# REDOX CHEMISTRY OF AQUIFER SYSTEMS IN THE PRESENCE OF RESIDUAL DRILLING FLUIDS

BY

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I. Introduction

II. Types of Drilling Fluids

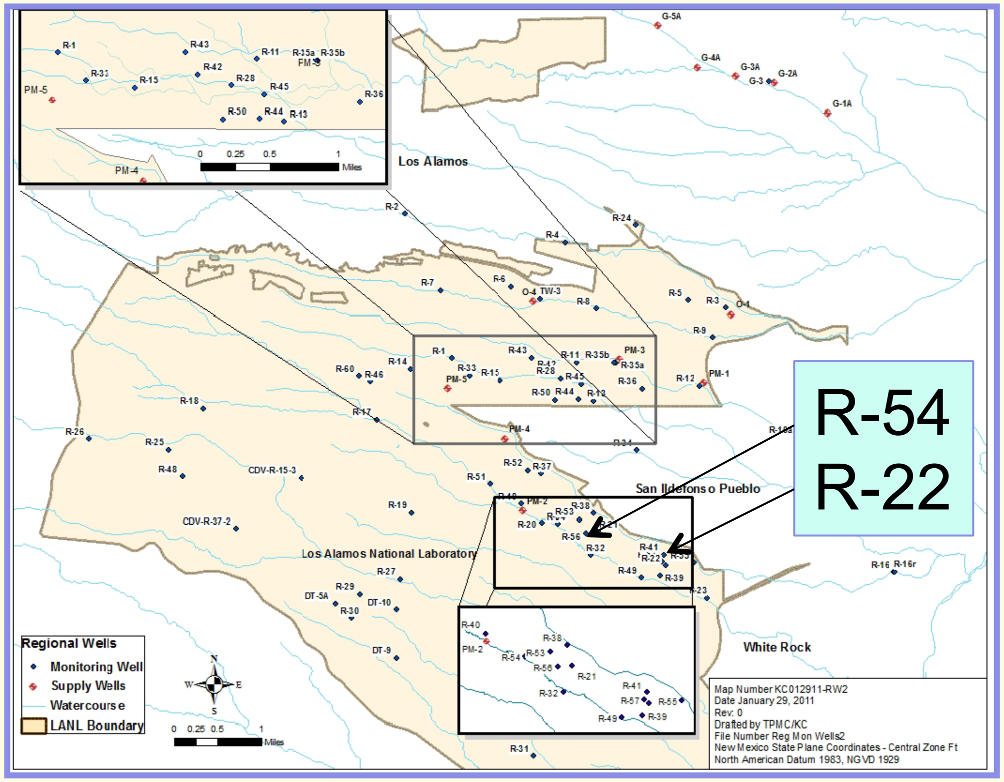
III. Background Solute Concentrations

IV. Residual Drilling Fluid Impacts

V. Well Rehabilitation

VI. Summary and Conclusions

# Map Showing Monitoring Well Locations at Los Alamos National Laboratory (LANL), New Mexico




**Los Alamos National Laboratory**

**A total of 67 regional aquifer monitoring wells have been drilled at LANL since 1997. This includes 35 single screen and 32 multiscreen wells.**

