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Assessment of Regional Aquifer Well-Development Techniques at the Los Alamos National Laboratory and Impacts on Sampling

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1. Executive Summary

This document addresses concerns about the procedures being used at the Los Alamos National Laboratory for developing the deep regional aquifer wells (RA wells) that are being constructed under the auspices of the Hydrogeologic Workplan.

Well development is the process used to repair the damage done to the borehole wall during well drilling to restore or improve the original porosity and permeability of the formation materials around the well. A number of techniques can be used to develop wells and very little standardization of the process has been accomplished, although ASTM has developed general guidelines. Well development can be a very difficult process to accomplish within very deep wells, especially when those wells are of small diameter, have deep static water levels and multiple screens with radically differing heads. The RA wells at LANL each have some or all of these characteristics.

It is our determination that the development of the RA wells at LANL has been appropriate, within established guidelines and comparable to well development at other deep well sites, but there is room for improvement. Improving the development would be useful in particular because the boreholes seem to be retaining quantities of drilling fluid residues that are impacting the quality of collected groundwater samples. Although this impact appears to be lessening with time, there is an emphasis on obtaining high quality samples as soon as possible.

Recommendations for improvement include the following:

- Having the ability to isolate the screened zones in multiple completion wells for all development methods
- In consultation with the drilling contractor select a development method(s) based on its effectiveness, practicality, and cost/benefit ratio. One potential methodology is provided in a subsequent section of this report.
- Have the final development step be pumping the individual isolated screened zones as vigorously as possible.

Following the general well development approaches that have been used, with the incorporation of these recommendations, should result in development that is as good as is currently possible for wells such as these.

2. Introduction

This assessment was developed at the behest of the Los Alamos National Laboratory (LANL) Groundwater Integration Team (GIT) under the auspices of Program Manager Charlie Nylander.

This assessment was motivated by concerns expressed by the New Mexico Environment Department (NMED) that deep regional aquifer monitoring wells (RA wells) being constructed as part of the Hydrogeologic Workplan (HGWP) are insufficiently developed

to provide high quality groundwater samples that are representative of formation waters. These concerns are primarily with regard to the multiple-screen installations wherein Westbay sampling systems are being installed. The dominant issue in this regard is the potentially incomplete removal of drilling fluid residues such as EZMud and Torque-Ease and the time interval that must pass before these materials are no longer exerting a negative impact on sample quality. Related somewhat to this primary issue are the issues of possible poor flow in the vicinity of the sampling points and the requests by LANL to allow tailored sampling suites of analytes until the sampling points have achieved equilibrium with the surrounding formation.

We have evaluated LANL's development strategy relative to ASTM guidelines, methods that are being used at other deep drilling locations, and in particular to the guidance of Westbay Instruments, Inc., and those institutions that have installed Westbay systems. In general, our determination is that LANL is following conventional and suitable well development practices. There are a number of modifications which can be made that should improve development efficiency, including better isolating the individual screens in multi-screen formations using straddle packer surging, jetting, or pumping equipment. The development techniques also need to be modified somewhat to account for this isolation and to provide greater energy input into the zone being developed. We also recommend that the final stage of development of these wells should again include isolating each of the screens in a multi-screen well and pumping them at a high flow rate. With regard to the wells that have been completed without this step, we concur with LANL that these wells should generally be sampled for targeted analytes, rather than a full suite of analytes, until the sampling points have equilibrated with the formation. Wells completed with this approach should be evaluated for the potential remaining effects of residual drilling fluids, as is currently being done by the GIT Geochemistry Subcommittee. Groundwater flow is very slow in the regional aquifer beneath LANL and an equilibration period of up to two years should yield no risk to human health and the environment, especially since the tailored analytical suites will include the expected contaminants of concern (COCs).

