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September 30, 2005

MEMORANDUM

SUBJECT: Los Alamos National Laboratory, Los Alamos, New Mexico (01RC06-001)
Impacts of Well Construction Practices

FROM: Robert Ford, Ph.D., Environmental Scientist
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TO: Richard Mayer
U.S. EPA, Region 6

As requested, various documents concerning well construction practices and water quality evaluations at the Los Alamos National Laboratory (LANL) have been reviewed by Greg Davis, a consultant to Dynamac Corporation, and us. Dynamac is an off-site contractor providing technical support services to this laboratory. The focus of this review has been on the questions posed by the Northern New Mexico Citizens= Advisory Board (NNMCAB) in a memorandum from DeLong to Mayer dated 1/4/05. The questions which were posed center on the capability of the existing hydrogeologic characterization wells to provide representative ground-water samples for all site-related constituents of concern. The specific questions are summarized below:

Issue 1: If LANL decides to convert characterization wells to monitoring wells, can wells drilled with bentonite clay or commercial fluids, such as EZ-MUD, Quik-FOAM, TORKEASE, and LIQUI-TROL, ever be developed and cleaned up adequately to provide analytical data representative of the ground water in the aquifer unit being sampled?

Issue 2: Will the use of commercial drilling fluids and bentonite clay preclude any contaminants from being accurately sampled even after well cleanup? If so, which ones?

Issue 3: Are tritium and other mobile constituents suitable indicators of possible impacts for the entire suite of site-specific constituents at LANL?

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Issue 4: (a) Can LANL derive an independent estimate of background concentrations of potential contaminants from accumulated ground-water data without using analytical results from the wells associated with the Hydrogeologic Work Plan? (b) Would such data constitute reliable criteria for judging when wells are suitable as monitoring wells?

The issues which have been raised by the NNMCAB are valid and, in many cases, difficult to reliably answer. The NNMCAB and the LANL are correct in identifying intrusion of bentonite and organic-based polymer drilling fluids as a potential problem for reactive contaminants of concern. These drilling fluids can introduce new reactive solid phases within the screened interval that may retard contaminant transport relative to un-impacted zones within the aquifer that the screened interval is intended to sample. Alteration of aquifer material reactivity results from one of two processes: 1) introduction of a reactive clay mineral, bentonite, that has significant sorption capacity for many of the site contaminants of concern, and 2) alteration of in-situ aquifer mineralogy via stimulation of biological manganese (Mn)-, iron (Fe)- and sulfate-reduction processes that result in the accumulation of reactive mineral phases such as Mn/Fe carbonates, Mn/Fe sulfides, and/or reduced Mn/Fe (hydr)oxides (Figure 1). Based on review of information presented in Table 1 of Bitner *et al.* (2004), intrusion of polymer-based drilling fluids is likely to have occurred in one or more screened intervals of all of the well locations whereas the intrusion of bentonite-based drilling fluids is likely to have occurred in fewer wells due to the more limited use that was reported (Table 1).

In an attempt to explain the possible impacts of these two classes of drilling fluids, two diagrammatic conceptual models were introduced in Figures 6 and 7 of Bitner *et al.* (2004) to depict the evolution of aqueous and solid phase chemistry within the impacted zone of a well screen. According to Figure 6 and accompanying discussion, degradation of polymer-based drilling fluids leads to reducing conditions that result in dissolution of Mn and Fe (hydr)oxides (with stated concomitant increases in dissolved Mn and Fe) and the reduction of sulfate, nitrate, and some site-specific contaminants of concern. These processes will also result in the production of dissolved carbonate (from organic carbon degradation) and dissolved sulfide (from sulfate reduction). It is implied that dissolved Mn and Fe derived from reductive dissolution of the original Mn- and Fe-bearing aquifer 'mineral coatings' will be conservatively transported from the zone of influence adjacent to the impacted well screen. However, a more probable scenario is the re-precipitation of Mn and Fe as carbonates and sulfides on aquifer solids within the zone of influence concomitant with increased production of dissolved carbonate and sulfide during degradation of polymer-based drilling fluids. Upon recovery of more oxidizing conditions, these newly-formed reactive mineral phases can subsequently be re-oxidized to their oxide forms with no net loss of Fe and Mn from the formation. This overall scenario is presented schematically in Figure 2 with changes in the relative abundance of specific aqueous and solid phase components documented as a function of the evolution of the aquifer adjacent to an impacted well screen.

The mineralogical alterations depicted in Figure 2 will result in changes to the chemical reactivity of aquifer solids within the impacted zone adjacent to the well screen. A likely outcome resulting from a change in aquifer solids reactivity is that contaminants of concern that

may be transported through the aquifer will interact with altered aquifer solids within the impacted zone adjacent to the well screen in a manner distinct from the unaltered aquifer solids at similar depth (Figure 3). Since the contaminants of concern relevant to LANL's ground-water characterization effort represent a wide range of chemical affinity for sorption onto aquifer solids, the potential exists for inaccurate identification of contaminant-specific transport. There is currently no direct evidence of the types and amounts of mineral alteration products within the impacted zones adjacent to well screens. Thus, there is no reliable means to assess whether a non-detect concentration (or a value below "background") of a strongly-sorbing contaminant of concern is indicative of 1) lack of transport of the contaminant through the aquifer to the well screen or 2) sorption of the contaminant within the impacted zone of the well screen. Based on review of technical communications from LANL, it is not clear that this factor has been given sufficient consideration relative to the development of assessment criteria for determining the adequacy of individual well screens to provide chemical data for ground water that are representative of pre-drilling aquifer conditions.

