyon Aquifer (map)
- Figure 5 - uranium concentrations and groundwater levels for trend well EF-3a
- Figure 6 - 2011 uranium concentrations (a plan view map)
- Figure 7 – schedule

2. Review of Introductory Materials in the Work Plan

The RAML work plan states that its purpose is to provide a supplemental site assessment to assess out-of-compliance conditions at the RAML Lisbon Facility located near La Sal, Utah. The out-of-compliance conditions involve exceedances of groundwater target action values over two or more consecutive sampling events for uranium in groundwater sampled from two monitoring wells: RL-1 and EF-8, which are defined as a Trend Wells in the License.

The target action level for uranium in Well RL-1 is 42.1 mg/L (RAM License No. UT1900481, Amendment 4, 53.B). The DRC notes that Figure 2 in the work plan shows the highest recent uranium concentration in groundwater at this well is about 47 mg/L, more than 10% higher than the target action level for uranium in groundwater sampled from this well.

The target action level for uranium in Well EF-8 is set much lower: 0.30 mg/L. The DRC notes that Figure 3 in the work plan shows that the highest recent uranium concentration in groundwater at this well is about 0.33 mg/L, again about 10% higher. Figure 3 shows that concentrations of uranium in this particular well have generally been increasing over time since 2007, with a nearly exponential rate of increase. The increase has been from less than 0.03 mg/L in 2007 to over 0.30 mg/L in mid-2010, a change in concentration of about one order of magnitude taking place in four to five years. This change in concentration seems to correlate in general with an approximately concomitant increase in water levels in the well from ~ 6462 ft amsl in 2004 to ~ 6497 ft amsl in the mid-2010.

The source of uranium in groundwater is believed to be infiltration and percolation of water from tailings impoundments used to dispose of tailings during uranium milling operations at the site from 1972 to 1989. The impoundments are said to have been covered by relatively impermeable soils in the mid 2000s.

Practices for monitoring of groundwater at the site are discussed in the Long Term Groundwater Monitor Plan (Komex, 2004), prepared in connection with and subsequent to a 2001 Application for Alternate Concentration Limits (ACLs) as well as in connection with and subsequent to documents presenting DRC responses for requests for further information (Lewis Water Consultants, 2001; Komex, 2003).

Regulatory requirements for groundwater monitoring at the site are discussed in Utah Radioactive Material License No. UT19000481. The License includes concentration limits based on prior approvals of an Application for Alternate Concentration Limits (ACLs) by the U.S. Nuclear Regulatory Commission (NRC). These are described in the May 11, 2004 License Amendment 66 (Source Materials License SUA-1119). The state of Utah obtained primacy from the NRC to administer the Uranium Mill program in Utah in August 2004, and, as part of this transfer of authority, the DRC included the conditions previously approved by the NRC in the License. Based on DRC concerns regarding the ACL concentrations, the groundwater monitoring compliance requirements and limits were subsequently revised and included in an amendment of the License on March 6, 2006 (Amendment 2). All changes to the concentration limits were based on ground water concentration breakthrough curves generated in a groundwater transport model and included in the Long-Term Groundwater Monitoring Plan.

DRC essentially changed the concentration limits from concentrations predicted by *maximum breakthrough concentration curves*, to concentrations predicted by *best estimate breakthrough curves*. This resulted in significantly lower concentration limits in the License for all monitoring wells, as well as specifying concentration limits for three monitoring well classes (background, compliance and trend).

While molybdenum, selenium, and arsenic in groundwater are monitored at the site Compliance Wells (EF-3A and OW-UT-9), the dominant constituent of concern (COC) in groundwater is uranium, which is the only parameter required to be monitored at the Trend Wells. The RAML work plan focuses primarily on this constituent.

The RAML work plan provides a brief summary of recent regulatory concerns at the site. Per a February 7, 2011 DRC Confirmatory Action Letter, the DRC and RAML agreed that RAML would hire and work with an independent consultant in addressing out-of-compliance conditions at monitoring well RL-1. The DRC required a review of existing pertinent documents and updated groundwater modeling, as needed. Also requested was submission of an Action Plan for review and approval addressing the following performance objectives:

- Provide information that permits assessment of whether the current RL-1 data set is sufficient to depict the uranium concentration trend
- Provide evidence as to whether the Lisbon Valley Facility is operating within or outside of the analyzed condition of the Nuclear Regulatory Commission (NRC) approved "Application for Alternate Concentration Limits" (Approved May 11, 2004), and the Long Term Groundwater Monitor Plan
- Evaluate whether the model used in developing ACLs should be revised to account for more recent data

On June 1, 2011, RAML submitted an Action Plan prepared by Montgomery & Associates (M&A, 2011a) to the DRC. Based on the Action Plan, which was approved by the DRC Executive Secretary on June 23, 2011, M&A assessed hydrogeologic conditions, groundwater quality, and the ACL groundwater model for the site. M&A submitted a memo to the DRC on August 10, 2011 describing this work. The concept of conducting additional investigations before attempting to address the performance objectives was proposed in the memo. This memo was followed up by a meeting between RAML, M&A and the DRC, which focused on investigations and assessment of compliance conditions and plans for a supplementary site assessment to be submitted to the DRC prior to December 16, 2011. The work plan entitled "Supplemental Site Assessment to Address Out-of-Compliance Status at Trend Wells RL-1 and EF-8, Lisbon Facility," and dated December 13, 2011, was recently received by the DRC. This document contains the review.

As stated in the License, when an exceedance has taken place, the licensee is required to do the following:

> Prepare and submit within 30 days of discovery a plan and schedule to evaluate and assess the source of the exceedence and possible actions needed to restore and maintain compliance with License Condition 53.B. Such actions may include, but are not limited to:
>
> a. Re-evaluation of the ground water flow and contaminant transport models used to set the compliance limits and target action levels;
> b. Additional site investigation and characterization, and investigation of potential contamination sources; and
> c. Active ground water remediation as deemed necessary by the Executive Secretary.

It is noted that the plan and schedule must evaluate and assess the source of the exceedence and possible actions required to restore and maintain compliance with License Condition 53.B. The three actions described above, including active ground water remediation as deemed necessary by the Executive Secretary, may be included to fulfill this requirement.

3. Review of Section on Site Conditions

RAML notes that data for the site obtained since 2004 are limited in quantity and in terms of spatial representativeness of the site, but that the data indicate a number of changing site conditions. These changing site conditions include partial recovery of previous groundwater levels in the southwestern part of the site. Because of limitations of available existing groundwater head data, additional head data will need to be gathered from existing and proposed wells before final groundwater modeling can take place. The DRC concurs with this assessment.

4. Review of Sections on Geology, Hydrogeology, Groundwater Flow and Uranium Concentrations

4A. Geology/Hydrogeology. Groundwater is found in the Burro Canyon Formation and in the underlying Brushy Basin Member of the Morrison Formation. The Burro Canyon Formation, which consists primarily of very fine to fine sandstone with interbedded layers of siltstone and mudstone, has fracture porosity as well as primary porosity. The underlying Brushy Basin Member consists primarily of claystone, but also contains layers of fine sandstone and mudstone.

Part of the site overlies the Lisbon Valley Anticline (LVA). The Lisbon Fault (LF) zone also occurs on the western portion of the site. The DRC notes that both the LVA and the LF strike northwest-southeast.

4B. "Dry" and "Wet" Portions of the LVA Crest. The work plan states that the Burro Canyon Formation "is currently unsaturated along the crest of the LVA and beneath most of the upper and lower tailings impoundments." Folding of the Burro Canyon Formation over an anticline parallel to the Lisbon Fault during at least one interval of geologic time resulted in the base of the Burro Canyon Formation currently being elevated too high along the crest of the LVA in some areas to be intersected by the groundwater table.

Field data, however, demonstrate that the statement in the work plan that "that the Burro Canyon Formation "is currently unsaturated along the crest of the LVA" is not justifiable as written. This statement definitely was not valid at various times over the past few decades, and it may not currently be valid along the entire length of the LVA, either.

There is abundant evidence for the historical presence of groundwater in the Burro Canyon Formation at or near the LVA crest. For example, consider the local area near and south of Well RL-1. The cross-section in Figure 4-2 in Komex (2003) shows that, in 1981, groundwater was present in the aquifer at the location of Well DM80-1, which was then located just to the S/SE of the current location of Well RL-1. Figure 2-25R of Komex (2003) shows that, in 1998, this DM80-1 well was completed in a "wet" section of the Burro Canyon Formation, where the lower portion of the formation was saturated, located in a gap between dry portions of the Burro Canyon Formation along the crest of the LVA.

Figure 2-13 of Komex (2003) shows that the elevation of the top of the Brushy Basin Member at this well location is about 6541 ft amsl. The elevation of the top of the groundwater at this well in 2003 is shown in Figure 2-12 of Komex (2003) as having been about 6550 ft amsl. This represents about nine (9) feet of saturated thickness, or nine (9) vertical feet of Burro Canyon Formation containing groundwater, on or near the crest of the LVA. Figure 1-3R, revised in 9/2003, shows that groundwater at this location was sampled. It had a concentration of uranium at the time of mapping between 10 and 30 mg/L, which is relatively high.

Figures 2-20 through 2-25 in Lewis Water Consultants (2001) show sizeable gaps in the so-called dry zone area. These figures indicate that at least the lower portions of the Burro Canyon Formation were fully saturated at various locations along the crest of the LVA in 1989, 1990, and 1998. These spots include saturated areas of the aquifer near Wells DM80-1, LT-10, H14, MW-4, and H43. These areas contained groundwater, and, in some places and times, they appear to been part of larger areas of hydraulic connection between the "north aquifer" and the "south aquifer" (e.g., see Figures 2-20 through 2-26 in Lewis Consultants, 2001).

Such saturated portions of the lowermost Burro Canyon Formation along the crest of the LVA are not shown in the work plan groundwater map. At least one statement in the work plan implies without qualification that no hydraulic connection exists between the North and South Aquifer areas. This implied apparent change from apparent former site conditions is not confirmed by available current data.