**The regional aquifer monitoring wells exceed 300 meters in depth and are constructed of stainless steel.**

# LANL Hydrostratigraphy and Reactive Solids

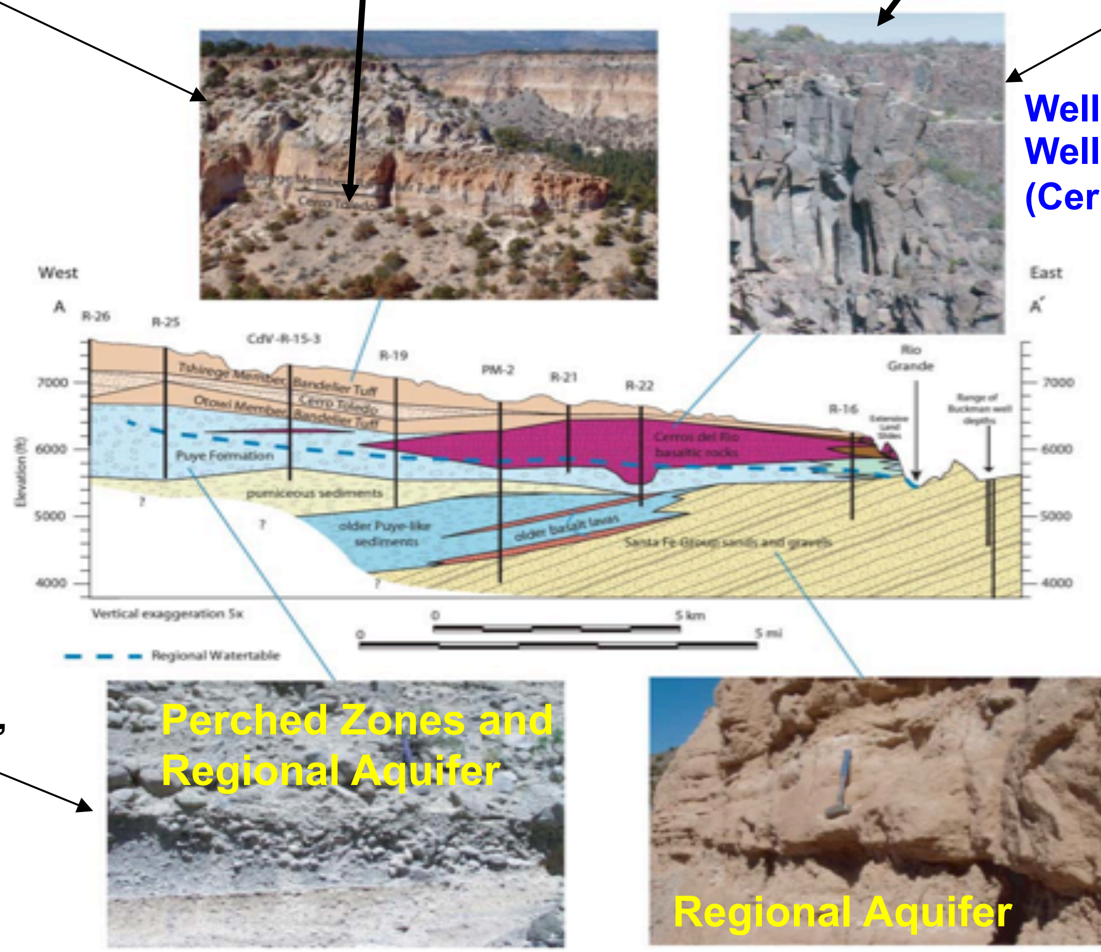
clay minerals, $Fe(OH)_3$, zeolites

Perched Zones

Perched Zones and Regional Aquifer

$MnO_2$, clay minerals, $Fe(OH)_3$, calcite

Well R-22, Screen 1
Well R-54, Screen 1
(Cerros del Rio basalt)




clay minerals, $Fe(OH)_3$

$MnO_2$, clay minerals, $Fe(OH)_3$, calcite

# Mean Background Concentrations of Redox-Sensitive Solutes and Eh for the Regional Aquifer, Los Alamos, New Mexico (NMED, 2013)

| Analyte | [1]mM or [2]µM | [1]mg/L or [2]µg/L |
|---|---|---|
| $ClO_4$ | [2]2.73e-03 | [2]0.27 |
| DO | [1]0.19 | [1]5.93 |
| $NO_3$-$NO_2$(N) | [1]0.03 | [1]0.44 |
| Mn | [2]0.03 | [2]1.82 |
| Cr | [2]0.06 | [2]3.12 |
| Fe | [2]0.20 | [2]0.27 |
| Total $CO_3$ Alkalinity | [1]1.23 | [1]61.4 |
| U | [2]1.81e-03 | [2]0.43 |
| $SO_4$ | [1]0.03 | [1]2.95 |
| Eh | Not Applicable | 401 (mV) |

Note: Nitrate-nitrite (412 analyses), sulfate (407 analyses), total carbonate alkalinity (409 analyses), DO (399 measurements), and Eh (367 measurements) provided by LANL. Analytical results for metals (102) provided by NMED. Mean pH = 7.84.