The implications of this conceptual model of biogeochemical conditions at well screen impacted by drilling fluids, the technical aspects regarding each issue identified by the NNMCAB, an evaluation of the current information, and recommendations for resolution of the issues are provided below.

Issue 1: It is possible that some impacted wells may ultimately be capable of providing representative samples provided that: 1) large quantities of additives did not infiltrate the screened zone, 2) methods that include purging of water prior to sampling are used, 3) protocol(s) to better evaluate return of aquifer materials to background conditions are established, and 4) implementation of sample collection, preservation and analysis procedures that minimize changes in chemical speciation of redox-sensitive parameters. Resolution of Issue 1 first requires identification of the wells that are sufficiently impacted by drilling fluids as to affect the chemistry in the aquifer surrounding the well screen. In this regard, the LANL has proposed draft criteria for determining impacts. An evaluation and recommendations concerning these criteria are provided below.

1. The proposed criteria are based on analysis of water chemistry. It should be noted that while analysis of changes in aqueous chemistry at a given well screen presents one potential tool for characterizing well recovery, there is a high degree of uncertainty associated with this avenue of analysis. Specifically, aqueous chemistry data cannot be used to infer the distribution of mass (between water and solids) of a given contaminant within the impacted zone adjacent to a well screen without knowledge of the initial concentration of the contaminant interacting with altered aquifer solids. Determination of the true fate of a particle-reactive contaminant within the aquifer can accurately be assessed only with knowledge of its mass distribution between water and solids within the impacted zone. Comparison of measured concentrations of indicator parameters (or contaminants of concern) to background ground-water concentrations are useful only when the chosen background condition is representative of the un-impacted aquifer adjacent to the well screen being sampled. Reliance on an uncertain background condition to assess apparent well recovery limits the reliability of this approach (see additional discussion under Issue 4).

The data used to characterize background conditions (LANL, 2005) appear to be too sparse, derived from sources representing mixtures of water that are significantly different from the samples obtained from the hydrogeologic characterization wells, and are representative of significantly different flow paths within the aquifer. It is recommended either that background data be obtained from monitoring wells screened within the specific units of interest and installed without the use of additives within the screened interval or that much less dependence be placed on the use of background data in this evaluation.

Due to the relatively large spatial variability and/or variability associated with rock type, the proposed trigger values may not be conservative enough to identify some impacted wells due to uncertainty in the appropriate background values. For example, criteria 2.1-2a and 2.1-2b use the minimum background concentrations for strontium and uranium as triggers to flag data as possibly non-representative. Actual background values at the locations of the characterization wells may be significantly different from the proposed values.

A cursory application of these criteria illustrates the uncertainty in the use of the minimum background values for strontium. Bitner *et al.* (2004) report that screen 3 in well R-22 appears to be impacted by residual bentonite based on elevated sodium and sulfate concentrations. Data obtained from Longmire (2002) indicate that strontium concentrations are above the minimum background values and may be declining with time. Evaluation of the data from this well screen using proposed criterion 2.1-2b would indicate that the strontium data are representative despite the large impacts evident in the sodium and sulfate data and the trend in the strontium data. Based upon this analysis, it does not appear that the strontium data should be considered representative. It is not clear that a detection of either strontium or uranium that is above a minimum background value demonstrates that there has been no impact due to small quantities of residual bentonite. Neither is it clear that detections of a parameter at a concentration above a maximum background value is a firm indication that bentonite is the source for the elevated constituent, as stated in criterion 2.1-1a. The logic supporting these assumptions should be described in detail and provided for review.

2. Development of a tiered process to assess the evolution of water chemistry at impacted well screens does provide one of several tools that should be implemented to judge the appropriate disposition of ground-water wells. The decision process should be based on comparison of measured ground-water chemistry to the anticipated chemical conditions based on the presumed conceptual model of the geochemical evolution of impacted well screens. Based on analysis of the current conceptual model proposed by the LANL, it is recommended that the proposed tiered review process be re-evaluated and revised to more appropriately represent the conceptual model depicted in Figures 1 and 2 of this review. It is recommended that this process be preceded by a screen-by-screen determination of where organic-based, bentonite, or both drilling fluids were used. Examination of these data on a well-by-well basis indicates that all wells are impacted by organic-based drilling fluids, and some wells are also impacted by bentonite. If it is determined that all screens are impacted by organic-based drilling fluids (*i.e.*, these fluids were used during drilling in the screened interval) some re-structuring of the flow of the tiered process may be required. In addition, the following three issues should also be

considered with respect to the choice of analytes that are used in criteria to assess apparent well recovery:

A. A subset of the analytes chosen for assessing impact of drilling fluid at a given well screen should be a component of the drilling fluid and have concentrations that are much higher than typical for site ground-water background conditions,
B. Analytes chosen to assess geochemical conditions or possible contaminant sequestration should not be susceptible to changes in chemical speciation during sample collection and preservation, and
C. Analytes chosen to assess the possible sequestration of contaminants of concern on aquifer solids surrounding impacted screens should possess a higher affinity for partitioning to the unaltered/altered aquifer solids.

With regard to issue (A), it appears that the currently recommended list of analytes used to assess drilling fluid impact is not adequate. A summary of deionized water extraction data made available for review is shown in Table 2. Analytes highlighted in yellow for a subset of drilling fluids would serve as appropriate indicators of the continued presence of several of the drilling fluids. It should be noted that no data were available for review for a number of the drilling fluids that were frequently employed during drilling operations (including EZ-MUD, Quik-FOAM, TORKEASE, and LIQUI-TROL). These data should also be obtained and evaluated as part of revisions to the analyte list.