Isolated saturated zones along the crest of the LVA may exist today, particularly since water levels have in general tended to increase over the last decade or so. Currently, there is insufficient well coverage to make a determination of whether these wet zones exist.

The DRC recommends that RAML obtain cores from the Burro Canyon Formation and the Brushy Basin Formation at sufficient coverage such that, in conjunction with existing data, the extent of saturation of the lowermost part of the Burro Canyon Formation along the LVA may be characterized. The DRC recommends that RAML complete groundwater wells in areas in which the lowermost part of the Burro Canyon Formation has historically been mapped as having been saturated or in areas that might be saturated today (e.g., near Wells DM80-1 and H-14), assuming that former wells in these areas can no longer be used for groundwater level monitoring. The DRC further recommends that RAML develop East-West cross sections using existing and new borehole and well data and include them in the work plan to justify any modeling assumptions of unsaturated zones across the crest of the LVA. Long term monitoring at the new groundwater well installations could then evaluate the validity of any such modeling assumptions.

4C. Potential for Westward, WSW and WNW Flow and Transport. The fact that some parts of the Burro Canyon Formation along the LVA crest have contained groundwater, with some having been in contact with both the "north aquifer" and the "south aquifer," at least for some times in the past, is critical information. It indicates that, for these times, at some locations, there has been no unsaturated barrier to potential westward groundwater flow and contaminant transport across the LVA crest. Groundwater as depicted in the August 1989-April 1990, August-December 1997, and May 1998, and 2003 maps is shown with diminishing hydraulic head predominantly from east to west in portions of the Burro Canyon Formation containing groundwater at several places along the crest of the LVA. It appears that groundwater movement may have been toward the west in at least some parts of the site during those times.

This raises the potential for not only current groundwater flow but also for current contaminant transport toward the west wherever hydrogeologic conditions might now permit it. For example, just northwest of where high uranium concentrations (> 40 mg/L) currently exist in Well RL-1, there is a part of the Burro Canyon Formation along the LVA crest that, at least in 2003, was saturated. This part of the Burro Canyon Formation along the LVA might also be currently saturated.

Groundwater in these saturated sections, if present, may be flowing W, WSW and/or WNW. The DRC notes that, as shown for 2010 data in Figure 4 of the work plan currently being evaluated in this review, the portions of lines of equal groundwater head located over a space of several thousand feet to the west of Well RL-1 are oriented nearly north-south, about 90 degrees to the orientation of lines of equal groundwater head to the southeast of Well RL-1.

This suggests that groundwater that flows NW in locations to the southeast of Well RL-1 may change direction at some point, possibly flowing through a saturated portion of the aquifer around the tip of an unsaturated portion of the Burro Canyon Formation at the LVA crest. There, the groundwater may start flowing toward the west, WNW or WSW through wet portions of the Burro Canyon Formation.

If this is the case, then it should be a serious concern, as there currently are no active monitoring wells located immediately to the west of Wells RL-1, RL-3 and RL-4. There would currently be no way to map or monitor an advancing plume through this area. Well RL-6 is over 4,500 feet away, and, besides that, it may or may not be in the direct path of the advancing uranium plume.

The DRC therefore requests that RAML drill and complete two wells, one about 500 and one about 3,000 feet west of Well RL-1, and an additional well about 800 feet southwest of Well RL-1 to assess the potential for a westward component of flow in this area.

4D. "North Aquifer" and "South Aquifer" Separate? The work plan states, "This unsaturated zone separates the BCA into two separate aquifer areas: the North Aquifer and the South Aquifer." As discussed above, the "north aquifer" and "south aquifer" in at least some times in the past were not separate, but rather were connected through portions of the Burro Canyon Formation containing groundwater within the LVA crest area. Current conditions relative to the hydraulic connections between the two aquifers are unknown, but it is suspected that the two aquifers are *not* separate in all areas along the LVA crest.

4E. Bounds of the "South Aquifer". The work plan states, "The South Aquifer is bounded on the southwest by the LF and on the northeast by the unsaturated zone of the BCA." As indicated above, what is termed the South Aquifer may *not* be bounded at all points along the northeast by a hydraulic boundary consisting of unsaturated Burro Canyon Formation at the LVA crest. Before being accepted as fact, the concept of a boundary existing between saturated and unsaturated Burro Canyon Formation lying to the northeast of the "South Aquifer" must be proven by field data. As stated above, there have been saturated sections along the crest in the past, and there may very well be saturated sections along the crest of the LVA currently.

There is also interest by the DRC in the statement that the so-called South Aquifer is bounded on the southwest by the LF. As discussed later, contouring of lines of equal head for the Burro Canyon Formation based on industry-accepted principles suggests that contoured lines of equal head in most areas of the site located west of the LVA are for the most part shown oriented with respect to the LF at angles less than 30 degrees. This implies nearly westward, WSW or WNW flow into a zone in or near the major LF zone. But groundwater flowing into such a zone would have to move out to some other location. The question is, where is it moving?

It is presumed that groundwater is flowing into highly fractured rocks in or along the LF. Highly fractured rock materials have been reported locally on site in a zone east of and/or proximate to the LF. Consider, for example, Burro Canyon Formation Wells MW-1 and MW-2, with reported pumping-test based hydraulic conductivity values of 798 and 133 ft/day (Lewis Water Consultants, 2001). These hydraulic conductivity values are extremely high compared to those of relatively unfractured rock on site, or even hydraulic conductivity values of rocks with discrete fractures. Other wells in the vicinity also have relatively high hydraulic conductivity values.

From one or more zones of highly fractured rocks in or along the LF, it is a possibility that groundwater moves horizontally, toward the northwest, nearly parallel to the LF. It is believed that groundwater is not likely to flow the west, into and then out of the LF, since the Chinle Formation located west of the LF and abutting the Burro Canyon Formation is generally recognized as being a very low-permeability barrier to flow, almost an aquiclude.

There is also a possibility that, from the area of the presumed fracture zone, groundwater might flow vertically downwards into lower water-bearing formations. This possibility has not yet been investigated.

Zones of highly-fractured rocks can at some sites create very complex hydrogeologic systems for groundwater and contaminant transport depending on the nature of the rocks. Thus far, there is insufficient field characterization of fracture zones in the Burro Canyon Formation along the LF. There is no way to currently know (and modeling itself cannot determine) whether or not there are one or more highly permeable groundwater conduits for flow and transport along the LF.

The DRC therefore requests that RAML place sufficient monitoring wells in the area to accomplish the following:

(1) determine whether or not one or more laterally extensive high-permeability fault zones exist along the LF, as suggested in at least one localized area by the presence of comparatively high permeability fractured rock zones in the vicinity of Wells EF-3 and other nearby wells
(2) determine whether or not groundwater from the east, ENE or ESE is flowing west, WSW or WNW towards the LF or towards a fractured rock zone nearby
(3) determine whether or not groundwater is flowing to the northwest in a fractured rock zone in or along the LF
(4) determine whether or not groundwater has a vertical component of flow in fractured rock zones in or along the LF
(5) determine whether said groundwater is impacted at a shallow depth in the Burro Canyon Formation, at or near the water table, by uranium or other constituents of concern
(6) determine whether said groundwater is impacted at and near the base of the Burro Canyon Formation by uranium or other constituents of concern

Contoured lines of equal head in a relatively homogeneous, isotropic aquifer should be oriented at or close to 90 degrees to a no-flow boundary (e.g., see, Domenico and Schwartz, 1998.) With a heterogeneous and/or anisotropic formation, the contour orientation could vary somewhat from being orthogonal to a no-flow boundary. If the LF, or a zone nearby, actually serves as a no-flow boundary for the aquifer, then there should be some indication of approximately WSW/ENE trending contours and of flow toward the NW or NNW. Additional wells installed in the area can provide groundwater head data supporting or refuting this assumption.

The question of whether contours proximate to the LF actually do turn to become orthogonal, or nearly orthogonal, to the LF, has not yet been established by field data. If, near the LF, there is no turning of contours to become orthogonal, or nearly orthogonal, then an explanation has to be advanced as to what is happening with the groundwater once it reaches the LF or its vicinity. Currently, there is insufficient well density in and near the fault zone and to the east between the LF and the LVA to determine exact directions of flow in and near the LF. There is no way to tell where site contaminants, if present locally in groundwater, are moving. The DRC expects that these important issues associated with establishing one or more potential conceptual models for the site will be elucidated by RAML and M&A by installing and completing one or more wells in this area at a sufficient spacing and by then using well hydraulic head data to reliably resolve flow directions along the LF.

4F. Hydraulic Conductivity of the Burro Canyon Formation. The work plan states, "Previous reports have identified three populations of horizontal hydraulic conductivity in the BCA: (1) unfractured rock (average conductivity of 0.2 feet per day [ft/d]), (2) fractured rock (average conductivity of 6 ft/d), and (3) extensively fractured rock (south aquifer only; 100 ft/d) (Lewis Water Consultants, 2001)." While it is true that the work plan states this at one point, the numerical groundwater flow model used by Lewis Water Consultants (2001) is said to use horizontal hydraulic conductivities for the Burro Canyon Formation of

K for unfractured rock = 5.4 ft/day
K for discrete fractures = 18 ft/day
K for fractured rock = 398 ft/day

The values used are problematic as described below and should not be used in future modeling. Note, for example, that the K value for unfractured rock used in the model (5.4 ft/day) is about 25 times greater than the geometric mean of field value for unfractured rock of 0.21 ft/day (Lewis Water Consultants, 2001, p. 18, 36). It is not documented why, for the modeling work, Lewis Water Consultants chose a value for horizontal hydraulic conductivity more than an order of magnitude larger than the geometric mean of field values. This is not consistent, and this inconsistency needs to be addressed in future modeling work.

The ratio between the "discrete fracture" and "unfractured rock" hydraulic conductivity values used in the model is 3.33. The ratio for reported actual field measurements is 28.9 (6.07 ft/day divided by 0.21 ft/day). Thus, the ratio used in modeling is more than eight times lower than field values.