# Typical Sequence of Drilling Fluid Use, Los Alamos National Laboratory, New Mexico

## *Drilling Phase*

**Mud Rotary-**

**Drilling Fluid (Bentonite, Soda Ash, Water);**

**Polymer Additives (EZ-MUD®); and**

**Air Rotary-**

**Water; Surfactant (QUIK-FOAM, AQF-2);**

**Injected Polymer Additives (EZ-MUD®); and**

**Casing Lubricants (TORKease)**

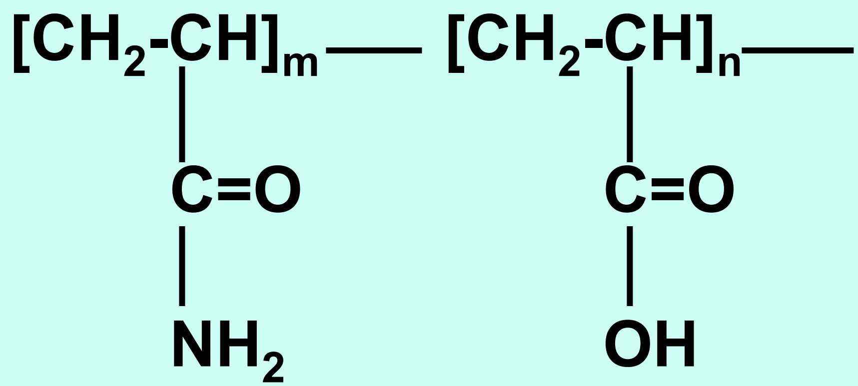
## *Well Construction Phase*

**Annular Fill, Water, Portland Cement, Bentonite Chips or Pellets, Polymer (EZ-MUD®)**

## *Well