With regard to issue (B), there is concern that sulfate may not be a reliable indicator under reducing conditions. Specifically, it is possible to obtain a false positive for the presence of sulfate due to inappropriate collection and preservation that will result in the oxidation of dissolved sulfide. This problem is magnified by the water collection configuration employing Westbay samplers. Based on our on-site observation of ground-water sampling activities at well R-22 on June 28, 2005, it is evident that there are no controls implemented to limit oxygen intrusion into water samples retrieved from the well screen. First, sampling vessels that are lowered to the well screen are sources of oxygen exposure to sampled water, even though the sampling vessels are deployed under vacuum. Quality control data were not available for this review to assess the reliability of this sampling configuration to prevent oxidation of dissolved sulfide [and Fe(II) or Mn(II)] during the timeframe of a typical sampling event. Secondly, oxygen exposure again occurs during transfer of collected water to individual containers prior to submission for laboratory analysis, since sample transfer is not conducted without air exposure. Based on our observation in the field, it appears that dissolved sulfide is not measured in the field, so there is no analytical mechanism in place to evaluate whether sulfate measured in the laboratory represents the true concentration at the well screen, the concentration following oxidation of dissolved sulfide after sample collection, or some combination thereof. This is of particular concern since sulfate is used as one of the initial criteria (2.2-2) for screening the impact of residual organic drilling fluids. It should also be noted that the existence of sulfate-reducing conditions does not preclude the presence of sulfate in water. The concentration of sulfate and dissolved sulfide in ground water within a sulfate-reducing zone will depend on two factors: 1) the kinetics of sulfate reduction relative to the concentration of sulfate (*i.e.*, supply of sulfate may exceed capacity for its reduction leading to continued persistence of sulfate in ground

water), and 2) the relative concentrations of dissolved ferrous iron and sulfide produced by sulfate reduction. If ferrous iron is present in molar excess of sulfide (*i.e.*, moles Fe(II) > moles dissolved sulfide), then precipitation of iron sulfides could effectively sequester biologically-produced sulfide and prevent its detection in the dissolved phase. The current uncertainties associated with sulfate measurements limit the reliability of this analyte for screening the condition of wells impacted by organic-based polymer drilling fluids.

For issue (C), it is important to identify analytes that are transported less conservatively than the contaminants of concern. Dissolved zinc is proposed for screening the condition of wells impacted by bentonite relative to the possible loss of cesium-137, cobalt-60, europium isotopes, and neodymium-147 onto residual bentonite solids adjacent to the impacted well screen (criterion 2.1-2). One significant limitation to this approach is that zinc has not been universally detected in site ground water. LANL (2005) reports non-detectable zinc in about 56% of the samples evaluated. Thus, non-detectable zinc at a given well screen could indicate either sorption onto residual bentonite or the lack of this constituent at measurable concentration in the native ground water at the interval sampled by the well screen. In addition, there are some published ion exchange selectivity series that indicate cobalt partitions more strongly than zinc to clay minerals (including bentonite). Thus, detection of zinc would not preclude loss of cobalt-60 on residual bentonite. Screening criterion 2.1-2 should be re-evaluated in an effort to identify a more reliable replacement or supplemental candidate to zinc. Barium presents a potential alternative/additional candidate (99% detect in area ground water), although it is unclear how prevalent this metal may be as a site contaminant of concern.

3. There is also concern regarding the use of only the three most recent measurements in these assessments without examination of trends. Although the concentrations of the parameters used as indicators in criteria 2.1-1, 2.1-2a, and 2.1-2b may change with time and eventually meet the proposed triggers, this does not imply that the data are now representative of the aquifer for each of the listed parameters. In general, these criteria may be most useful for identifying the degree of impact to a well screen rather than whether the well in question now produces fully representative data for many of the constituents.

4. The Tier 2.2 criteria are designed under the assumption that once oxidizing conditions have been re-established the sorption characteristics of the aquifer material immediately adjacent to the well screen have returned to pre-drilling conditions. This is not necessarily the case. As described above, the reducing conditions established by biodegradation of organic-based polymer drilling fluids are likely to alter the mineralogical composition of the aquifer solids adjacent to impacted well screens. These processes generally increase the mass of reactive minerals resulting in an increase in the sorption capacity of aquifer materials impacted by biodegradation of organic-based polymer drilling fluids. Thus, contaminant concentration data collected from impacted well screens may be biased low relative the actual concentration of contaminants in un-impacted aquifer materials in the same flow path. Without collection and characterization of altered aquifer materials, it is difficult to determine the extent of this problem on a screen-by-screen basis. A potential indirect method of assessing changes in sorption reactivity between impacted and un-impacted aquifer materials would be to conduct push-pull tests at impacted and un-impacted well screens that sample from a similar lithology using a range of dissolved

constituents that capture the particle-reactivity of site contaminants of concern. In addition, it may be beneficial to attempt removal of mineral alteration products via physical or chemical processes that mobilize or dissolve these phases.

5. It is noted that technetium is not mentioned under these criteria and should be included.

6. Due to uncertainties in the utility of aqueous chemistry assessments for the determination of whether samples are fully representative of aquifer conditions, it is recommended that field studies be designed to validate these or similar criteria. As noted above, it is possible that push-pull tests using a conservative tracer and surrogates for the contaminants of concern may provide a qualitative evaluation of differences in sorptive capacity, if performed in impacted wells and adjacent wells of similar design that were installed without additives in the screened zone. Although detailed quantitative interpretations of such tests would likely be uncertain in this setting, the data may still provide one of the few available insights into the current well conditions.