North and east of the LVA crest is what has historically been called the "North Aquifer." In the Lewis Water Consultants (2001) document, most of the supposed aquifer material in this area is modeled as "unfractured rock." The very low geometric mean of field hydraulic conductivity values reported for unfractured rock of the Burro Canyon Formation is significant. What it implies is that all significantly rapid flow and transport through the Burro Canyon Formation is through fractures in the rock; assessing the lateral and vertical extent of discretely fractured rock at the site, particularly along the wet/dry boundary of the LVA is important.

Along the eastern edge of the LVA crest, in discretely fractured aquifer material, there is a large uranium plume, with the bulk of it trending NNW to NW as currently mapped (see Figure 6 of the work plan). The high-concentration axis of this plume corresponds with a large, elongate feature denoted as "fracture" on Figure 2-27 in the Lewis Water Consultants (2001) document but otherwise poorly characterized in the report.

This same Figure 2-27 also shows hydraulic conductivity values as measured in the field for various wells, including wells near the plume, and hydraulic conductivity values are also provided in Table 2-1. A well that is in or near the "fracture" area just north of the former Upper

Impoundment is noted as having a hydraulic conductivity of 10.1 ft/day. Table 2-1 and Figure 2-23R of the same report indicate that this is Well OW-UT9. In line with the drawn "fracture" feature, just to the south, are wells EF-16 and EF-17, with hydraulic conductivities of 8.70 and 6.20 ft/day, respectively. Thus, in the somewhat linear zone that corresponds with the high-concentration axis of the uranium plume, there appear to be several wells with hydraulic conductivity on the order of 8.3 ft/day.

RAML and M&A state in the work plan that "additional testing is needed to develop better estimates of the horizontal and vertical hydraulic conductivity for the" Burro Canyon Formation aquifer. The DRC concurs with this assessment. Horizontal hydraulic conductivity values for the Burro Canyon Formation need to be better assessed in a number of places, e.g., in and near wells such as Wells RL-1 and RL-3 in what appears to be the leading edge of the uranium plume. This assessment will be needed to better evaluate changes in flow and transport in this part of the plume area.

4G. Hydraulic Conductivity of the Brushy Basin Member. The work plan states, "A representative horizontal hydraulic conductivity value for the BBA on the order of 0.01 ft/d has been reported (Lewis Water Consultant, 2001)". This is a misleading statement, as written. The statement therefore requires revision.

The Lewis Water Consultants (2001) document actually states on page 19, "Limited information is available concerning the permeability of the Brushy Basin Aquitard. Slug test data from well H-72 yield values ranging from 0.01 to 0.96 ft/day." While the lower end of the range, 0.01 ft/day, is equal to the purportedly representative value quoted above in the RAML and M&A work plan, the actual reported hydraulic conductivity value in the upper range is nearly two orders of magnitude greater than that mentioned in the work plan.

Also, the value of hydraulic conductivity used for Lewis Water Consultants (2001) modeling purposes varies from that quoted in the work plan. It is stated on page 36 in Lewis Water Consultants (2001) that the selected Brushy Basin Member hydraulic conductivity value chosen was 0.2 ft/day, which is an order of magnitude greater than the value reported in the work plan.

It is noted that Lewis Water Consultants (2001) document uses the term "permeability" in describing the aquifer hydraulic quantity measured in feet per day. However, only the term "hydraulic conductivity" should be used in this sense. Hydraulic conductivity is the term currently considered correct when discussing an aquifer hydraulic quantity with units of feet per day or similar units. Permeability has dimensions of length squared, whereas hydraulic conductivity has dimensions of length per unit time.

Of interest, the reported high value for hydraulic conductivity (K) of 0.96 ft/day for the Brushy Basin Aquitard is nearly five times as great as the reported geometric mean hydraulic conductivity of 0.21 ft/day based on field data for unfractured Burro Canyon Formation rock in the "North Aquifer" (Lewis Water Consultants, 2001, p. 18). The modeling done for the 2001 Lewis Water Consultants document utilized a value for horizontal hydraulic conductivity for the Brushy Basin Member of 0.20 ft/day (Lewis Water Consultants, 2001, p. 18). That is nearly equivalent to the 0.21 ft/day value reported from field tests for the geometric mean horizontal hydraulic conductivity value for unfractured rock of the North aquifer.

It is conceivable that groundwater is flowing through the Brushy Basin Member in horizontal or semi-horizontal directions, perhaps in places not yet considered. Indeed, a fractured upper zone of the Brushy Basin Member could be a continuation of the Aquifer. This would have significant implications for transport in the Brushy Basin Member of uranium or other contaminants westward, including that in locations where there appears to be no groundwater in the overlying Burro Canyon Formation. It is likely that the Brushy Basin Member has a significantly lower hydraulic conductivity than that of the Burro Canyon Formation in general, and that less-fractured portions of the Brushy Basin Member act as a lower aquitard, based on literature reports. However, this aquitard is still likely to be saturated in most areas, and it may permit some horizontal or near-horizontal movement of groundwater along with contaminants.

The DRC requests that RAML and its consultants better assess the hydraulic conductivity values of both aquifer and aquitard materials and use an appropriate range of hydraulic conductivity values in their modeling consistent with field values to better limit uncertainty, and provide a sensitivity analysis.

Part of this work should involve further investigation of the horizontal hydraulic conductivity of the upper 30 feet of the Brushy Basin Member in at least three locations: (1) part way between the highly fractured rock zone near Well EF-3 and Well OW-UT-9 in the source area, (2) approximately 500 feet west of Well RL-1 if it turns out that that particular location is dry in the Burro Canyon Formation, and (3) approximately 800 feet southwest of Well RL-1 if it turns out that that particular location is dry in the Burro Canyon Formation.

4H. Horizontal Groundwater Velocity. The work plan states, "Horizontal groundwater velocities may vary from a few feet per year (ft/y) in unfractured rock (primarily North Aquifer) to over 100 ft/y for extensively fractured rock (Lewis Water Consultants, 2001)". Again, although the Lewis Water Consultants (2001) document does indeed provide such information, that information is poorly calculated and does not fully take into account actual data for the Burro Canyon Formation along the uranium plume's high-concentration axis in an apparently elongated zone of "discretely fractured rock" on the east side of the dry zone (which is explicitly *not* considered to be "extensively fractured" by Lewis Water Consultants, 2001).

Since reported hydraulic conductivity values for "discretely fractured rock" in that zone are only about one-tenth of those of the "highly fractured" rock, it would also be assumed, based on the Lewis Water Consultants (2001) statement above, that the groundwater velocity for the "discretely fractured rock" in this area would only be about 10 ft/day, or one-tenth the 100 ft/day value quoted for "extensively fractured rock". Calculations below demonstrate that this estimate would be one to two orders of magnitude too low.

It is not currently known whether groundwater velocity for the fractured rock zone in the Burro Canyon Formation north and east of the LVA can be estimated using an equivalent porous medium model. However, in the absence of additional information, use of such an approach may be an initial step toward understanding flow in this particular area. Groundwater velocity, assuming an equivalent homogeneous porous medium, can be calculated based on a modification of the Darcy equation: $v = -Ki/n_e$. This equation depends on K, hydraulic conductivity, i, hydraulic gradient, and n_e, effective porosity.

Average hydraulic gradient used in the previous groundwater model is given as -0.008 ft/ft (Lewis Water Consultants, 2001). Current values near the fracture may be somewhat greater, closer to -0.01 ft/ft. This can be determined more precisely from an accurate map of recent hydraulic head data. As reported by Lewis Water Consultants (2001), the hydraulic gradient, at one point in time, was once much greater than it appears to be today.

The average hydraulic conductivity in the fractured rock zone is unknown, but it can be assumed for rough calculation purposes to be approximately 8.2 ft/day, the geometric mean of the reported K values for Well OW-UT-9 of 10.1 ft/day, for Well EF-16 of 8.7 ft/day, and for Well EF-17 of 6.2 ft/day. This value is similar to that used previously by Lewis Water Consultants (2001) for "discretely fractured rock" in modeling groundwater at the site, but the model used K values for unfractured rock much greater than that suggested by field values.

Reports by several scientists, including Freethey and Cordy (1991) and Kirby (2008), suggest that the effective porosity for the Burro Canyon Aquifer might vary between 0.02 and 0.22, with an average value around 0.10. Using what appear to be best estimates of representative values in the equation below gives the following estimate of groundwater velocity along the high-concentration uranium plume axis:

$v = -Ki/n_e = -$ [(8.2 ft/day)(-0.01)/(0.10)](365 d/yr) = 299 ft/yr

The significance of this, assuming that aquifer conditions are relatively uniform over the selected transport distance, is that any conservative, or nearly conservative, solute, such as uranium, perhaps, could likely travel relatively rapidly, moving up to nearly 3,000 feet within 10 years, and more than a mile in 20 years. This is consistent with what is observed in the field, based on contaminant concentrations for a variety of species, including uranium. However, this finding is contrary to that which is stated or implied in the work plan, as it represents much faster groundwater flow and contaminant transport than that reported there. Again, the rock aquifer associated with the elongate, high-concentration uranium plume northeast of the LVA is not supposed to be "extensively fractured", but only "discretely fractured".

If there is an "extensively fractured" zone paralleling the LF, or a series of such zones, west of the LVA, then flow velocities there may be even greater than that calculated above. In addition, flow rates in the past may have been much greater due to higher hydraulic gradients associated with leakage from the former Upper Tailings Impoundment and other surface water bodies existing in the past.

Because of the uncertainty about uranium movement in groundwater in the "discretely" fractured-rock zone, it is very important to account in upcoming modeling activities for the possibility of relatively rapid fracture flow and for relatively rapid uranium migration through the Burro Canyon Formation in the high-concentration uranium plume zone. The current presence of rising concentrations of uranium in Well RL-1 signifies a need for improved predictive capability in modeling for the site. How fast groundwater is moving in this area is vitally important in assessing how fast uranium is moving, and how fast uranium is moving in groundwater may be critical in assessing risk to potential receptors downgradient. Once field data are collected and modeling is revamped, then the results can be incorporated in license modifications.