3. Well Development and Sampling Concerns

The NMED has expressed a variety of concerns regarding the development and sampling of the deep regional aquifer wells at LANL. These can be summarized as follows:

1. Potential problems with low-flow rate sampling in potentially underdeveloped wells.

   a) Effects of residual drilling fluid materials

   There is concern that the residual drilling fluids that are incompletely removed from the borehole during well development will negatively impact sample quality. This concern is supported to an extent by data gathered by the Geochemistry Subcommittee of the GIT. These findings are addressed in more detail in a later section of this report.

b) Possible poor flow in the vicinity of screens/sampling ports

One of the primary goals of monitoring well development is to improve flow in the vicinity of the well screen to approximate or exceed the native undisturbed flux at that point. If well development is insufficiently rigorous to remove clay smears, drilling fluid residues, and to remove bridging mineral particles then flow may be decreased in that zone relative to the surrounding aquifer. In extreme cases it might be hard to collect groundwater samples from that screen in a reasonable amount of time.

c) Particular concern that the Westbay wells are not properly developed

The multi-screen nature of the Westbay systems makes them somewhat harder to develop than a single completion well. This is because it is difficult to isolate the development energy being exerted on the screen of interest from the other screens. Typically the individual screens must be isolated by packers above and below the screened interval to efficiently accomplish development. This topic is addressed further in a later section.

Because of these three issues, there are concerns that the samples collected from the RA wells may not fully represent formation concentrations. If drilling fluids residues remain on the borehole walls, and possibly as intrusions into the aquifer, then contact of groundwater constituents, including potential contaminants, with these materials might result in chemical reactions that alter their actual aqueous concentrations as sampled. Additionally, the residues themselves might contain materials that appear to be contaminants or may cause effects on parameter values typically measured in wells to understand the geochemistry at that sampling point. Examples would include impacts on pH, DO, Eh, alkalinity, TOC, COD and so on.

2. LANL's proposal for two quarters of tailored analytical suites, followed by a full suite of analytes during the next quarter, i.e., a delay in providing full analytical suites. This proposal includes a delay of six months before acquiring the first full suite of analytes for multiple completion wells and three months before acquiring the first full suite of analytes for single completion wells. NMED is concerned that:

a) potential contaminants will be omitted from the suites and not measured

Although the GIT intends to include COC that would be expected or possible in the analytical suite for a given well, the NMED has concerns that other, unanticipated contaminants will not be discovered because they are not included in these suites.

b) data indicate that well equilibration may take 15 months

The NMED is concerned because this period for equilibration is based on estimates of the decreasing impacts of drilling fluid residues over time. It is the NMED's belief that better well development would result in much shorter equilibration periods.

c) NMED is impatient to wait this long for best quality data

Both the tailored analytical suites and the data indicating a need for 15 months of well equilibration are bothersome to NMED. This is because they would like to have quality data immediately and for that data to include not only contaminants that might be expected for a particular well but also a complete analyte suite to account for unexpected contaminants and to provide geochemical understanding.

4. Drilling Processes That Might Affect Well Development and Sample Quality

Well development is done during the final construction phase of a monitoring well for a variety of reasons. A properly constructed and developed well should provide "representative samples of ground water that can be analyzed to determine physical properties and water-quality parameters of the sample or potentiometric levels that are representative of the total hydraulic head of that portion of the aquifer screened by the well, or both. Such a well may also be utilized for conducting aquifer tests used for the purpose of determining the hydraulic properties of the geologic materials in which the well has been completed" (ASTM D5521-94, 1994). It is important that well development remove residual drilling fluid materials and provide adequate flow to the sampling point in the well.

Recently, to improve drilling efficiency, RA wells at LANL have been drilled using EZ Mud as an additive to the water used in the drilling process. This was done in an effort to improve drilling efficiency and reduce drilling cost relative to the air-rotary casing advance method that had been previously used. The transition to using this additive seems to have accomplished the goal of improving the overall drilling. However, as with most things, making an improvement in one aspect has possibly caused negative impacts in other aspects. The increase in drilling efficiency may be at least partially offset by increased difficulty in developing the wells and delays in obtaining high quality samples from them.