Development-Rehabilitation Phase*

**Formation Water, Physical Methods, KOH, $H_3PO_4$, Sodium Acid Pyrophosphate (SAPP)**

## Chemistry of Polyacrylamide-Polyacrylate Copolymer (EZMUD®) (Longmire, 2002)

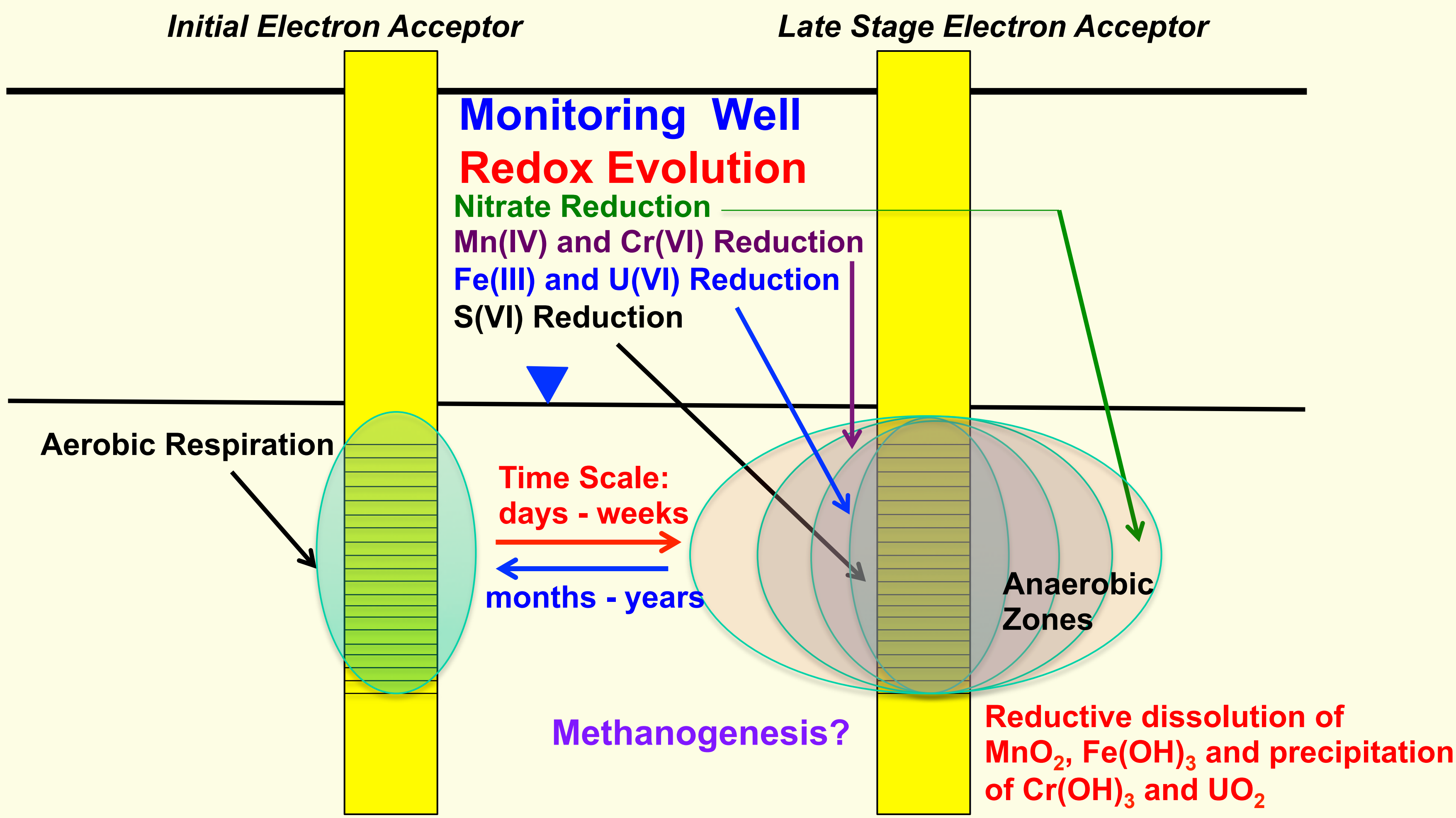



***Acrylamide Unit*** **(70%)**
**(produces TKN, TOC)**

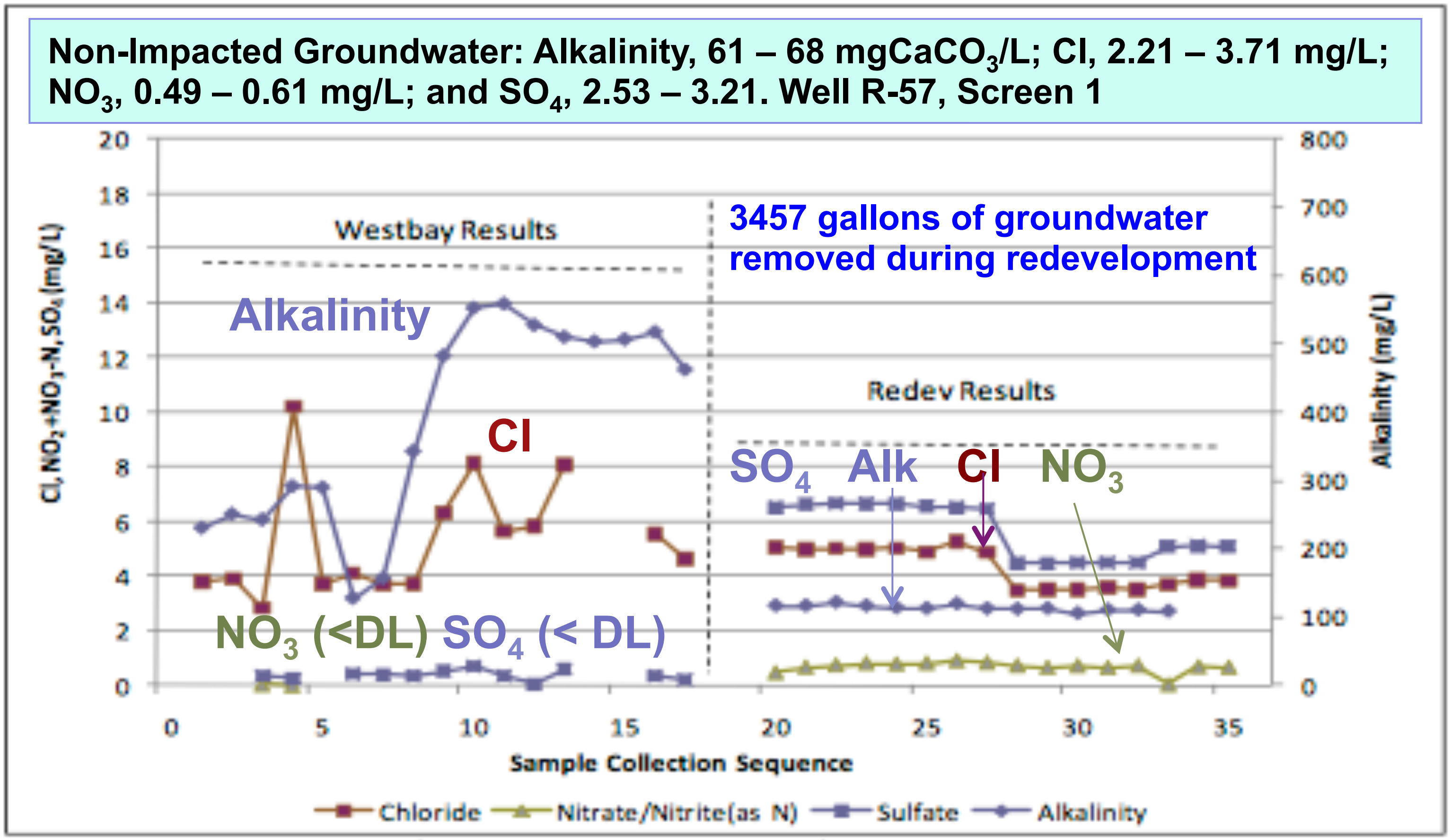
***Acrylic Acid Unit*** **(30%)**
**(produces TOC)**

**Final Oxidation Products: Ammonia, TKN, and Carbonate Alkalinity**
**Molecular Weight: 4 to 6 million atomic mass units**