4I. Groundwater Flow Directions. The work plan states, "Figure 4 shows a groundwater contour map inferred from the 2010 groundwater elevation data. The current direction of groundwater flow at the Site is generally from southeast to northwest." The DRC does not necessarily concur with this assessment of the general direction of groundwater flow, at least for a number of areas of the site, particularly several areas where knowledge of approximate flow direction is critical to understanding contaminant transport. To better understand the directions of groundwater flow at the site, it is necessary to re-examine contouring in Figure 4 of the work plan.

Figure 4 is entitled, "2010 Groundwater Level Contours in Burro Canyon Aquifer." The current contouring of groundwater levels as shown in Figure 4 is not performed in accordance with a number of common, industry-accepted principles of contouring and knowledge of hydrogeology. Specifically, five rules or guidelines are not complied with:

(i) Groundwater at the boundary between two contiguous dipping porous media formations must have identical head values in each formation
(ii) A given line of equal head, unless closed, must be continuous across the domain of the saturated mapped region
(iii) Where groundwater moves across a boundary from one formation to another formation of much different permeability, that groundwater must be shown on a plan view map to be refracted in accordance with the tangent law of refraction
(iv) Heads at points located between two different lines of equal head should, unless the data dictate otherwise, have values that progress smoothly from the lower value to the higher value as a function of distance from the lower value
(v) In general, a good practice, unless the data dictate otherwise, is to keep lines of equal head fairly parallel

Each of these five rules or guidelines are violated to some extent in Figure 4. Mistakes made in applying or not applying these rules or guidelines may introduce significant bias into the contouring and create a potentially misleading depiction of the groundwater's potentiometric surface or water table at the site. This leads to errors in interpretation of the direction of site groundwater flow and contaminant transport. The following sections discuss several aspects of site hydrogeology and contouring related to Figure 4 and focusing on the first three rules or guidelines.

4J. Two Contiguous Dipping Formations. The Brushy Basin Member, a recognized aquitard, is contiguous with the stratigraphically younger Burro Canyon Formation, which overlies it. The two formations dip down away from the crest of the LVA, which strikes NW/SE. Thus, a horizontal slice through the two formations would, in plan view, show portions of the formations located side by side. The same would be true when visualizing these formations along the surface of the water table.

The contact between the Brushy Basin Member and the Burro Canyon Formation intersects the water table at many locations along the LVA. Where the water table intersects the contact between these two formations in plan-view, a boundary is noted on maps as existing between the "wet" (saturated) and "dry" (unsaturated) portions of the Burro Canyon Formation along the LVA. This boundary has been identified on maps several times, e.g., as the saturation limit of the Burro

Canyon Formation (e.g., see Figure 2-23R of Lewis Water Consultants, 2001). This saturation limit boundary has been depicted as having changed location over geologic time based on a comparison of groundwater levels and elevations of the top of the Brushy Basin Member.

Closer to the crest of the LVA than this boundary, the stratigraphically higher Burro Canyon Formation is unsaturated where the base of the arching formation rises up over the level of the water table. In the same area, the stratigraphically lower Brushy Basin Member is either fully saturated (at the boundary) or mostly saturated (nearer to the crest). Farther away from the LVA crest, at least part of the lower portion of the Burro Canyon Formation is saturated, and the underlying Brushy Basin Member is fully saturated.

As a recognized aquitard in the literature, the Brushy Basin Member appears to have a geometric average hydraulic conductivity value not nearly as great as that of the Burro Canyon Formation. However, the value of the geometric average hydraulic conductivity of the Brushy Basin Member is currently not known, and it needs to be investigated as part of the work plan.

Nevertheless, the Brushy Basin Member is still expected to have some hydraulic conductivity, and the formation is expected to be saturated when it locally lies at or below the water table.

Portions of formations having significant hydraulic conductivity are typically saturated at or underneath the water table. Slug tests have been conducted in the Brushy Basin Member in the past, so this formation therefore had to be saturated, at least at the time.

It is also important to consider the possibility that, while in general the Brushy Basin Member most likely acts as an aquitard, in some places, its hydraulic conductivity, due to fracturing, may in places approach that of unfractured rock of the Burro Canyon Formation. Moreover, the Brushy Basin Member is expected to contain groundwater at all points below the potentiometric surface, and that groundwater has measurable hydraulic head. Portions of the two formations, when viewed in plan view at the level of the water table, are laterally contiguous, as is the groundwater within the formations at the contact between them.

Currently, the work plan groundwater level map shows lines of equal head terminating at the water-table boundary between these two formations, as if there were no groundwater in the Brushy Basin Member. This is an inappropriate approach, for reasons discussed below.

4K. Continuity of Contours of Head Across Formation Boundaries. As long as groundwater is present on either side of a boundary between two contiguous porous formations, simple physics demands that mapped contours of head for groundwater within one formation do not stop at that boundary. Each point along the boundary is a point that has a given value of hydraulic head that is the same for both formations.

4L. Mapping of Potential Per Unit Weight in Groundwater. Lines of equal head represent fixed values of potential energy per unit weight of water. It is the groundwater that has head, not the formation, and it is therefore the potential energy per unit weight of groundwater that must be mapped on a groundwater level map, not the characteristics of the geology. In other words, where a water table exists, contours do not stop simply because there is a change in geology in plan view, but the geology may have an effect on the contours. The potential energy per unit weight of groundwater mapped on one side of a boundary between formations must match the potential energy per unit weight of contiguous groundwater mapped on the other side of the boundary (see, for example, Bear, 1979, p. 366).

At the site, groundwater at or near the water table in the Burro Canyon Formation is in direct, intimate contact with the groundwater in the Brushy Basin Member on the other side of the dipping contact between the two formations. Both formations have at least some permeability. The groundwater at any point along the contact has essentially the same potential energy per unit weight of water for both formations. Therefore, hydraulic head contours that are mapped at the water table must run continuously through both formations, even where groundwater is located too low to be present in the Burro Canyon Formation.

The groundwater under the "dry" part of the Burro Canyon Formation at or near the LVA crest is still present in the underlying Brushy Basin Member. The groundwater is contiguous with adjacent groundwater in the Burro Canyon Formation immediately outside of the wet/dry boundary. And the groundwater in the Brushy Basin Member has hydraulic head values, and those hydraulic head values need to be mapped along with those for groundwater in the adjacent Burro Canyon Formation. This is currently not done in the work plan.

4M. Internal Termination of Contours on Maps. One of the primary principles of contour mapping is that contour lines cannot terminate internally within the boundaries of the mapped variable space for which data is present. In this case, the variable is hydraulic head, and the contours represent lines of equal head. It is evident on first glance at the map in Figure 4 that at least two of the contours terminate internally, i.e., not on the edge of the map. Stubs of 6500 ft amsl and 6520 ft amsl contours appear in the northern part of the map. These stubs terminate in a southward direction shortly after commencing in the north, and the terminations are marked on the map with question marks.

While the terminated contours may represent some apparent interpreter uncertainty in regard to the presence or absence of a dry zone of the Burro Canyon Formation in the LVA directly to the west and the south, there is no evidence that supports the termination of these contour lines. Groundwater located at the edge of a dry zone in the Burro Canyon Formation near the crest of the LVA does not simply stop there; it is in hydraulic connection with groundwater in the Brushy Basin Member.

4N. Refraction at Formation Boundaries. When groundwater moves northwestwardly from the Burro Canyon Formation into the Brushy Basin Member at the eastern wet/dry boundary near the crest of the LVA, that groundwater must be refracted, or bent, much as light is refracted when moving from air into and out of a prism. Refraction always occurs when groundwater flows from one formation to another formation having a different hydraulic conductivity at any angle of incidence with the normal to a boundary between the two formations other than zero. The angle of refraction is a function of the angle of incidence and the ratio of hydraulic conductivities of the formations involved. The law describing this is often called, appropriately enough, the Tangent Law of Refraction.

The Tangent Law of Refraction is formulated as follows. Assume that groundwater flowing from Formation 1 of hydraulic conductivity (K_1) impinges on a boundary with Formation 2 of hydraulic conductivity (K_2) at a point of contact C. The incident angle with respect to a normal at C (called α_1) is related to the angle of refraction with respect to a normal at C (called $\alpha2$) in Formation 2 as shown below (see Bear, 1979):

$$[\tan(\alpha_1)]/[\tan(\alpha_2)] = K_1/K_2$$

The angle of refraction can thus be calculated as

$$\alpha_2 = \tan^{-1}\{[\tan(\alpha_1)]K_2/K_1\}$$

Thus, in the case of the Lisbon Valley site, if groundwater moving along the high-concentration plume axis from the Burro Canyon Formation has a streamline that intersects the wet/dry boundary with the Brushy Basin Member at, say, three degrees, then the angle of that streamline with respect to the normal will be 87°, and, if there is a ratio of K_2/K_1 of, say, 0.02, then that streamline will change direction within the Brushy Basin Member to 20° with respect to the normal. In other words, it will be refracted in a direction of 70° with respect to the boundary. It is evident when looking at a properly contoured groundwater level map of the site that, based on lines of equal head that pass through the Brushy Basin Member, something similar to this is happening.

The current contoured groundwater map work plan does not show lines of equal head passing through the Brushy Basin Member, and it does not show refraction when groundwater passes from the Burro Canyon Formation into the Brushy Basin Member or vice-versa.

4O. Accounting for Refraction on Groundwater Level Map Needed. With these concepts in mind, it is apparent upon observation that there are not only two, but nine, incorrectly terminated contour line segments on the map. Each of the other seven stubs abuts the apparent wet/dry contact. None of these contour segments should be terminated. All should continue past the wet-dry boundary into or out of the Brushy Basin Member, and the contours all need to be adjusted to indicate appropriate refraction of groundwater streamlines.

Where groundwater enters highly obliquely into the Brushy Basin Member east of the eastern "dry zone" boundary, refraction is extreme, appearing on an appropriately contoured groundwater level map to change to an orientation on the order of 60-85° with respect to the boundary. Where groundwater exits the Brushy Basin Member and moves into the Burro Canyon Member west of the western "dry zone" boundary, north of Well EF-3a, the direction of streamlines is nearly orthogonal to the boundary, and relatively little refraction takes place. Where groundwater exits the Brushy Basin Member and moves into the Burro Canyon Member south of the western "dry zone" boundary, and east of Well EF-3a, the directions of streamlines vary, as the wet-dry boundary changes orientation in this area. Refraction varies from a little to a comparatively high amount, depending on the angle of incidence with the boundary.