EZ Mud is a C-H-O-N copolymer that tends to bind to soil and aquifer materials, providing stability to the borehole during drilling. An unfortunate consequence of this binding is that it can be difficult to remove from the aquifer materials surrounding the screened intervals where the groundwater is to be sampled and it exerts significant geochemical effects on the water with which it is in contact. These effects include having a 30% negative charge density, hence having the capacity to capture and bind cationic ground water constituents, and serving as a carbon source and electron donor to subsurface microorganisms, creating very reducing conditions in the affected borehole. The External Advisory Group (EAG) to the GIT has previously expressed concern about the use of drilling additives and had the following comments in their report dated October 2000:

"There are several factors related to drilling that could affect the ground water sample quality, including:

- Analyte sorption by residues of either bentonite or synthetic fluids such as EZ Mud.
- Higher turbidity values due to entrained bentonite
- High organic carbon values due to EZ Mud
- Increased biomass on and around well screen due to EZ Mud degradation (plugging potential)
- Sorption/transformation of contaminants due to increased biomass (EZ Mud)

These influences would be expected to be transient, with the effects decreasing over time as sorption capacity is exceeded, degradation is completed, etc. However, data users should be aware that changes in parameters might be noted for an unknown number of quarterly sampling events. Caution is warranted and over-interpretation of, and over-reliance on, sampling results from the early quarterly monitoring events should be avoided."

Recently acquired analytical data seem to support the occurrence of these effects when EZ Mud is used.

5. Data on the Effects of EZ Mud on Sample Quality for the LANL RA Wells

Data have been collected and analyzed that support the EAG's concerns about drilling fluids affecting sample quality for some period of time following well completion. These data have been collected by the GIT Geochemistry Subcommittee. TOC values have been excessively high in wells drilled using EZ Mud relative to those where it has not been used and the known background TOC concentrations in the aquifer. Sulfate reduction has also been occurring, indicating a significant decrease in the Eh (oxidation/reduction potential) of the groundwater in the vicinity of the RA wells drilled with EZ Mud. Changes in conditions such as this can cause significant impacts on the water chemistry and result in poor understanding or misinterpretations of the presence of contaminants and their transport and fate. EZ Mud is strongly hydrophobic (a high molecular weight polymer), which probably has the ability to partition organic compounds such as RDX, HMX, and TNT. The nitrogen functional groups in EZMud mimic nitro (NO_2^-) and amino (NH_2^-) functional groups present in high explosive (HE) compounds and associated degradation products.

For example, residual drilling fluids (EZ Mud) have resulted in false positives for HE compounds and degradation products in some of the samples. Also, in screen 5 of well R-22, the water chemistry is totally different from what it was in the open borehole or what would be expected in the regional aquifer as a whole. Alkalinity increased from about 86 to 150, mg/L as $CaCO_3$. Sulfate decreased from about 9

mg/L to 1 mg/L, while dissolved Fe (Fe^{2+}) and TOC went from non-detects to 4.3 and 13 mg/L, respectively. These are all strong indicators of the presence of organic carbon in the system, undoubtedly present due to the residual EZ Mud, which is serving as an electron acceptor and allowing reductive microbial processes to occur. In this particular case the microbes are using sulfate as the electron donor. Patrick Longmire and his colleagues on the GIT Geochemistry Subcommittee have summarized these reactions in a conceptual manner as follows:

Overall Reaction

anaerobic microbes + iron(III) + sulfate + EZ Mud (organic substrate) → iron(II) + hydrogen sulfide + alkalinity

Reduction Reactions (anaerobic conditions)

iron(III) solids reduce to iron(II) aqueous species
sulfate reduces to hydrogen sulfide

Oxidation Reaction

EZ Mud (C-H-O-N copolymer) → inorganic carbon (H_2CO_3 and HCO_3^-)

Although these reactions are occurring and are undoubtedly due to the presence of EZ Mud residues introduced via the boreholes, it is not certain that more vigorous well development can completely ameliorate the problem. Well development energy dissipates rapidly with increasing distance from the borehole, whereas the drilling fluids, depending on the strata, the volume introduced and the conditions of introduction, might infiltrate a significant distance from the borehole into the aquifer to locations where development procedures might have little or no impact.