# Conceptual Model of Electron Acceptor Zones Surrounding a Monitoring Well Containing Residual Organic Drilling Fluids

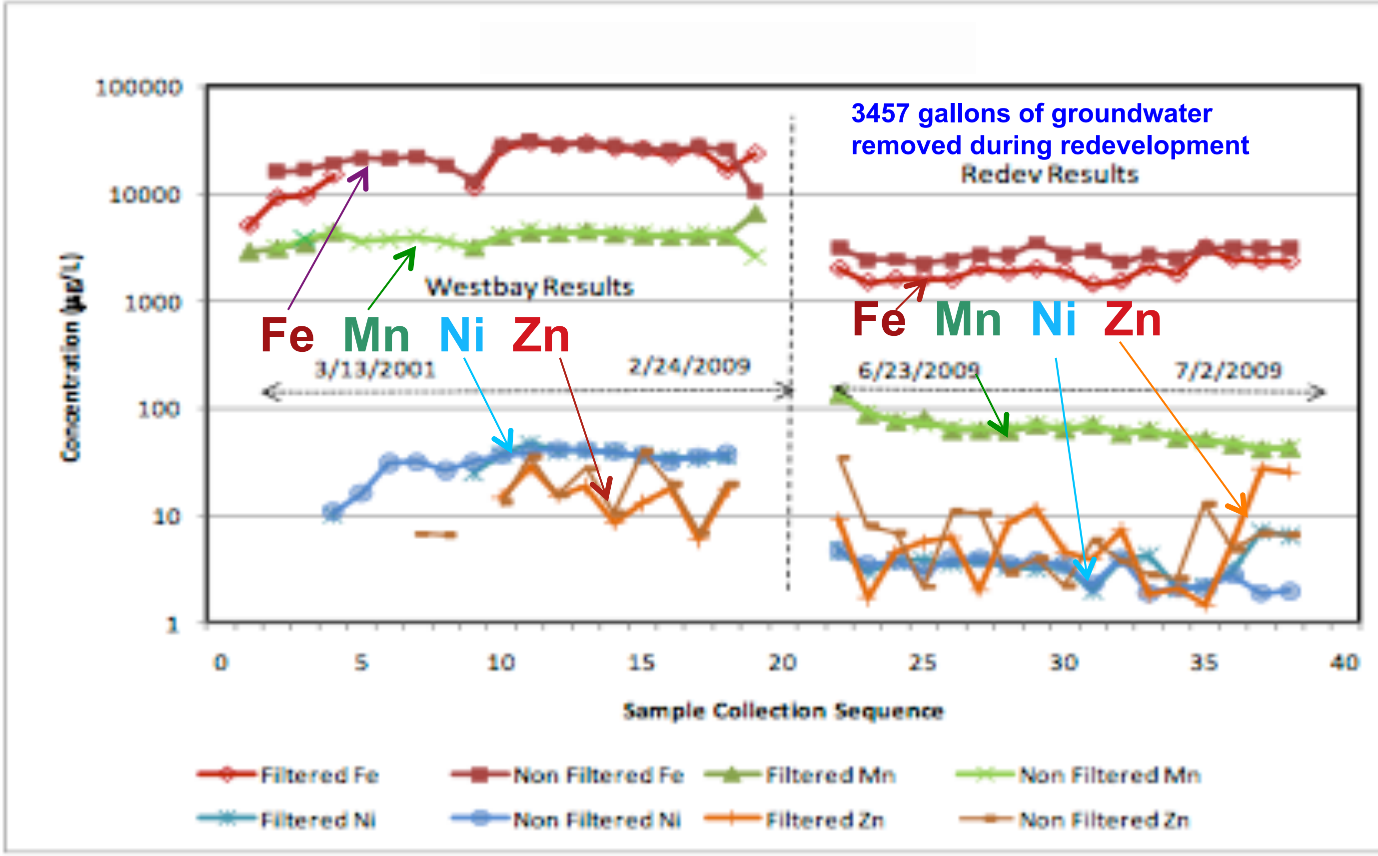


# Concentrations of Dissolved Anions at Regional Aquifer Well R-22, Screen 1, From 2001 to 2008 (Longmire, 2002; LANL, 2009)




Note: Total carbonate alkalinity ($CO_3^{2-}$+$HCO_3^-$), chloride ($Cl^-$), sulfate ($SO_4^{2-}$), nitrite+nitrate (as N) ($NO_2^-$+$NO_3^-$–N) during characterization sampling using Westbay equipment (March 2001–September 2008) and during redevelopment (June and July 2009).

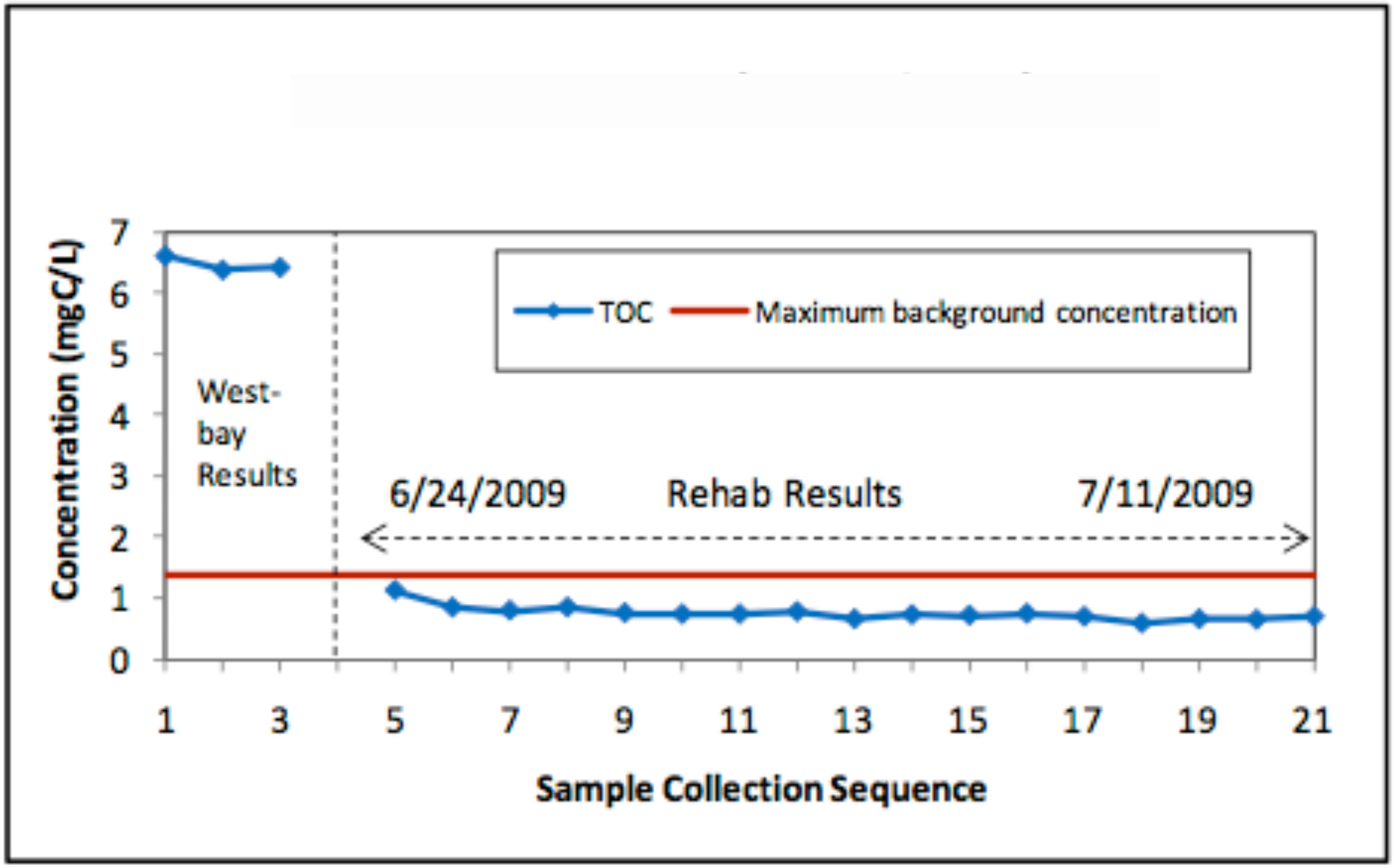
# Concentrations of Dissolved Metals at Regional Aquifer Well R-22, Screen 1, From 2001 to 2008 (Longmire, 2002; LANL, 2009)