It is recommended that such studies be considered for locations determined to be critical to the monitoring program. The results may then be used to evaluate the need for additional studies or well installations at other locations. One possible location for additional study is near well R-22 which demonstrates impacts from both bentonite and polymer-based additives. Based on previous studies at this location, single-screen well completions could be installed in the most important monitoring zones. Comparisons of aqueous chemistry between R-22 and the new well cluster and the results of studies such as push-pull tracer tests may provide much insight into the magnitude and long-term impacts of the problems associated with residual additives at other locations.

7. The proposed criteria did not specify specific actions to be taken, other than flagging of data, if evaluations indicated impacts due to drilling additives. It is recommended that the criteria be expanded to specify precisely what flagging the data means with respect to data limitations, usability, and corrective actions such as well re-development or replacement.

Issue 2: Site-specific contaminants of concern include americium, cesium, iodine, plutonium, strontium, technetium, uranium, chlorinated solvents, perchlorate, and others. Whether samples obtained from the hydrogeologic characterization wells following re-development are representative of aquifer conditions will depend on the degree to which residual drilling fluids and altered aquifer materials have been removed or returned to their unaltered states. This question can only be answered following re-development and demonstration that the geochemical properties of the aquifer materials surrounding the well screen have not been altered with respect to geochemical/sorption characteristics for the contaminants for which sorption or geochemical environment is a significant concern, such as strontium-90, americium-241, cesium-137, strontium-90, and isotopes of plutonium. Studies such as those discussed above will be necessary to validate predictions made based on aqueous chemistry.

As noted in Bitner (2004), analyses for contaminants that may undergo biological transformations, such as chlorinated solvents and perchlorate, may not provide representative

results as long as reducing conditions caused by degradation of organic carbon associated with polymer-based drilling additives exist adjacent to impacted well screens. Continued monitoring of redox-sensitive parameters may be used to determine when the polymer materials have been degraded, an oxidizing environment has been re-established, and samples for these constituents may be considered representative.

Other issues affecting whether samples from the hydrogeologic characterization wells are representative of aquifer conditions include the design and construction of these wells. Many of the wells, particularly those constructed at the top of the regional aquifer, use screens as long as approximately 60 ft. This type of construction often results in significant dilution of any contaminants that may be present unless the contaminant is pervasive throughout the entire screened interval. Interval sampling using a pump/packer system may provide information concerning differences in water chemistry within the screen and the possible effects of dilution. Although the use of long screens may extend the useful life of the well in a setting where the regional water table is declining, it may render early detection of contaminants highly uncertain.

In addition, the use of a long screen increases the risk of cross connection of different hydrostratigraphic units. Cross connection of different units may result in significant vertical flow within the well and the transport of contaminants, if present, to other parts of the aquifer system. The existence of a vertical flow field within the well may also be characterized using a sensitive electromagnetic or heat-pulse borehole flowmeter as described in Young *et al.* (2000). Additional information and advice regarding design and use of borehole flowmeter surveys to characterize both the vertical flow within a well and the zones from which water enters a long-screened well during purging and sampling can be provided, if desired.

At other locations, it appears either that the uppermost well screen may be installed far below the top of the regional aquifer or that one of more of the most transmissive intervals was not screened, making early detection of contaminants highly uncertain. The former is illustrated by screen #1 in well R-16, where the screen is isolated within the casing, due to problems encountered during well installation (*e.g.*, drillers unable to withdraw casing and thereby abandoned casing in place). The end result is that the upper 200+ feet of the regional aquifer is not being monitored at this location. Additionally, based on the as-built diagram of R-16, screen #4 appears to be impacted by slough materials. The latter may be illustrated by specific intervals of well R-22, where geophysical logging appears to indicate the presence of numerous water bearing zones which could contribute to the transport of contaminants of concern.

As the focus of the issues raised by the NNMCAB appeared to relate to the effects of drilling additives, a detailed evaluation of the individual well constructions was not performed. However, it is recommended that such an analysis be performed before wells are determined to meet criteria normally applied in a detection monitoring program. In summary, factors other than the effects of drilling additives may also impact whether ground-water samples are suitable for the purpose of early detection of contaminant releases or migration and should be considered during specification of a detection monitoring network.

Issue 3: The contaminants of concern vary in their mobility in the environment due to differences in their physical/chemical properties. In principle, accurate knowledge of the concentrations of the most mobile contaminants, particularly tritium, can be used as an indicator of the maximum extent of the less mobile contaminants of concern, such as the isotopes of plutonium. However, this type of evaluation assumes that all of the contaminants of concern in a given area were spatially and temporally co-disposed and that the concentration of the mobile contaminant was sufficiently high in the waste stream to allow detection at a given distance from the disposal point. It is further noted that Bitner *et al.* (2004) also consider nitrate and perchlorate to be conservative environmental tracers that travel at the speed of the ground water. However, these constituents may be subject to removal under certain conditions, such as in a reducing environment surrounding wells screens impacted by polymer based additives. Therefore, well-specific evaluations using these compounds should be performed with care.