6. Assessment and Discussion of the Well Development and Sampling Concerns

1. Potential problems with low-flow rate sampling in potentially underdeveloped wells.

   a) Effects of residual drilling fluid materials

   There are no perfect techniques for sampling groundwater. The key is to determine what must be known from a groundwater sample and, in fact, whether the information desired is even attainable under a given set of circumstances. Low-flow rate purging and sampling techniques were developed to minimize disruption to both the standing water column and the surrounding aquifer materials when sampling a traditional monitoring well and when the desire was to understand the water quality at the point designated by the location of the sampled screen. No sampling approach can truly compensate for the damage done to an aquifer in the vicinity of a borehole as a result of the drilling process. Although one might believe that pumping rapidly and withdrawing large volumes of water might reduce the impact of residual drilling fluids on the water sample, other questions are introduced when such an approach is

used. For example, if there is a known effect of residues on the samples collected by low-flow techniques, which should almost fully quantify the impact, what is the impact on a sample collected by high-flow techniques? It may be less, but what is it exactly? How does one assess the additional impacts of sample turbulence, potential aeration, and the entrainment of significantly greater quantities (usually) of solid aquifer materials in the samples? Where does the water come from that is being pumped at such a high rate, the same zones that contaminants are in or could the concentrations of contaminants be (apparently) lower because of dilution effects?

It is commonly known that, following the disruption of the aquifer that is imparted by drilling, a period of time is required before data that are considered truly reliable can be obtained from a monitoring well. This is particularly true in wells that are difficult to drill, deep, and require additives to accomplish the drilling. It is the contention of the authors of this report that reverting to high-flow sampling techniques is not a good answer and will probably not accomplish the goal of obtaining representative groundwater samples. It is probably a moot point for the Westbay wells anyway since they are not designed for extremely high flow rate sampling.

b) Possible poor flow in the vicinity of screens/sampling ports

Incomplete or insufficient development of a screened interval in a well can indeed result in restricted flow to the sampling device. However, poor development is not the only cause of restricted flow. If a screen has been set in a zone of limited water supply or in an extremely tight formation (silt, clay), then restricted flow may have nothing at all to do with the development process. At LANL, screens set in some of the zones that seemed to hold perched water during the drilling phase are not yielding water. It may simply be that these zones no longer contain sufficient water. We are not aware of any screened intervals below the regional aquifer water table that are not yielding water sufficient for sampling with the Westbay systems. In addition, recent publications have indicated that the Westbay systems are useful for testing and sampling even under extremely low-yielding conditions (T. Ishii, H. Nakashima, T Hokari, M. Horita, H. Sugawara and T. Mase, 1998, "In-situ measurement of low permeability of formation by use of MP System", Japanese, First Atomic Power Industry Group).

c) Particular concern that the Westbay wells are not properly developed

The small diameter, great depth, and multiple screened intervals of the Westbay systems undoubtedly makes them harder to develop than shallow single screened wells. Using this type of well was a conscious choice, however, to maximize the information that could be obtained from a single borehole since it would have been prohibitively expensive to drill nested wells to such extreme depths at LANL. Additionally, Westbay systems can be developed sufficiently to obtain quality groundwater samples. This has been done at other locations and we believe it is also being accomplished at LANL, even though improvements are possible. Most of the

installations of Westbay systems in the U.S. have been drilled by bentonite mud rotary, using typical water well development techniques. Sometimes chemical stimulants, such as SAPP (sodium acid pyrophosphate) have been used to assist the process. Straddle packer pumping has been used for the final step of development. Example sites include the San Gabriel Valley Superfund site, the NASA site in Pasadena, and the Orange County Water District in California. Installation contractors have included Lang Drilling, Beylik Drilling and Water Development Corp. Turbidity specifications were set for each screen, straddle packer final development was used and they were also videoing each screen in certain cases (David Larson, personal communication).

2. LANL's proposal for two quarters of tailored analytical suites, followed by a full suite of analytes during the next quarter, i.e., a delay in providing full analytical suites. This proposal includes a delay of six months before acquiring the first full suite of analytes for multiple completion wells and three months before acquiring the first full suite of analytes for single completion wells. NMED is concerned that:

   a) potential contaminants will be omitted from the suites and not measured

   The NMED concern that other, unanticipated contaminants will not be discovered because they are not included in the analytical suites proposed by the GIT is understandable, but should be considered within the context of the overall situation. The GIT has proposed these suites and sampling intervals to allow the well bores and adjacent formation materials to come back into a state of pseudo-equilibrium with the surrounding aquifer. It is fairly common knowledge that the extreme disruption imparted to a formation during the drilling process can impact the results of sampling due to the impacts on both the water chemistry and the disrupted mineralogy (freshly exposed reactive surfaces, residual drilling fluids, aeration, etc) for some period of time. The GIT intends to include COC that would be expected or possible in the analytical suite for a given well, without resorting to analysis of the complete list of priority pollutants. This should significantly reduce costs while incurring no significant increase in risk to human health and the environment. It might, in fact, reduce the risk of false positives resulting from the degradation of the EZ Mud that have been noted and avoid unnecessary response actions or the requisite paperwork burdens, discussions, and addressing of citizen concerns that such false positives could incur. Should the expected COCs designated for the suites be non-detected, or at extremely low levels, the odds of finding unanticipated contaminants are also very low. Even should it be discovered, following the full suite analyses, that something unknown was present, or that conditions are not exactly as expected, the groundwater flow in the RA is so slow that this difference in time should be of no consequence.

   b) data indicate that well equilibration may take 15 months

   The Geochemistry Subcommittee of the GIT has extrapolated, from data on sulfate reduction, that some RA wells might take up to 15 months to equilibrate before EZ

Mud residues are sufficiently degraded and mineralized that data of the best quality can be obtained from the wells. Although this might seem to be a long time, it is brief relative to the 50 year expected lifetimes of the RA monitoring wells. In the meantime, the GIT does propose to continue quarterly monitoring for the COCs and certain other parameters throughout this equilibration period even while warning that the data might not be of the best quality. Increasingly rigorous well development might reduce this period but would be unlikely to entirely negate it by eliminating all traces of the EZ Mud residue (as discussed previously). The amount of reduction in the equilibration periods with increased well development is not predictable. What is predictable is that increasing the well development activities will rapidly increase the overall cost of completing the wells. There is a point of diminishing returns on the investment and the advantages of having highest quality data sooner must be contrasted against the expense of obtaining it.

c) NMED is impatient to wait this long for best quality data

It is certainly understandable that NMED would like to acquire groundwater data of the highest quality as quickly as possible since they are charged with protecting human health and the environment. It is very important, however, to understand that every process involved in acquiring groundwater samples can impact the quality of the data and that decisions that are made with regard to well installation, completion and sampling techniques will all affect the results and interpretations.

It was a conscious decision to begin drilling with the use of drilling fluid additives, a decision that was initially introduced and promoted by the NMED to speed the well installation process. These equilibration period estimates are based on empirical data resulting from sampling of the wells after drilling with these additives. LANL should be commended for doing the work to make these estimates rather than chastised because consensus drilling decisions have caused a short-term impact on data quality. These estimates provide a useful tool for determining when it is appropriate to begin having a higher degree of confidence in the data obtained from the wells.

7. Discussion and Recommendations for the Well Development Process at LANL

Well development can be defined as the process used to repair the damage done to the borehole wall during well drilling to restore or improve the original porosity and permeability of the formation materials around the well. It involves the removal of drilling mud and solids circulated in the mud system as well as formation fines near the borehole face. Results of well development are improved well efficiency (higher flow rates) and stabilization of the formation solids so that water produced from the well will be sediment free.

Development is usually performed with various combinations of mechanical agitation including pumping, backwashing, surging and jetting. It also can employ the use of

chemicals, such as polyphosphates, that help loosen silts and clays, facilitating their removal.

Regardless of the procedures chosen for well development, two key tasks must be accomplished to maximize the development effect:

1) Flow reversal
2) Fluid removal

Flow reversal involves reversing the direction of water flow by periodically forcing water to move from the well into the formation, rather than only from the formation into the well. When water moves only one direction, i.e., only into the well, fines outside the borehole "bridge" and remain locked in place. Periodically reversing the flow direction breaks the sand and silt bridges, allowing more fines to enter the well during the next pumping cycle. Thus, the flow from the formation into the well, and vice-versa, has the beneficial effect of dislodging fines trapped in the formation adjacent to the borehole. As a corollary, this means that developing a well strictly by pumping can be ineffective. Flow reversal can be accomplished by using backwashing, surging, water jetting, or operating a compressed air system.

Fluid removal involves pumping, bailing or airlifting water from the well. Removing water from the well purges sediment from the screened area so that it will not be re-introduced into the formation where it can exacerbate clogging of the pore spaces or negatively impact sample quality for an extended period. This means that surging or jetting alone may not provide effective well development because fines that are brought into the well are continually pushed back into the formation. Removing water during development is essential to prevent re-introduction of fines into the aquifer.