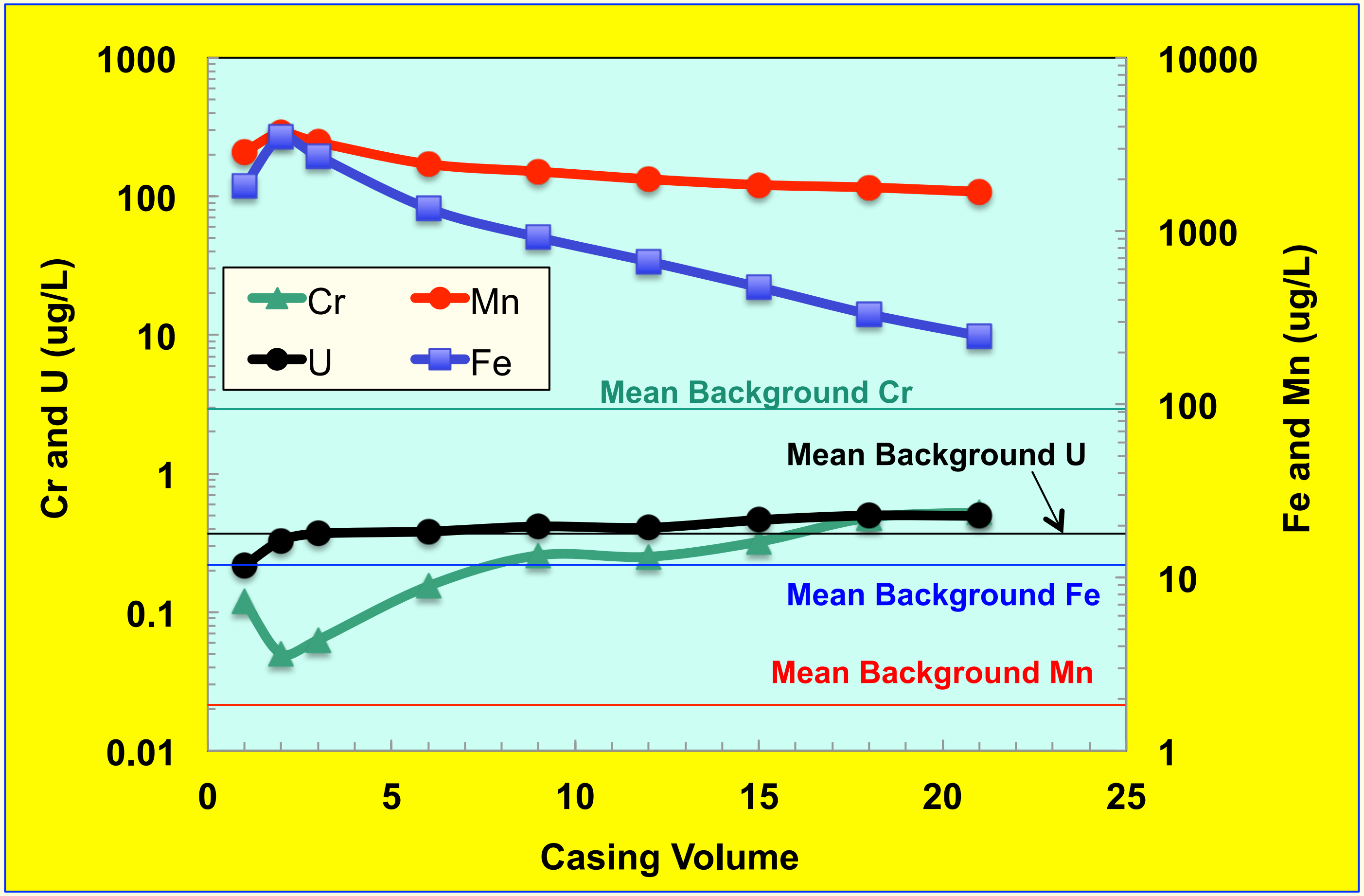

Note: Dissolved (filtered) and total (nonfiltered) concentrations of iron (Fe), manganese (Mn), nickel (Ni), and zinc (Zn) during characterization sampling using Westbay equipment (March 2001–September 2008) and during redevelopment (June and July 2009).