Documents provided for this review did not include information concerning the analyses of historical waste streams. Therefore, this issue was not evaluated in detail. Based on experience at other sites, it is quite likely that the available information may only allow a screening-level evaluation to be performed. Tritium activity is also used as an indicator of the ground-water age or elapsed time since ground water entered the subsurface. This evaluation is useful in assessing the potential for contaminants of concern to be present. However, care must be exercised in the interpretation of these data due to the effects of dilution of samples within long-screened wells, uncertainty with respect to the effects of biological processes in impacted well screens sampled using a no-purge technique, and related factors.

Issue 4: An evaluation of Abackground@ ground-water chemistry is provided in LANL (2005). In this study, sources for the data determined to reflect conditions in the regional aquifer were limited to springs and long-screened water production wells located at significant distances from many of the characterization wells. These types of sources generally produce water that is a mixture of contributions from different lithologic units and different areas. This type of study may provide useful information on Abackground@ constituent concentrations for the purpose of siting a water supply well. However, it does not appear to be appropriate for detailed comparisons with water samples obtained from monitoring wells that provide samples from discrete zones and likely represent much smaller volumes of the aquifer and different flow paths within the aquifer. Although the information in LANL (2005) provides insight into the possible range of Abackground@ conditions, data from monitoring wells located upgradient of waste management units/disposal areas are required to allow reliable comparisons with wells located downgradient of these units. Therefore, the current Abackground@ data should not be used as a sole indicator of whether samples are representative of aquifer conditions.

Recommendations

Identification of Impacts: It is recommended that all well screens impacted by residual drilling additives be identified, corrective actions to be taken be specified, and field studies performed to verify these evaluations. LANL has proposed a tiered approach, dated September 6, 2005, to support these assessments. Comments and recommendations concerning this approach are provided above.

Future Well Installations: The following recommendations for improvement during the drilling and construction of future monitoring wells should allow installation of wells that provide the most representative samples possible for the contaminants of concern at LANL.

1. Drill boreholes using no bentonite or organic additives within screened intervals. Additives may be used in intervals above the target monitoring zone if a telescoping construction is used and the hole is adequately cleaned before drilling the final footage within the interval to be screened. Although this may require the use of significant quantities of water to control heaving in the saturated zone, the effects of potable water are minimal and can be mitigated during well development. This will likely necessitate the use of single-screen well completions. Such constructions allow for more effective development and greater confidence in both the chemical data and estimates of hydrogeologic parameters. Targeting of monitoring intervals prior to drilling should be possible at locations where data from the existing characterization wells are available.

2. Limit screened intervals to no more than approximately 10 ft to 20 ft in length, depending on the formation characteristics at a given site, to minimize dilution and the potential for interconnection of separate aquifer units.

3. Eliminate the use of pipe-based screens with openings drilled in the field. This screen construction likely renders uniform development of the borehole wall more difficult than if rod-based screens or similar materials are used.

4. Minimize the time between drilling and well development. During well development, use aggressive methods that result in water movement into and out of the well screen within the constraints imposed by the depth to the ground water.

5. At locations determined to be critical to the detection monitoring program, consider replacement of wells that were drilled using bentonite or organic additives with wells installed without additives in the screened zones. As noted above, data available from installation of the hydrogeologic characterization wells at these locations will allow specific intervals to be targeted for screening. Drilling additives may be used in intervals above the target screened zone. However, a casing should be pressure grouted in place and the hole cleaned prior to drilling into the screened zone and subsequent well installation.

Summary: Most of the hydrogeologic characterization wells at LANL appear to have been installed using drilling additives that may impact the quality of data obtained from the affected well screens. Some of these impacts have been documented in various LANL publications. However, a systematic study to identify impacted screens and assess data usability has not been performed. In general, it is likely that many of these screens may not produce representative samples for constituents that strongly sorb to clays or whose fate in the environment is sensitive to changes in redox conditions. In particular, the constituents of concern that may be most affected by the residual drilling additives are certain radionuclides, such as americium, cerium,

plutonium, radium, strontium, uranium, many stable metal cations, and organic compounds that may be degraded in the impacted environment near the well screens.

The impacts are not well understood due, in part, to the difficulty in directly characterizing aquifer materials adjacent to the screen. Thus, predictions of the time frames for the impacted intervals to return to natural conditions should not be considered to be reliable. It is also likely that the inability to fully remove the additives which were used during drilling has reduced the hydraulic conductivity of some or most of the impacted screened zones. The use of the Westbay sampling system employing the MOSDAX method of no-purge sampling in the impacted screens likely maximizes the effects of the drilling additives since the sample is obtained from the region immediately adjacent to the well screen.

The path for resolution of issues concerning the impacts of drilling additives on the quality of ground-water samples should include identification of all well screens impacted by drilling additives, specification of the corrective actions to be taken, and field studies performed to verify these evaluations. Based on the uncertainty in characterizing the condition of aquifer materials adjacent to the well screens and the potentially long time frames that some impacts may last, installation of replacement wells at critical locations should also be considered. If you have any questions concerning these comments, please do not hesitate to call us (Acree: 580-436-8609; Ford: 580-436-8872; Ross: 580-436-8611) at your convenience. We look forward to future interactions with you concerning this and other sites.

cc: Mike Fitzpatrick (5303W)
Jo Ann Griffith (5202G)
Vince Malott, Region 6
Dr. Stephen G. Schmelling, GWERD