Thus, for development to provide maximum effectiveness, it must combine both flow reversal and fluid removal. Accomplishing both of these tasks in the RA wells at LANL is a difficult job because:

1) The wells are deep.
2) The wells are small in diameter.
3) The static water levels are deep.
4) Some of the screen zones are tight and low yielding.
5) Multiple zones have substantially different piezometric heads.

There are two other considerations to keep in mind regarding well development. First, simple flow reversal and fluid removal do not guarantee good development if there is severely impacted drilling mud, silt or natural clay in the formation pores. Under these conditions, it may be necessary to apply maximum hydraulic energy to the affected zone by high velocity water jetting in addition to flow reversal and fluid removal. Second, the selection of the filter pack affects the ability to develop the well. In general, the coarser the filter pack, the easier and more effective development will be. This is because

formation solids can be moved through a coarse pack more easily than through a fine-grained pack.

Currently, conservative (fine-grained) filter packs are being used in all RA well screen zones. The use of these fine-grained packs maximizes the difficulty of developing the zones. One way to make the development process easier and more effective would be to use a coarser filter pack design in screen zones where the grain size distribution of the natural sediments is compatible with the coarser pack material. (Note: the grain size of the filter pack cannot be increased arbitrarily. The pack must still be designed using standard well design and filter pack selection criteria and must remain fine enough to stabilize the formation materials and provide sand free production.)

Before settling on a development approach, it is constructive to consider the challenges associated with conditions at LANL. First, consider the large head differences that can exist among screened zones. In R-25, for example, the head in the upper screens is hundreds of feet higher than that in the lower screens.

Under such conditions, merely pumping the well (via airlift or using a submersible pump) is ineffective for the deeper zones. Prior to pumping, the effective static water level in the well represents a weighted average of the water levels in each of the screened intervals. As a consequence, under non-pumping conditions, the upper screens continuously produce water while the deeper screens continuously take water. Pumping the well lowers the effective water level in the well, but usually still leaves it above the static levels of the deeper screens. Thus, the deepest zones still take water, even when the well is being pumped. Physically placing the pump inside a deep screen interval does not change this – the deep interval in which the pump is placed continues to take water rather than make water. Under these conditions, simply pumping the well accomplishes zero development of the deeper screen zones.

In areas of downward gradients, it is necessary to place a packer immediately above the screen to be pumped to make sure that water will be produced from that zone. Similarly, in areas where the gradient is upward, near the Rio Grande River for example, a packer would be required just beneath the screen zone to be pumped to assure production from that zone. To be sure of effective pumping regardless of head conditions, packers above and below the target interval would be beneficial. Without isolating the individual screen zones, it is not possible to achieve the required *fluid removal* from all zones.

Vertical head gradients also can affect the ability to achieve *flow reversal* by surging. In areas of steep downward gradients, the upper screens may lie above the effective average water level in the well. Thus, the upper screens may not even be filled with water, thereby precluding surging with a surge block. In this situation, high velocity water jetting could be used to achieve flow reversal. Alternatively, it would be possible to isolate each screen using packers above and below the screen and operating a small diameter surge tool inside the pipe on which the packers are run.

Tight zones also can be problematic with respect to achieving either flow reversal or fluid removal. For example, if a tight zone is isolated with straddle packers and pumping is attempted with a submersible pump, the zone may not supply enough water to satisfy the pump. This will render the attempted pumping ineffectual. Even if the pumping rate can be reduced to match the capacity of the screen zone, the low production rate may be inadequate to remove fines effectively. As a result, production of solids (turbidity) could persist for an extended period when the well is sampled. In some wells and screen zones, there may not be a practical way of overcoming this limitation.

The deep static water levels and small diameters of the RA wells offer challenges to well development. The deep static water levels make airlift methods marginally effective compared to hydrologic settings with higher water levels. The slim holes limit the equipment that can be run in the wells for development purposes. For example, it is not possible to simultaneously reverse flow and remove fluid, say by high velocity water jetting while pumping the well at the same time. Thus, these tasks must be done alternately, which can take an enormous amount of time running equipment in and out of the well. In fact, regardless of the development method used, the great depth of the RA wells adds to the cost of development because of the time it takes to run equipment at these depths.