**Non-Impacted Groundwater: Fe, <10 µg/L; Mn, 17.9 – 44.2 µg/L; Ni, 1.06 – 1.20 µg/L; and Zn, 4.2 – 6.48 µg/L. Well R-57, Screen 1**

# Concentrations of Total Organic Carbon at Regional Aquifer Well R-22, Screen 1 (Longmire, 2002; LANL, 2009)

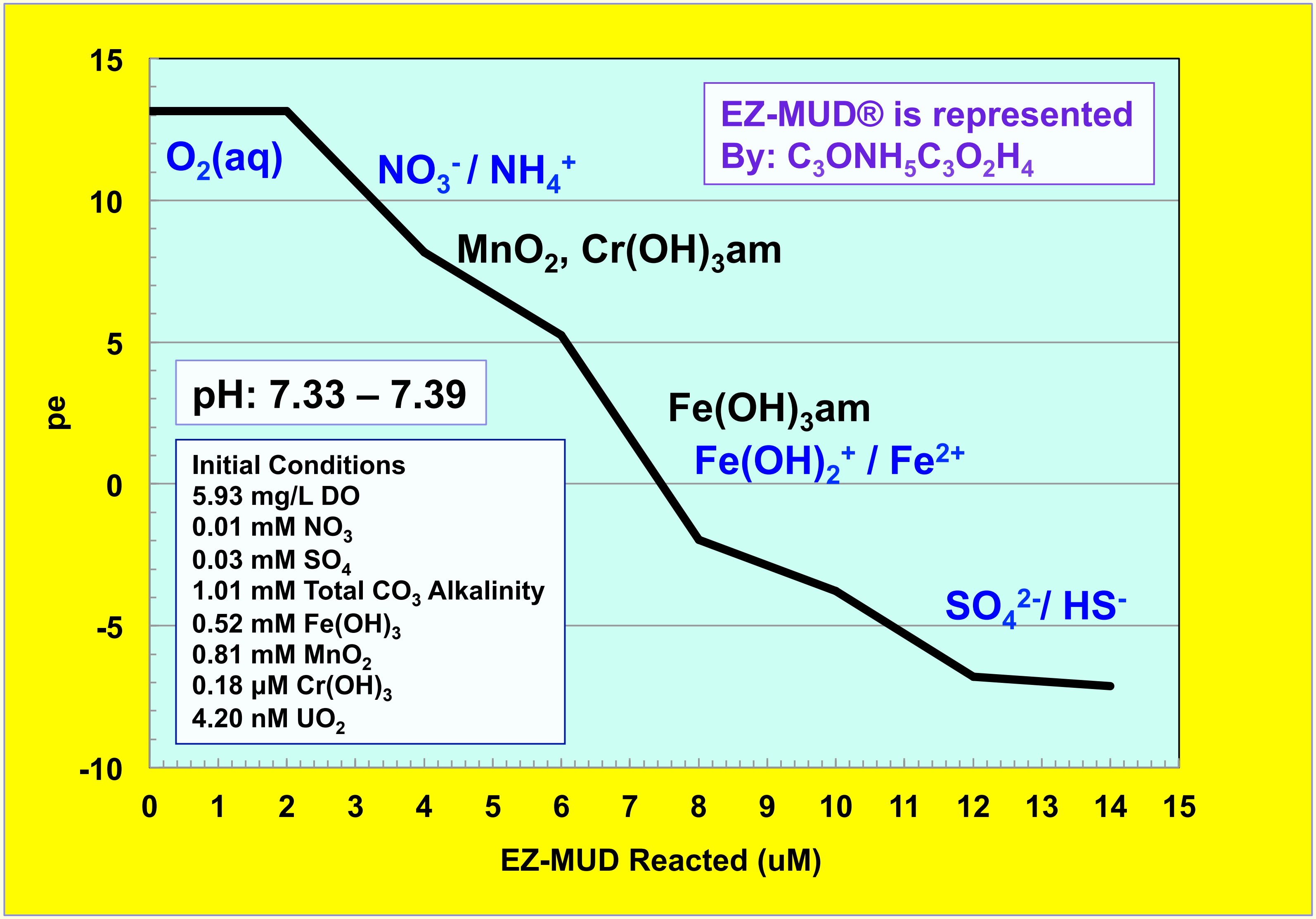


# Concentrations of Dissolved Chromium, Iron, Manganese, and Uranium at Regional Aquifer Well R-54, Screen 1 (11/02/2011)