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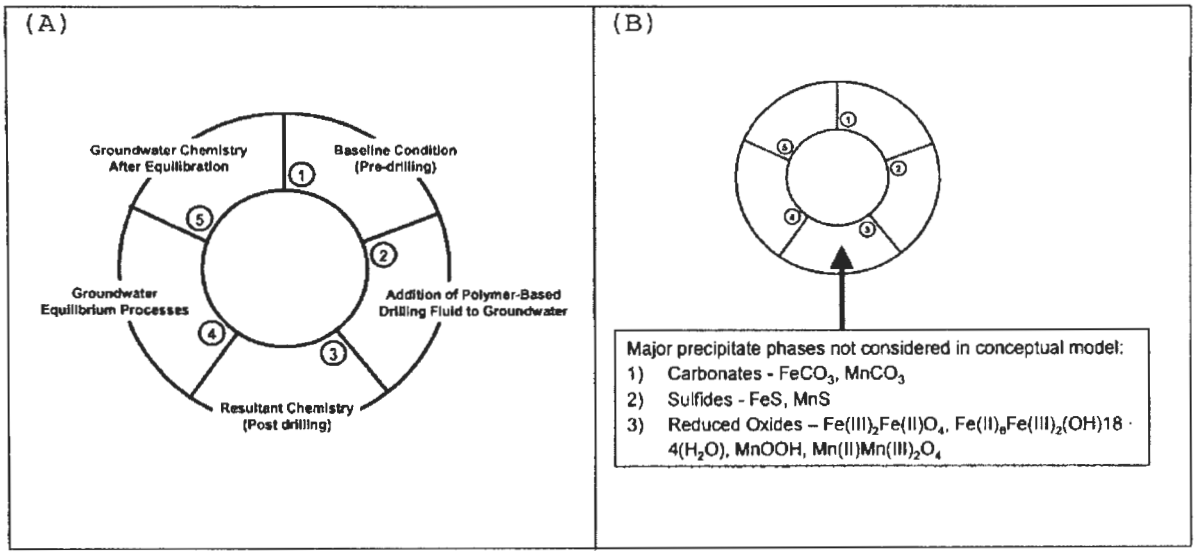

Figure 1. Illustration of certain aspects of solid phase chemistry not considered in the Bitner *et al.* (2004) conceptual model describing the evolution of aqueous and solid phase chemistry at well screens impacted by biodegradation of polymer-based drilling fluids. (A) Simplified depiction of the LANL conceptual model relative to the various stages of geochemical evolution in the impacted zone adjacent to the well screen. (B) Precipitation of major precipitate phases that can occur during Stage 3 reduction processes.