4P. Extension of Terminated Contours Needed. By way of example, the 6540 ft amsl contour stub shown on the map on the north and east of the crest of the LVA is located very close to Well RL-1, which has a reported groundwater level in the Burro Canyon Formation of 6536.18 ft amsl. Moving slightly south from the well, the 6540 ft amsl contour hits the relatively nearby eastern saturation limit or wet/dry boundary, where the water table meets the contact between the dipping

Burro Canyon Formation and parallel dipping Brushy Basin Member. This represents a point where a streamline of groundwater entering into the Brushy Basin Member from the Burro Canyon Formation at that contact is refracted approximately 60-80 degrees. Refraction of the groundwater streamline is to the WSW. The 6540 ft amsl head contour is correspondingly re-angled at that point. It is re-angled SSE, and it continues throughout the Burro Canyon Formation until it exits it at the dry zone boundary to join the 6540 ft amsl contour for groundwater in the Burro Canyon Formation existing south of the dry zone. That 6540 ft amsl contour lies between Well EF-3a (at 6495.00 ft amsl) and Well MW-13 (6548 ft amsl), but it is closer to Well MW-13, and it is oriented at the boundary, because of refraction, nearly due south.

The 6520 ft amsl contour stub is shown on the map on the north near Well RL-4. It needs to be extended and to run SSE through the zone west of Well RL-1, which may or may not be wet, and then continue into the Brushy Basin Member (indicated as the dry zone on Figures 1 and 4 of the work plan). It exits the Brushy Basin Member on the south and joins the rest of the 6520 amsl contour, which exists between Well EF-3a (at 6495.00 ft amsl) and Well MW-13 (6548 ft amsl), but is somewhat closer to Well EF-3a, and it is oriented at the boundary, because of refraction, SSW.

The 6500 ft amsl contour stub shown on the map on the north needs to be extended to run semi-parallel to the 6520 ft amsl contour and to run continuously from the northwest to the southwest, past Well ML-1, which has a groundwater level of 6484 ft amsl, past Well EF-6, which has a groundwater level of 6492.5 ft amsl, past Well EF-8, which has a groundwater level of 6494.86, and past Well EF-3a, which has a groundwater level of 6495.09 ft amsl, and on toward the southwest, where it may intersect a presumably high-permeability fractured rock zone near the LF. It is apparent that groundwater in each of these wells just listed has a hydraulic head value that is relatively close to 6500 ft amsl. The 6500 ft amsl contour should therefore run near them. This is not done in the current work plan map of groundwater levels.

The triangle formed in the NE part of the map by the three wells Well RL-6 (with a groundwater level of 6444.78 ft amsl), Well RL-4 (with a groundwater level of 6524.23 ft amsl) and Well RL-3 (with a groundwater level of 6484.09 ft amsl) to the northwest on the map indicates that there have to be

- four contours, 6460 ft amsl, 6480 ft amsl, 6500 ft amsl, and 6520 ft amsl, located between Wells RL-6 and RL-4
- two contours, 6460 ft amsl and 6480 ft amsl, located between Wells RL-6 and ML-1
- two contours, 6500 ft amsl and 6520 ft amsl, located between Wells ML-1 and RL-4

This in turn requires that each of these contours is oriented nearly N/S to NW/SE. The 6500 ft amsl contour that runs SE to the east of Well ML-1 must continue to the east of Well EF-6, located just to the SE of Well ML-1, and with a hydraulic head value even closer to that of the 6500 ft amsl contour. Again, the running of these contours to the southeast is not done on the current work plan groundwater level map.

4Q. Other Contouring Issues. Because, as mentioned above, the four contours up toward the northwest part of the map, along with two adjacent contours, are basically oriented N/S or NW/SE, and because hydraulic head values decrease toward the west, this means that groundwater will tend to flow somewhat toward the west or WSW in this area. It will continue to flow in that direction either until meeting a highly fractured zone, which may allow flow to change direction to the NW, or until meeting the LF. However, the groundwater has to go somewhere after that, and the only reasonable directions at that point would either be toward the NE or downward, since the Chinle Formation to the southwest is considered very tight.

Farther southeast, and across the dry crest of the Burro Canyon Formation in the LVA, is another area with three wells that illustrate a drop in head, but this time to the West/Southwest. These three wells are Well OW-UT-9 (with a groundwater level of 6580.07 ft amsl), which has to be nearly coincident with the 6580 ft amsl contour, Well H-63 (with a groundwater level of 6552.77 ft amsl), which needs to be shown between the 6560 ft amsl contour and the 6540 ft amsl contour, and Well MW-13 (with a groundwater level of 6548 ft amsl), which also needs to be shown between the 6560 ft amsl contour and the 6540 ft amsl contour.

Flow near the LF is currently uncharacterized by field data. More wells need to be drilled and completed in this area to obtain groundwater data to determine flow directions. Contouring of lines of equal head for the Burro Canyon Formation based on industry-accepted principles suggests that contours in areas of the site located just west of the LVA and somewhat east of the LF are generally oriented with respect to the LF at angles ranging from only 5 to 30 degrees. This implies flow toward the LF. The actual flow could be moving into the fault zone itself, into a highly fractured rock zone running parallel and fairly close to the fault zone to the NE, or downward through fractures to a deeper water-bearing stratum.

Putting all of this together and making sense of it will require RAML and M&A to acquire more data in the field and to re-contour the work plan figure to more accurately illustrate site groundwater levels and show contours of equal head. When properly mapped, this figure will show groundwater flow at many site locations west of the LVA having a very strong W or even WSW component, contrary to the implication of the work plan's depiction of general flow direction toward the northwest. There is no question that flow in some specific areas is toward the northwest. Flow just east of the eastern dry-zone boundary where the extensive NW tending high-concentration uranium plume exists is, for example, toward the NW, and it is likely that flow in a narrow zone close to the LF is toward the NW, as well. But in many areas, flow is toward the W or WNW or in other directions.

4R. Flow and Transport from Well OW-UT-9 to Well RL-1 and Elsewhere. It is expected that groundwater represented in the SE part of the map near OW-UT-9 and along some parts of the dry zone of the LVA, near its eastern boundary, cannot easily flow directly toward the west, WNW or WSW, because, to do so, the groundwater would have to move through the Brushy Basin Member, which presumably has a much lower permeability than the aquifer. Much of the groundwater in this local area therefore flows NW, up to a point near Well RL-1. Groundwater sampled from the well is currently heavily contaminated with uranium.

It is possible that this groundwater then continues to flow until conditions are such that the plunging LVA lowers the bottom of the Burro Canyon Formation along the crest of the anticline to an elevation below the water table. This would allow groundwater in the local area there to flow in a direction WSW, west or WNW in response to the apparent hydraulic gradient. Local anisotropy of rock may also have an influence on the flow direction. Since the areas just to the west, southwest and northwest of Well RL-1 are currently devoid of or nearly devoid of active monitoring wells, it is not possible yet to determine precisely the local hydraulic gradient or tell how much of the uranium plume has moved in that direction.

The DRC requests that RAML install several monitoring wells in an appropriate coverage pattern west and southwest of Well RL-1 (e.g., one well ~500 feet west, and the other ~1000 SW). Doing so may accomplish several purposes. First, it will allow for better assessment of the local groundwater head distribution west and southwest of where coverage now exists near Wells RL-1 and RL-3, now that recovery from groundwater pumping seems to have largely taken place. Second, it will enable better determination of where the eastern and western boundaries of the "dry zone" are located, if that zone is indeed present in the area. Third, it will help evaluate if the tip of the high-concentration uranium contaminant plume (the one that currently is identified farther to the SE along the eastern wet/dry boundary) has made a turn toward the west, WSW or WNW somewhere in the vicinity of RL-1 and RL-3. Such a turn toward the west, WSW or WNW seems highly possible since the lines of equal head seem to change direction in this area, indicating a change of groundwater flow from a northwesterly advancing direction to a westerly, WSW or WNW advancing direction.

4S. Further Groundwater Level Information in and near the LVA. The work plan states, "Due to the limited number of monitor wells remaining at the Site after 2004, the state of water level recovery in the North Aquifer between OW-UT-9 and RL-1 is unknown, thus the current local direction and rate of horizontal and vertical groundwater flow in this area are unknown. Additional monitor wells and testing are needed in this area to resolve these uncertainties." The DRC generally concurs with this statement.

In addition to installation of one or more additional monitoring wells in the Burro Canyon Formation in this area, it is also advised that RAML and M&A install and screen one or more monitoring wells in the Brushy Basin Member NE of Well EF-3a. This would appear to be under the dry zone of the Burro Canyon Formation near the crest of the LVA, and it would facilitate assessing hydraulic head in the aquifer/aquitard system and better establishing contours of equal head in this area. While the presumably lower hydraulic conductivity of the Brushy Basin Member might require more time for the groundwater in the well to achieve a static water level after purging than for that of a well installed in the Burro Canyon Formation, the additional groundwater level data in this area would permit better assessment of groundwater flow through the Brushy Basin Member under the dry Burro Canyon Formation zone. Locating a well in this area and sampling groundwater from it would also help evaluate whether contamination in the area of Well EF-3a has moved directly from high-concentration area near Well OW-UT-9 in response to apparent hydraulic gradient with groundwater flow within the Brushy Basin Member trending toward the SW in this area. Also, with a well present in this location, hydraulic testing can be conducted to better assess potential for flow and transport in the Brushy Basin Member.