To properly develop the screen zones in the RA wells, it will be essential to identify procedures that will accomplish the two objectives of flow reversal and fluid removal.

Flow reversal can be accomplished by:

1) High velocity water jetting with clean water or a polyphosphate solution
2) Running a surge block inside the screen zones (provided the screens are filled with water)
3) Surging with a double disk surge block while adding clean water
4) Isolating individual screens with straddle packers and operating a slim surge tool inside the tubing on which the packers are run
5) Isolating individual screens with straddle packers and alternately airlift pumping and backwashing by adding clean water

Another approach that could be investigated would be to see if it is possible to rig up a submersible pump with isolation packers in such a way that it would be possible to alternately pump and backwash (perhaps by inflating and deflating the upper packer to allow adding water from the surface between pumping cycles).

Fluid removal can be achieved by:

1) Bailing
2) Airlifting
3) Pumping with a submersible pump

However, at the great depth of the RA wells, bailing would be very slow and airlifting may be marginally effective. In multiple screen completions, isolation packers will be essential to make pumping effective. In areas of downward gradient, a packer is required above the zone that is pumped. In areas of upward gradient, a packer is required below the pumped interval. Optimum results will be obtained by placing straddle packers both above and below the pumped interval to handle any conditions encountered.

Often, two or more development techniques will be required to accomplish both flow reversal and fluid removal. Unfortunately, it is very time consuming to run different tooling strings in and out of the well and set isolation packers around individual screens. As a result, it is inevitable that well development will be time consuming and expensive.

To try to minimize the time invested and the associated costs, specific development plans should be made in cooperation with the drilling contractor to use the most practical approach possible to accomplish the desired objectives. The methods selected should be those that accomplish flow reversal and fluid removal in the fastest way practical. While numerous combinations of techniques may all work satisfactorily, some may be slower and, therefore, more expensive than others. The contractor can best judge the time required for various tasks.

It may be necessary to do some "experimentation" to find out which methods work best and how long they actually take. By trying various approaches and measuring their effectiveness and cost, it should be possible to optimize the effort. Regardless of the approach taken, straddle packers will almost surely be required for some or all of the development work.

In preparing this report, drilling contractors and consultants who have worked on deep, multi-screened monitoring wells were contacted and queried about the development methods that have worked successfully. In most cases, setting isolation packers along with pumping, surging or airlifting has been used effectively.

It is important to point out, however, that the static water levels at most sites are relatively shallow compared to those at LANL. This makes development much easier. For example, airlift methods are vastly more effective because greater submergence of the airline allows pumping at substantially greater rates, resulting in more rapid and effective development. Also, a greater variety of submersible pumps are available for low-head conditions, making it easier to pump large quantities of water, speeding sediment removal and cleanup.

Comparisons often are made regarding wells at LANL and those at either the Nevada Test Site (NTS) or the Idaho National Engineering and Environmental Laboratory (INEEL). It is significant that wells at the NTS and INEEL are developed *open hole* prior to running screen, casing and filter pack. Open-hole development is enormously easier and more effective than development after well completion, because there are no screen and filter pack to create a "barrier" to effective development as in completed wells. Thus, a comparison of development procedures and effectiveness at LANL and

the other two sites is really an "apples-and-oranges" comparison. Open-hole development at NTS and INEEL is made possible because the formations are stable and will stand open readily. This is the same circumstance that makes the drilling process itself less costly at those locations.

8. Example Development Procedure

The foregoing discussion illustrates that there are numerous development methods that can be applied successfully. The exact approach used at LANL will probably require some trial and error to evaluate site-specific effectiveness and cost of implementation. The following is a three-step development process that may work effectively at LANL in areas where the vertical gradients are downward. It is just an example of a set of procedures that could provide effective development of the RA-wells. At each step, the suggested development action could be replaced by any of a number of options from the preceding lists of development procedures. These steps are intended to serve as a "straw man" that can be customized and modified based on input from the driller and LANL personnel and field experience gained as various development techniques are applied to completed wells.

Step 1. Initial Cleanup

Use simple pumping to purge the well of excess drilling fluids and solids that can be removed easily. The well should be pumped until the water removed is clear and sediment free. Pumping should be from the very bottom of the well. Pumping can be accomplished with a submersible pump or a dual-pipe airlift assembly.