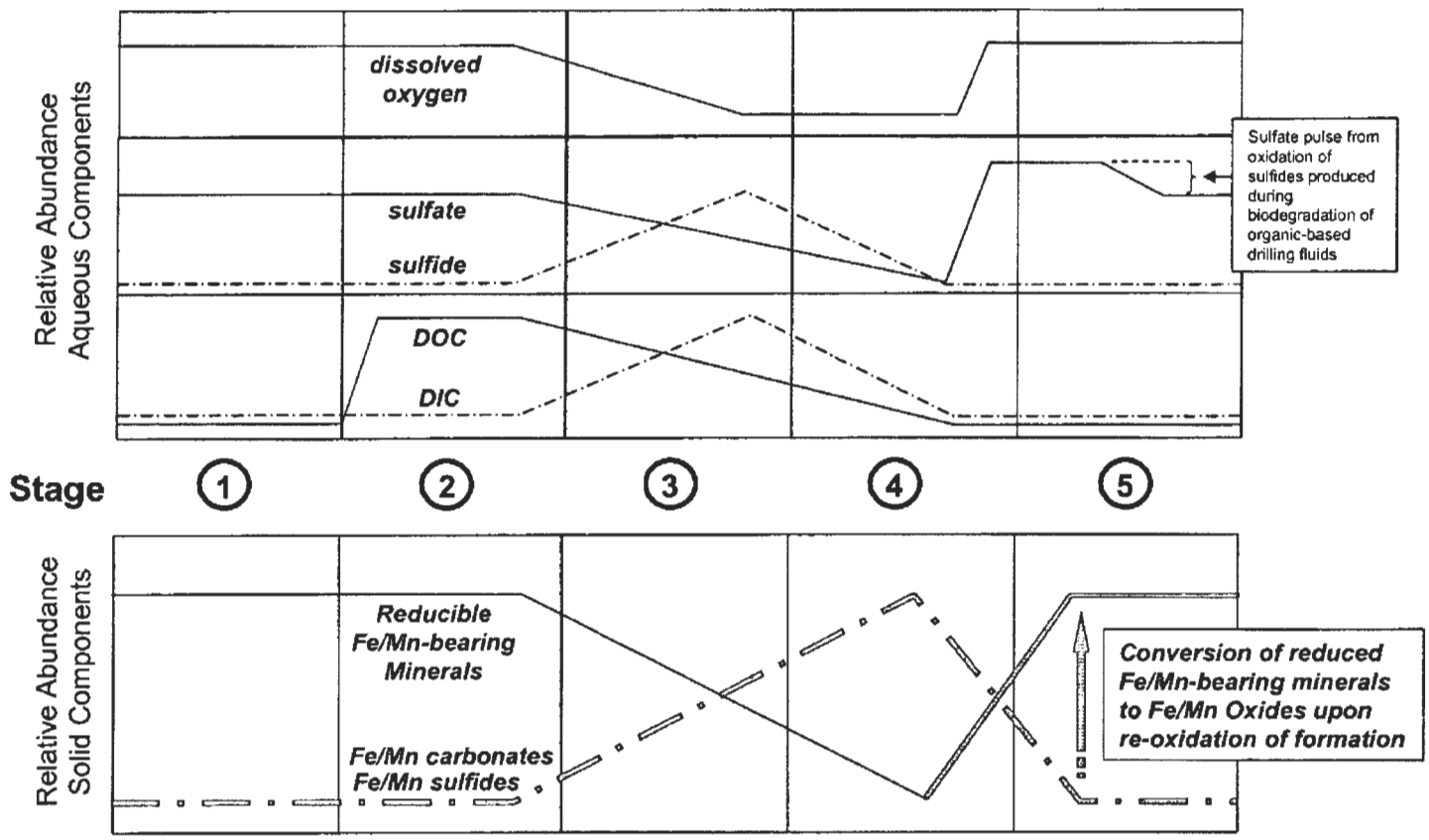

Figure 2. Schematic diagram depicting the evolution of aqueous and solid phase chemical components within the impacted zone of the aquifer adjacent to well screens impacted by the biodegradation of organic-based polymer drilling fluids. Changes in relative abundance of individual chemical components are depicted based on the current state-of-knowledge of mineral alterations that accompany organic biodegradation reactions (*i.e.*, microbially-driven iron-, manganese-, and sulfate-reduction) in subsurface environments.

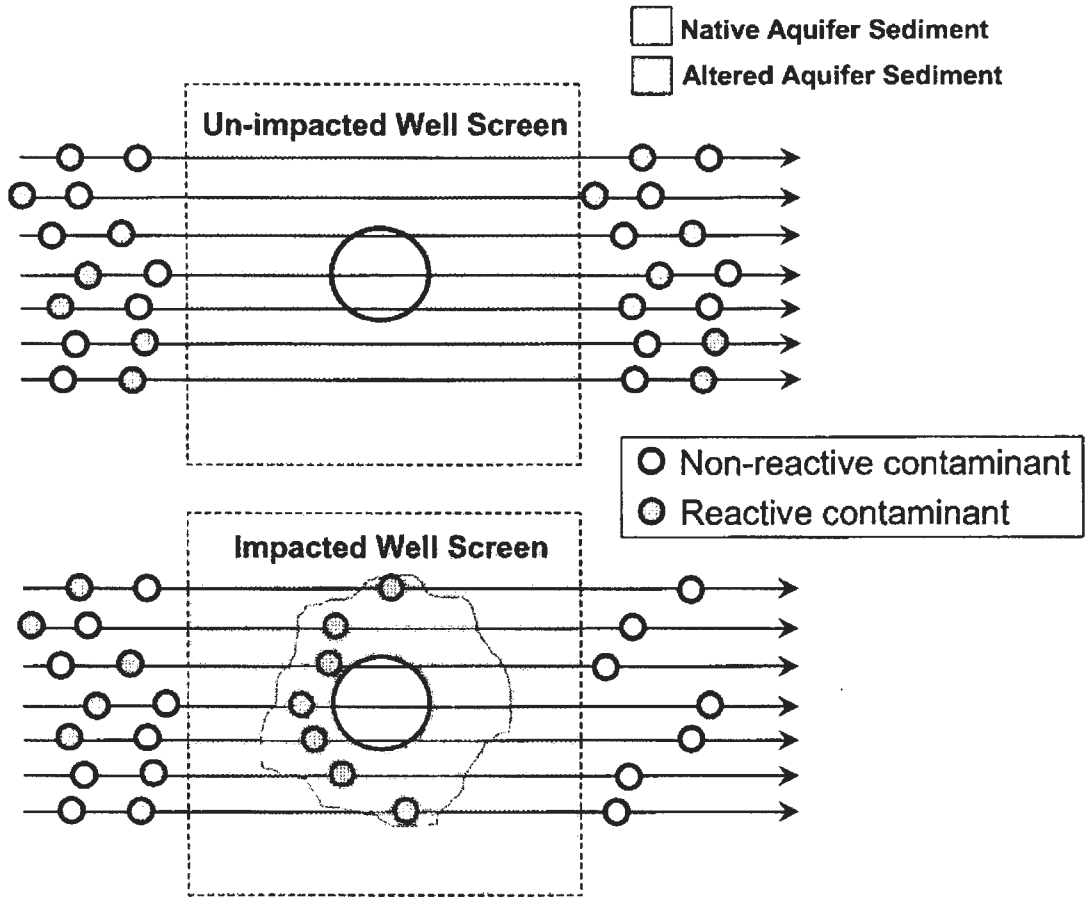

Figure 3. Schematic illustrating differential transport behavior of site contaminants of concern within the impacted zone adjacent to well screens influenced by biodegradation of organic-based polymer drilling fluids.

Table 1. Listing of drilling additives employed during implementation of the hydrogeologic characterization program at LANL.

		Drilling Fluid *										Impact Category		
Well	Elapsed Time Before Development (Days) **	EZ-MUD	QUIK-FOAM	TORKEASE	LIQUI-TROL	PAC-L	Bentonite	QUICK-GEL	N-SEAL	Magma Fiber	Soda Ash	Biodegradation	Bentonite	Both
		Polymer-based					Bentonite-based		Other					
R-1	11													
R-2	7													
R-4	10													
R-5	12													
R-7	16													
R-8	11													
R-9	115													
R-11	No report													
R-12	26													
R-13	33													
R-14	17													
R-15	Chrono uncertain													
R-16	16													
R-19	Chrono uncertain													
CdV-R-15-3	~92													
CdV-R-37-2	~25													
R-20	9													
R-21	170 mb file - gotta be kidding													
R-22	~40													
R-23	20													
R-25	64													
R-26	12													
R-28	30													
R-31	~31													
R-32	11													
MCOBT-4.4	~23													
MCOBT-8.5	No well													
R-9i	Chrono uncertain													
CdV-16-1(i)	No report													
CdV-16-2(i)	No report													
CdV-16-3(i)	No report													

* Based on information presented in Table 1 of LA-UR-04-6777 (September 2004).