4T. Further Groundwater Level Information Needed near Highly-Fractured Zone. A highly fractured zone exists in the vicinity of Wells EF-3a and EF-8 west of the dry zone of the Burro Canyon Formation associated with the LVA (Lewis Water Consultants, 2001). The work plan states that "groundwater levels in South Aquifer wells EF-3A and EF-8 are still recovering from CAP pumping . . . Additional characterization and data analysis may be required to further evaluate the cause of the slow groundwater recovery. Based on the available information and data, it is unclear whether groundwater occurs under confined or unconfined conditions in the area near these wells. In addition, the effect of fractures in the South Aquifer on groundwater conditions is not fully understood. Additional monitor wells are needed in the South Aquifer to address this uncertainty."

The DRC concurs with a need for conducting further investigations in this area, but primarily for other reasons. It is stated in the work plan, Wells "EF-3A and EF-8 are screened immediately above the contact between the BCA and BBA. Current groundwater levels in these wells are approximately 35 to 87 feet above the tops of the well screens. Rationale for the design of these wells is not available."

There is an arithmetic error in the above statement. The lower number in the range of heights above well screens given above is not correct. While the number given for Well EF-3a is correct, the distance between top of screen for Well EF-8 and the groundwater level is incorrect. This distance should actually be 133.88 feet (i.e., the potentiometric level of 6494.86 ft amsl minus the top of screen elevation of 6360.98 ft amsl).

There is thus a large fraction of the saturated thickness of the aquifer unavailable at this location for low-flow sampling from either well (assuming unconfined conditions). It is doubtful that representative samples from the entire saturated thickness could be obtained from either well using any method. Sampled groundwater from each well sampled by low-flow sampling cannot be assumed with high confidence to be representative of aquifer conditions, since most of the groundwater coming into the well is coming in from that part of the aquifer corresponding to the elevation range of the screened interval of the well. There is much groundwater above the screened interval which is largely unavailable for sampling by low-flow sampling and possibly by other commonly used techniques.

4U. Need for Sampling from at Least Two Depth Intervals. Groundwater near the screen of EF-3a is highly contaminated with uranium (with levels at over 20 mg/L over the last several years). Because the groundwater water table level near this well is 87 ft higher than the top of the screen, where low-flow sampling currently takes place, a substantial portion of the potentially contaminated groundwater column (if unconfined conditions do indeed exist here) cannot be sampled using current approaches. This is unacceptable in an area where substantial contamination exists in the screened zone at the base of the Burro Canyon Formation, and where the extent and magnitude of contamination at higher levels in the formation are unknown.

Therefore, the DRC requires that an additional well (EF-3b) be drilled very close to current Well EF-3a and be screened approximately 60-80 feet higher in the aquifer than the current Well EF-3a is screened. This will accomplish two purposes. First, it will allow for calculation of the vertical component of hydraulic gradient in this area, which is essential to know in order to assess local groundwater flow and contaminant transport directions. Second, it will allow for evaluation of groundwater contamination in the upper portions of the aquifer, as this cannot currently be done. Third, it will allow for hydraulic testing of the upper part of the Burro Canyon Formation in this area.

Any attempts to purge and sample groundwater from a single well whose screen is located near the base of the saturated thickness of the Burro Canyon Formation in an effort to try to sample the entire groundwater column is not acceptable. This is because, due to the mixing accompanying purging, it would not be possible then to determine with any confidence even the gross levels above the screen where groundwater contamination might exist.

4V. Low-Flow Sampling Not Appropriate for Some Wells on Site. While low-flow sampling conducted under appropriate conditions can in general significantly diminish the time and effort of sampling, the use of low-flow sampling, with respect to Wells EF-3a and EF-8, is inappropriate. This is because there exists for each well a significant column of groundwater above the reach of the sampling capability of low-flow sampling equipment. The groundwater level in Well EF-8 is 134 feet above the top of the screen. The groundwater level in Well EF-3a is 87 feet above the top of the screen. Most of the groundwater above the screens is inaccessible to low-flow sampling due to the nature of the sampling equipment and potential well response.

Even when a shallower well is installed nearby, the vertical range over which sampling needs to occur may require a sampling technique other than low-flow sampling.

The DRC therefore requests that wells in this particular area be sampled from now on using standard methods of purging of three (3) well casing volumes followed by sampling using a sampling pump. This approach will be needed in order to obtain a more nearly representative sample of groundwater from areas outside of but reasonably close to the screened interval.

Similarly, for all other wells on site for which groundwater levels are higher than 10 feet above the screened interval, low-flow sampling should not be used, but rather conventional methods (purging of three (3) well casing volumes) that pull groundwater into a well from over a significantly larger interval than the screen interval.

4W. Assessment of Vertical Components of Hydraulic Gradient Needed. Throughout the site, there currently are no data for vertical components of hydraulic gradient. Having such data is important for understanding three-dimensional flow. It is possible that flow through the Burro Canyon Formation is almost entirely horizontal, but it is also possible that there may be either local or regional components of flow in the vertical direction. This could arise from a number of different hydrogeologic situations. These might include the following:

(1) some component of flow downwards into a more permeable zone within the Burro Canyon Formation
(2) some component of flow upwards into a more permeable zone within the Burro Canyon Formation
(3) some component of flow downwards into the Brushy Canyon Member
(4) some component of flow upwards from the Brushy Canyon Member
(5) some component of vertical flow along a sloping water table within the Burro Canyon Formation

Assessing the potential for vertical flow requires assessing local vertical components of hydraulic gradient in the field, with head measurements being made at the same x and y points, but at different z points.

Changes in head as a function of depth can be measured to establish vertical components of hydraulic gradient either in the same hydrostratigraphic unit, such as an aquifer (e.g., see Price, 2004), or across a low-permeability confining layer. Assessing head in this way requires measurement of head in two wells or piezometers installed side by side, but screens at different depths. It is preferable for the depths to be as different as possible when testing occurs within a single hydrostratigraphic unit. The change in head divided by the difference in water-entry elevations gives the vertical component of the hydraulic gradient. Generally, the mid-point of saturated screen is considered a depth point in the case of wells.

Drilling and completion of Well EF-3B will allow RAML, and M & A to use groundwater level data from both that well and Well EF-3A to assess vertical component of hydraulic gradient in that area. For shallow aquifer water quality assessment, installation of Well EF-3B, to be screened at or near the water table, is already requested. Another location where the vertical component of hydraulic gradient needs to be evaluated is in the zone of highly fractured rock located in or near the LF in the northwest part of the site.

It is noted that this evaluation of the vertical component of hydraulic *gradient* is in addition to assessment of the vertical component of hydraulic *conductivity* which RAML has already committed to in the work plan.

4X. Flow near Northwestern Tip of Uranium Plume near LVA. The work plan on page 8 states, "Lisbon Valley Anticline – because of uncertainties in the nature of the LVA northwest of the Site, groundwater flow directions near the northwestern extent of the LVA (near the Long-Term Surveillance and Monitoring [LTSM] boundary) are also uncertain (Figure 4). Groundwater flow in this area could continue to the northwest or change to a more westerly direction. Additional monitor wells and testing in this area is needed to resolve this uncertainty. This area is especially important for projecting the near-term impact of uranium in groundwater at the Site."

The DRC emphatically concurs with this assessment. As previously stated, a number of new monitoring wells need to be installed in this area.

4Y. Tailings Source Area. Again, on page 8, the work plan states, "The shape and extent of the unsaturated zone in the BCA near the tailings impoundments has changed over the years due to changes in the tailings seepage rate and groundwater pumping during the CAP. The historic and current groundwater flow regime beneath the tailings in the BCA and BBA are not well understood. Additional characterization may be needed near the tailings to improve understanding of the groundwater flow regime in this area, which is important characterizing the tailing source area for modeling."

The DRC agrees that work to characterize the unsaturated zone near the tailings source area would be beneficial in understanding source-area contaminant behavior. However, there is no discussion in the work plan about how this would be accomplished in practice. Please elaborate, providing details.

4Z. Uranium Concentrations. In Section 2.4 of the work plan, entitled Uranium Concentrations, it says, "A map depicting 2011 uranium concentration contours is presented on Figure 6. The concentration contours are dashed to indicate areas of uncertainty. The contours represent our current understanding of the uranium plume in the BCA. However, historic data from abandoned monitor wells indicate that uranium concentrations in both the North and South Aquifers were higher than current concentrations and reached 180 milligrams per liter near the tailings. Therefore, it is likely that higher uranium concentration still exist in parts of BCA."

The DRC concurs that past uranium concentrations in sampled groundwater were much higher than those reported for recent samples. However, this does not necessarily mean that such high concentrations still exist today. Rather than stating "it is likely that higher uranium concentrations still exist in parts of BCA", the DRC would prefer a statement simply indicating the potential, or the possibility, for uranium concentrations to still exist at higher concentrations than those currently measured in groundwater sampled from existing monitoring wells.

The work plan states, "fluctuations in groundwater levels may have left residual uranium in the unsaturated zone beneath and near the tailings impoundments." The DRC concurs with this statement. For this reason, the DRC also requests that RAML investigate the unsaturated zone and upper portions of the saturated zone in this area and also map uranium concentrations in groundwater at the level of the water table. Investigation of the unsaturated zone in this area should include assessment of sorbed uranium in rock samples and dissolved uranium in soil moisture.

5. Review of Supplemental Site Assessment Tasks

5A. Probabilistic Modeling. The work plan says on page 11, "3.1.1 Task 1 – Conduct Phase 1 Groundwater Modeling. Important uncertainties still exist at the Site that limit our ability to adequately model uranium fate and transport at the Site. Some of these uncertainties relate to the sparse nature of data available over the last 7 years, while other uncertainties relate to insufficient understanding of contaminant sources and hydrogeologic structures, properties, and conditions. Given this uncertainty, a single deterministic model of the Site is unlikely to accurately represent the groundwater system and result in robust projections of future system behavior. For this reason, we recommend using probabilistic modeling methods that considers numerous possible models and will result in a robust projection of future system behavior. The results of the Phase 1 modeling will be used to formalize the final field program."

The DRC concurs that important uncertainties still exist at the site, and a major challenge will be the development of a more meaningful and reliable model. Given the existing uncertainties, a single deterministic model of the site is unlikely to accurately represent the groundwater system and result in robust projections of future system behavior. A number of these uncertainties are already discussed in this DRC response to the RAML work plan. Other uncertainties may be conceptualized and discovered during the course of the flexible framework proposed for the pre-field-work probabilistic modeling, which will help organize and systematize sporadic data and provide a platform for more logical hypothesis testing.