Step 2. Surging

Surge the well by operating a surge block or dual surge packers in each of the screen intervals. Those screen intervals that lie above the effective average static water level in the well would have to be developed using a double disk surge tool while adding clean water between the disks. The surging is intended to create frequent and rapid cycles of flow reversal to loosen drilling solids and formation fines and bring them into the well.

Step 3. Pumping Between Isolation Packers

Run a submersible pump and dual isolation packers into the well and, starting from the top, isolate and pump from each individual screen zone. Once clean water is produced, stop the pump and temporarily release the top packer to create a surging action (flow reversal) by adding water from the surface or by allowing water to flow down from the overlying screen zones, if the natural flow rate is sufficient. This will reverse the flow and drive water from the well, through the screen, and into the formation. Once flow reversal has been achieved, quickly re-inflate the upper packer, restart the pump, and pump until clear water is produced from the isolated screen. Repeat this process as long as each new cycle produces additional sediment from the target interval.

As mentioned previously, the proposed development method is only one of many options available. Before this suggestion is used, the identified procedures should be reviewed by the contractor and LANL personnel so that if needed, pragmatic modifications can be applied to ensure an optimum combination of effectiveness and cost. For example, when appropriate, the first step could also incorporate wire brushing the inside of the well, if that is deemed useful. Similarly, in the second step, high velocity water jetting with chemical additives could be substituted for surging. There is not one single "perfect" approach that is guaranteed to produce ideal results. The methods eventually selected for developing the RA wells will probably depend on the number of screened intervals in each well, yields of individual zones, magnitude and direction of vertical gradients, cost, available equipment, input from LANL personnel and the contractor, and empirical results obtained in the field over time.

9. Summary and Conclusions

At present, water samples obtained from completed wells at LANL show the presence of drilling additive residues that haven't been removed completely during the well development process. NMED is concerned about this apparent lack of complete development.

As a consequence of the drilling fluid residues being present in initial water samples, LANL has proposed the idea of limiting analytical testing to tailored suites of parameters until the sampling points are closer to achieving equilibrium with the surrounding formation. LANL has proposed a delay of 3 to 6 months before running a full suite of analytes. It appears that it actually could take 15 months for the effects of drilling additives to dissipate. NMED has expressed a desire to achieve complete chemical analyses more quickly.

Because of its concern regarding complete development of the RA wells and desire to obtain representative water quality information quickly, NMED has suggested that well development procedures be examined and improved so that screen zones can be made efficient and high yielding, and that the drilling fluid additives can be purged from the well during the development process.

While the NMED goals and concerns are valid, well development approaches will be unavoidably limited by economic practicality (cost) and the physical constraints of the hydrogeolgic setting. The key physical parameters that profoundly affect the ability to develop the RA wells include the following:

1. The wells are deep.
2. The wells are small in diameter.
3. The static water levels are deep.
4. Some of the screen zones are tight and low yielding.
5. Multiple zones have substantially different piezometric heads.

This combination of physical constraints is largely unique to LANL. Other drilling environments exhibit some of these characteristics, but it is difficult or impossible to find an analogous setting where all come into play simultaneously. It is this combination of conditions that limit well development options and effectiveness and drive up costs at LANL.

Development procedures used heretofore at LANL are standard and appropriate procedures, consistent with ASTM standards and accepted groundwater industry practice. However, the unique conditions at LANL require that additional development measures be considered as presented previously in this report. Included in this approach are the following:

- Having the ability to isolate the screened zones in multiple completion wells for all development methods
- In consultation with the drilling contractor select a development method(s) based on its effectiveness, practicality, and cost/benefit ratio.
- Have the final development step be pumping the individual isolated screened zones as vigorously as possible.

Even when more extensive development procedures are employed, the challenges caused by the physical constraints of the hydrogeologic setting at LANL may tend to neutralize these efforts to some extent. Thus, it likely will not be feasible to develop individual screen zones to "near perfect" conditions, as might be possible in a large diameter, shallow well in a permeable aquifer with a high static water level. However, with a thoughtful approach that is monitored and modified as deemed appropriate, it should be possible to obtain acceptable well development and reasonable results.