** Determined as the time from completion of the entire borehole to initiation of development activities.

Table 2. Listing of water-leachable chemical constituents present in drilling fluids employed during implementation of the hydrogeologic characterization program at LANL.

Analyte *	Concentration Unit	Bentonite	EZ-MUD	Quik-FOAM	TORKEASE	LIQUI-TROL	PAC-L	Soda Ash	Quick-gel	magma-fiber	n-seal	Regional Aquifer	Intermediate Perched Zones
Ag	ppm	<0.009					<0.2		<0.01		<0.01		
Al	ppm	0.229					3.860		1.006		5.971		
Alk(Lab)	ppm CaCO3	—					85557.377	1052213.087	17595.519		75253.552	150.000	65.000
As	ppm	1.374					<0.2		0.091		<0.01	<0.007	<0.007
B	ppm	1.008					<2		0.302		0.379		
Ba	ppm	0.018					1.103		0.101		0.209		
Be	ppm	<0.009					<0.2		<0.01		<0.01		
Br	ppm	0.275					<4		6.336		<0.2		
C DIC	ppm	—					295.915		156.886		25.779		
C DOC	ppm	—					196663.745		94.232		30.423	<12	<12
C TIC	ppm	—					—		—		—		
C TOC	ppm	—					—		—		—		
Ca	ppm	9.984					115.793		137.778		593.288	38.000	16.000
Cd	ppm	<0.009					<0.2		<0.01		<0.01		
Cl	ppm	116.332					20769.162		65.067		3.981	9.100	71.000
ClO3	ppm	<0.09					<4		<0.2		<0.2		
ClO4	ppm	1.191					—		—		—		
Co	ppm	<0.009					<0.2		<0.01		<0.01		
CO3	ppm	—					0.000	602459.000	886.000		910.000		
Cond.(F)	µS/cm	—					—		—		—		
Cond.(L)	µS/cm	—					—		—		—		
Cr	ppm	0.082					2.941		0.070		0.009		
Cs	ppm	<0.009					<0.2		0.020		<0.01		
Cu	ppm	0.062					3.492		0.131		0.171		
F	ppm	7.236					1630.287		10.560		16.017		
Fe	ppm	<0.09					5.514		0.503		<0.1		
Hardness	CaCO3 ppm	—					—		—		—		
HCO3	ppm	—					104380.000	58700.000	19665.000		89959.000		
Hg	ppm	0.002					<0.02		<0.001		<0.001		
I	ppm	—					—		—		—		
K	ppm	6.046					33.084		15.387		80.084	5.100	7.500
Li	ppm	0.247					<0.2		0.704		0.265		
Mg	ppm	1.282					16.542		13.778		0.853		
Mn	ppm	0.016					0.368		0.080		<0.01		
Mo	ppm	2.473					<0.2		0.825		<0.01		
Na	ppm	1346.520					93553.127		5390.440		64.162	31.000	36.000
NH4	ppm	—					—		—		—		
Ni	ppm	0.016					0.368		0.040		0.019		
NO2	ppm	0.183					<4		<0.2		<0.2		
NO3	ppm	196.940					<4		237.340		<0.2	0.910	0.500
OH	ppm	—					—		—		—		
Oxalate	ppm	4.855					<4		<0.2		<0.2		
Pb	ppm	<0.0009					0.368		<0.01		<0.01		
pH	Lab	—					7.970	11.380	9.090		9.470		
PO4	ppm	6.504					10586.759		<0.5		<0.5		
Rb	ppm	0.011					<0.2		0.040		0.171		
Sb	ppm	0.056					<0.2		<0.01		0.020		
Se	ppm	0.092					<0.2		0.191		0.066		
Si	ppm	204.268					110.279		159.903		211.347		
SiO2	ppm calc	437.134					235.996		342.192		452.283		
SO4	ppm	1007.600					<4		9483.553		95.722	17.200	11.300
S2O3	ppm	—					—		—		—		
Sn	ppm	<0.009					<0.2		<0.01		<0.01		
Sr	ppm	0.030					0.551		2.011		1.137		
Th	ppm	<0.009					<0.2		<0.01		0.023		
Ti	ppm	<0.009					<0.4		<0.02		<0.02		
Tl	ppm	<0.009					<0.2		<0.01		0.023		
U	ppm	0.070					<0.2		0.040		0.023		
V	ppm	0.128					<0.4		<0.02		0.152		
Zn	ppm	<0.009					<0.4		<0.02		<0.02		
TDS	ppm	—					231339.313		36259.586		92184.026		
Acetate	ppm	++					+		-		-		
Formate	ppm	++					+		-		-		

No data reported for these analytes.

Indicates analyte with elevated concentration that may serve as a useful indicator for water quality in impacted well screens.

* Data were copied from Excel file (Drilling_Additives.xls) provided by Patrick Longmire/LANL to Richard Mayer/R6 via e-mail on April 19, 2005.

** Data were derived from Table 4.3-1 (Draft, 06-Sep-05) and/or LA-UR-05-2295, Appendix C.