Several critiques of the model presented by Lewis Water Consultants (2001) are presented in this DRC response. New, probabilistic models may collectively provide insights leading to introduction of other improvements over the former model as well. However, it is important to point out that the new, probabilistic models can only introduce improvements if ideas worthy of testing are first conceptualized by the modeler and included within model runs by way of appropriately inputted model parameter values. One purpose of this DRC response is to discuss proposed changes in modeling that should be evaluated in the new probabilistic models.

5B. Time Interval for Modeling. Please explain and justify the choice of the time interval for modeling. On page 11, it says, "Groundwater flow and transport will be simulated for the period between 2004-2212." Why this particular period of 208 years? Why are pre-pumping and pumping-period data prior to 2004 being excluded? Would not their inclusion potentially enhance the validation of the modeling results? These data are the only examples of field data obtained to date directly illustrating the effects of pumping stress on the groundwater system.

5C. Number of Modeling Runs. On page 12, it says, "As many as 5,000 model simulations may be conducted during the Phase 1 modeling." In the phone conversation held between RAML, M&A, and the DRC on January 5, 2012, Phase 1 modeling was said to include over 10,000 model simulations. Please clarify.

5D. Outcomes of Concern. The work plan on page 13 states, "Similar to the likelihood weighting, models that are 'important' are simulations that results in an outcome of concern. If a model results in an outcome of concern, it will have a high importance weight; however, if a model indicates that an outcome of concern is not likely, it will have a low importance weight."

The DRC has its concerns about the meaning of the term "outcome of concern" and, in particular, how these outcomes of concern are determined. Obviously, one outcome of concern that would be of interest to the DRC would be an exceedance of groundwater quality criteria in sampled groundwater. However, there may be many other outcomes of concern that might not be as readily identified. For example, one possible outcome of concern to the DRC would be evidence of the likelihood that groundwater may be flowing in a different direction locally than previously supposed. While this might not necessarily result in an exceedance of groundwater quality criteria in sampled groundwater from pre-identified monitoring wells, it could be very important in determining where additional monitoring wells in the field would need to be placed in the future. So, again, how will outcomes of concern be identified?

5E. Final Work Plan. The work plan states "M&A will prepare a final work plan to address UDRC comments on the initial work plan, summarize the Phase 1 modeling results, and present the final field program. The work plan will include a map showing proposed monitor well locations where additional groundwater level, uranium concentration, and aquifer property data will be obtained. In addition, M&A will provide specifications for well drilling, construction, development, and testing. The final work plan will be submitted to UDRC in by the end of March 2012. At that time, a meeting with UDRC will be requested to review the final work plan and expedite UDRC final approval."

The DRC approves of the concept of M&A preparing and providing to DRC a copy of a final work plan that addresses DRC comments. It is important to emphasize that DRC comments must be addressed in a way satisfactory to the DRC such that the work plan accomplishes objectives meeting goals outlined in State Rules.

The DRC is also in favor of having periodic review meetings with RAML and M&A to work together to develop a final work plan satisfactory to all parties.

5F. Key Uncertainties. The D&C concurs that some of the key uncertainties at the site that need to be tested in the field program include the following discussed in the work plan:

- Hydraulic conductivity of the BCA and BBA
- Initial distribution of uranium mass within the BCA
- Characteristics of tailings source area
- Nature of groundwater boundaries at the Site
- Nature and extent of the LVA

To these uncertainties, the DRC would add

- Boundaries of wet (saturated at and near the base) and dry portions of the Burro Canyon Formation located in or near the crest of the LVA
- Places of hydraulic connection between the so-called "North Aquifer" and "South Aquifer"
- Groundwater flow directions for all areas of the site potentially contaminated
- Nature, extent and magnitude of uranium distributed in groundwater in areas near the currently identified NW tip of the NW-trending uranium plume along the eastern flank of the LVA; this would include areas west and south of Wells RL-1 and RL-3
- Nature, extent and magnitude of uranium distributed in shallow (water-table depth) groundwater in the Burro Canyon Formation in the vicinity of Wells EF-3a and EF-8, where only deeper groundwater in the formation appears to have been sampled and analyzed in recent years
- Nature, extent and magnitude of uranium distributed in both shallower and deeper groundwater of the Burro Canyon Formation in areas located to the west, WSW and WNW of Wells EF-3a and EF-8
- Nature, extent and magnitude of uranium distributed in the vadose zone located in the vicinity of disposed tailings in the former upper and lower impoundments and surrounding areas
- Nature, extent and magnitude of uranium distributed in shallow and deeper groundwater located in or near fault zones located parallel to the LF
- Potential for westward, WSW and/or WNW flow and transport in various areas of the site, particularly between the LVA and the LF
- Location and characteristics of subsidiary faulting in one or more fault zones located proximate to and/or east of the identified primary LF
- Vertical components of hydraulic gradient in the Burro Canyon Formation at several representative locations across the site
- Vertical components of hydraulic gradient in the Brushy Basin Member (if vertical components of hydraulic gradient are found to be significant in the Burro Canyon Formation)

• Distribution of head, leading to accurate maps of lines of equal head, for all groundwater present at the site, including that in saturated porous media of either the Burro Canyon Formation or the Brushy Basin Member, as well as determination of appropriate refraction at hydrostratigraphic boundaries

• Hydraulic head as well as groundwater quality at and near the water table in the Burro Canyon Formation as determined through installation and monitoring of one or more shallow monitoring wells close to Well EF-3a

5G. Geophysical Survey. It is understood by the DRC that some preliminary resistivity surveying (three transects) will be conducted by subcontractors to M&A prior to other work being done in the field. This method is relatively inexpensive, nondestructive, and non-intrusive, but it may allow the determination of some hydraulic conditions and properties. The preliminary surveying will attempt to delineate boundaries and depths of water tables located in both the Burro Canyon Formation and the Brushy Basin Member in and near the LVA and in and near the LF. The work plan states, "Results will be used to determine the present extent of the unsaturated portion of the BCA." However, although this method promises a significant benefit to the investigation, determining parameters and conditions using relatively little, somewhat noisy information symbolizing boundaries clearly represents a tough task/challenge. The DRC does not have a problem with the undertaking of this work. In our experience, this approach may or may not work. It is understood that if the data prove to be useful in identifying water tables, then additional resistivity survey work will be done to help characterize the wet and dry portions of the Burro Canyon Formation at and near the crest of the LVA more fully.

5H. Monitor Well Construction. The work plan states, "Monitoring Well Construction – Results of the Phase 1 modeling, combined with the results of the geophysical surveys, will be used to select the number and locations of new monitor wells. Based on current understanding of site conditions, the SSA would likely include a minimum of 4 to 7 new monitor wells."

RAML needs to also include requirements on monitoring wells construction, as follows:

All newly monitoring wells must be designed and constructed in compliance with UAC R317-6-6.3(I)(6), including the EPA RCRA Ground Water Monitoring Technical Enforcement Guidance Document, 1986, OSWER-9950.1.

As-built reports for new groundwater monitoring wells should be submitted for Executive Secretary approval within 60 calendar days of well completion, and at a minimum will include the following information:

- Geologic Logs – these must detail all soil and rock lithologies and physical properties of all subsurface materials encountered during drilling. Said logs shall be prepared by a Professional Geologist licensed by the State of Utah, or otherwise approved beforehand by the Executive Secretary.

- Well Completion Diagrams – these must detail all physical attributes of the well construction, including:
  - Total depth and diameters of boring,

- o Depth, type, diameter, and physical properties of well casing and screen, including
- o well screen slot size,
- o Depth intervals, type and physical properties of annular filterpack and seal materials used,
- o Design, type, diameter, and construction of protective surface casing, and
- o Survey coordinates prepared by a State of Utah licensed engineer or land surveyor, including horizontal coordinates and elevation of water level measuring point, as measured to the nearest 0.01 foot.

After review of DRC records, the DRC does not have well completion as-built drawings for all the monitoring wells on site at the RAML facility. Please submit well completion as-built drawings for all the existing wells on site with the Revised Work Plan.

The DRC notes that the SSA is said to likely include a minimum of 4 to 7 new monitoring wells. However, to meet the requirements of adequate characterization of the site, as discussed above by DRC in this response to the original work plan, a number of wells in addition to the minimum of 4 to 7 mentioned above will likely need to be installed.

The work plan states, "The new monitor wells will be used to characterize the geology, measure groundwater elevations, estimate hydraulic gradients, characterize groundwater chemistry, and estimate hydraulic conductivity within the BCA and BBA. Well construction methodology would likely require cuttings and fluid containment and disposal. Use of conventional or reverse-circulation air drilling would allow detection of groundwater during drilling."

The DRC generally concurs. However, air drilling typically cannot be used at depths below the water table where groundwater movement into a borehole or corehole becomes significant.

5I. Hydraulic Testing. The work plan states, "Hydraulic Testing – all new monitor wells, and selected existing wells, would be tested to determine formation hydraulic conductivity. Testing methodology would depend on results of drilling, but would likely include slug tests, short-term pumping tests (if possible), and laboratory analyses. Short-term constant rate pumping tests with observation wells provide the best estimate of hydraulic conductivity. If possible, M&A would conduct such tests on clean wells if approval is obtained from UDRC to discharge the extracted groundwater without treatment."

The DRC concurs with the plan by RAML and M&A to hydraulically test all new monitoring wells. While the work plan indicates planned testing of "selected" existing wells, it will be important to include enough wells that are sufficiently geographically dispersed throughout the site so that, in combination with testing of new wells, the testing of these selected existing wells will fully characterize hydraulic conductivity and storativity for all areas on the site that could potentially be significantly contaminated, including the following:

(1) areas of potential uranium sourcing of groundwater in shallow and deep portions of the Burro Canyon Formation aquifer at or near the former upper and lower impoundments

(2) middle section of dry Burro Canyon Formation area (but screening of the well in the Brushy Basin Member, at a location WSW of Well OW-UT-9 and midway to Well EF-3a)
(3) area in the contaminated zone at the base of the Burro Canyon Formation at and near Well EF-3a
(4) area in the potentially contaminated but uncharacterized shallow part of the Burro Canyon Formation at or near the water table next to Well EF-3a
(5) area in the potentially contaminated but uncharacterized deeper part of the Burro Canyon Formation several hundred feet to the WSW of Well EF-3a
(6) area not yet characterized in one or more potential fractured rock fault zones running along the LF and in proximity to it to the east where two or more wells should be installed to better characterize the fault zone hydraulics
(7) areas W, WSW and WNW of wells RL-1 and RL-3 to identify aquifer characteristics in locations to which the Uranium plume that originates on the eastern side of the dry zone might be moving in response to apparent hydraulic gradients that would favor flow and transport past RL-1 to the W, WSW and/or WNW
(8) If any of the wells drilled to satisfy (7) do not encounter the Burro Canyon Formation, then the Brushy Basin Member should be penetrated during drilling to a depth of at least 25 feet before completing the well; a long-term slug or pumping test should be conducted therein

In addition, selected wells in non-contaminated areas should be tested so that reasonable estimates for hydraulic conductivity and storativity in the Burro Canyon Formation and Brushy Basin Formation can be assessed for these areas, wherever groundwater head there could have a significant influence on groundwater flow in contaminated areas.

The work plan states, "Short-term constant rate pumping tests with observation wells provide the best estimate of hydraulic conductivity. If possible, M&A would conduct such tests on clean wells if approval is obtained from UDRC to discharge the extracted groundwater without treatment."

While it is true that short-term constant rate pumping tests with observation wells generally provide better estimates of hydraulic conductivity as well as of storativity for a more laterally extensive portion of an aquifer than those provided by a slug test, the DRC requests that any hydraulic tests conducted at the site *not* do any of the following:

(1) remove contaminated groundwater to the surface in a manner in which the contaminated groundwater is allowed to contaminate surficial materials, near-surface materials or other subsurface materials
(2) remove clean groundwater at first but then start to remove contaminated groundwater pulled in from nearby contaminated areas
(3) alter the hydraulics of the subsurface in such a way that a nearby contaminant plume is enlarged or moved to a formerly clean location or position, regardless of whether the groundwater removed during pumping is clean

The DRC recognizes that, for modeling purposes, it is helpful, perhaps even necessary, to conduct hydraulic testing to obtain representative values of hydraulic conductivity and storativity, but such testing must be in areas where none of the above three problems could be induced. During pumping, groundwater must be frequently checked as to quality, with monitoring of actual contaminants of concern or suitable surrogates. If there is any evidence of contamination starting to become present in the removed groundwater, then the pumping test must be stopped immediately. If RAML and M&A would like to conduct a pumping test, then will they need to first describe to the DRC how it will be done in such a way that none of the three problems described above are caused.

If a highly fractured zone is found near the LF near the NW part of the site, and the groundwater there is clean, then that might be a good place to conduct a pumping test.

For areas that are contaminated or close enough to contaminated areas that pumping tests could pull in contaminated groundwater or modify an existing plume in an adverse way, it is recommended that carefully performed slug testing be conducted instead, followed by appropriate analysis. In general, a carefully performed and appropriately analyzed slug test can provide relatively good values for local hydraulic conductivity. Slug tests making use of nearby monitoring wells can even be used to obtain values for local storativity.

With slug testing, as well as with pumping testing, it is important not to contaminate any uncontaminated media. Moreover, it is important in slug testing not to introduce any contaminants into the wellbore during the testing process. There are several different types of slug tests that can be performed. The DRC requests that RAML and M&A propose which type of slug test that they intend to use and explain how they will protect against contamination of all media potentially involved. The four possibilities are

(1) rapid introduction of a solid slug into the groundwater, with subsequent measurement of falling head of the groundwater
(2) introduction of a solid slug into the groundwater, with a subsequent delay allowing for the groundwater head to return to static conditions, followed by rapid removal of the slug, followed by measurement of rising head of the groundwater
(3) rapid introduction of a slug of native groundwater (that had been previously been recovered by the bailer from the same well, with sufficient time permitted to elapse so as to allow a return of groundwater head to static conditions), with subsequent measurement of falling head of the groundwater
(4) rapid withdrawal by bailer of native groundwater from the well (that had been allowed over a sufficient time to allow the groundwater head to return to static conditions following an earlier introduction of the bailer), with subsequent measurement of rising head of the groundwater

Any potentially contaminated groundwater removed by pumping must be containerized and properly disposed. Groundwater removed by slug testing must also be containerized and properly disposed. All equipment used in hydraulic testing must be properly cleaned between uses to avoid cross-contamination.

5J. Monitoring and Sampling. The work plan states, "Monitoring – all new wells would be sampled immediately after development and quarterly for at least 1 year."

It is understood that monitoring associated with the work plan is only that for the currently planned work. Monitoring for other purposes is not necessarily limited to a timeframe of a single year.

Contrary to the current work plan strategy, sampling immediately after well development is not acceptable to the DRC. This practice is strongly discouraged by the U.S. EPA. Puls and Barcelona (1996), who wrote the 1996 U.S. EPA approach, state, "Water samples should not be taken immediately following well development. Sufficient time should be allowed for the ground-water flow regime in the vicinity of the monitoring well to stabilize and to approach chemical equilibrium with the well construction materials. This lag time will depend on site conditions and methods of installation but often exceeds one week."

Furthermore, wells must be purged prior to sampling. Puls and Barcelona (1996) state, "Well purging is nearly always necessary to obtain samples of water flowing through the geologic formations in the screened interval." The U.S. EPA recommends purging with a low-flow device (e.g., ≤ 0.5 L/min) followed by periodic (every several minutes) monitoring with an in-line device and waiting until several water-quality indicator parameters (e.g., pH, specific conductance, redox, dissolved oxygen, turbidity) reach stable levels. Example guidelines given include three successive readings within ± 0.1 for pH, ± 3% for conductivity, ± 10 mv for redox potential, and ± 10% for turbidity and DO.

The work plan states, "UDRC has requested information regarding the adequacy of low-flow sampling at the Site. During evaluation of site conditions, M&A conducted a field audit of the low-flow sampling procedures at the Site. Based on this audit, the field sampling protocols followed standard low-flow procedures (U.S. Environmental Protection Agency, 1996)."

While undoubtedly low-flow sampling procedures at the site have followed many of the standard low-flow procedures, this sampling approach, as currently practiced at the site, misses one essential criterion established by the U.S. EPA for low-flow sampling. That criterion is that of sampling be representative (see Puls and Barcelona, 1996). Because low-flow sampling involves vertical flows so small that not even the stagnant water in the well above the screened zone is meant to be pulled into the sampler, it clearly follows that groundwater outside of the well at elevations a good distance above that of the top of the screen will not be pulled into the sampler, either, when low-flow sampling is properly done. Varljen et al. (2006) and Varljen and Kaminski (2006) show through numerical modeling that low-flow sampling basically entails groundwater coming from the formation into the well over its screened length plus from a little more of the formation beyond the end(s) of the screen.

This means that the low-flow sampling, when done right, can effectively sample from the screened interval itself, but it simply cannot representatively sample groundwater from locations a significant distance *above* the screened interval. This means, for example, that sampling using low-flow sampling from within the screened interval inside Well EF-8 might possibly be able to sample representatively from formation groundwater up to the top of the screened interval at an elevation of 6360.98 ft amsl. But use of low-flow sampling cannot, and never will, be able to sample formation groundwater representatively from at or near the groundwater table at an elevation of 6495.00 ft amsl, located 134 feet higher than the top of the screen. It is likely that no sampling method exists that can obtain representative samples of groundwater from at or near the water table from within the well with a screen installed at 6330.98 ft amsl to 6360.98 ft amsl. And it is certain that low-flow sampling cannot do it. So, sampling from that well is missing anything representative of that 134-foot column of groundwater above the screen.

The work plan states, "In particular, the water level and field chemistry parameters were stabilized prior to collecting samples. In this case, the samples are considered representative of groundwater conditions and not of well casing water. Based on the available information, M&A believes that the low-flow sampling methods are adequate for Site conditions."

The DRC agrees that the samples taken might be considered representative of groundwater outside the well over a range of elevations corresponding to those of the screened interval. But the DRC asserts that this approach does not work for groundwater located a significant distance above the screened interval, and that the approach is inappropriate for a single well for which the screened interval represents a length considerably smaller than the thickness of a recognized or potential contaminant plume.

5K. Well Installation. On page 15 of the work plan, it is stated, "The well construction and testing program is expected to commence in April 2012, would be completed in about 50 days, and is projected at this time to be completed by the end of May 2012."

The DRC is concerned that installation of all needed wells may take longer than anticipated in the work plan, because of the likelihood of an increased number of wells being needed. The DRC recommends that this issue be considered carefully and that a revised schedule be prepared, as needed.

5L. Data Interpretation. Also on page 15 of the work plan, it is stated relative to interpreting field data, "Task 4 would commence during the field program to the extent possible and is expected to take about 30 days to complete depending on the number of wells installed and hydraulic tests conducted."

Again, the DRC is concerned that interpretation of all field data may take longer than anticipated in the work plan, because of the likelihood of an increased number of wells being needed. The DRC recommends that this issue be considered carefully and that a revised schedule be prepared, as needed.

5M. Phase 2 Modeling with Probabilistic Model. The Phase 2 modeling using the probabilistic model will involve incorporation of field data to further develop model parameter values more realistically. This will help determine which model runs represent more likely realistic scenarios and help determine revised ACLs, if appropriate.

The DRC concurs with this approach.

5N. Report. A final report that summarizes findings and makes recommendations will be prepared. The target date for completion is currently mid-October 2012.

5O. Coordination with DRC. The DRC is interested in working with RAML and its consultants in developing a work plan that will result in an adequately characterized and modeled site. To this end, the DRC requests that RAML maintain close contact with the DRC in developing its work plan until a final product acceptable to both parties is completed and submitted.

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