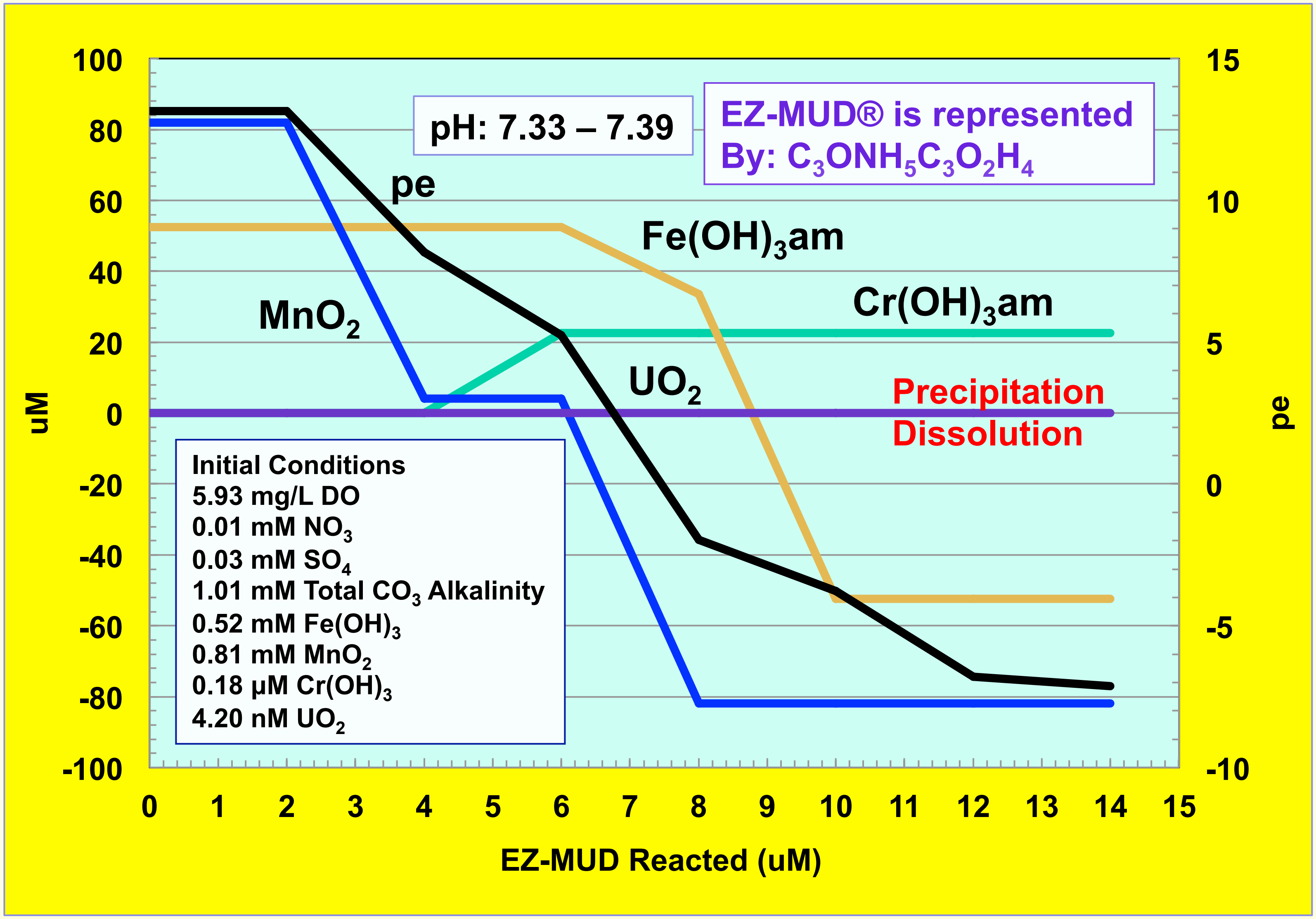



**Well R-54 was drilled using an air rotary method with AQF-2 (surfactant). Hammer oil leaked into regional groundwater creating anaerobic conditions, initiating multiple redox reactions over time. R-54, screen 1 is completed In basaltic sediments of the Cerros del Rio basalt.**

# Results of Calculated Redox Titration Curve (25°C) Using PHREEQC for the Mean Regional Aquifer Composition Reacting with EZ-MUD®



# Results of Mass Transfer Calculations (25°C) Using PHREEQC for the Mean Regional Aquifer Composition Reacting with EZ-MUD®



# Summary of Impacted Monitoring Wells Completed in the Regional Aquifer, Los Alamos National Laboratory, New Mexico

| Impacted Well Screens | Original Completion | Primary Residual Drilling Fluids | Rehabilitated | Conversion | Representative Samples |
|---|---|---|---|---|---|
| **Regional Aquifer Screens** | | | | | |
| CdV-R-15-3 (S4 to S6) | No-purge Westbay | EZ-MUD, QUIK-FOAM, Bentonite Mud | Yes | Single Screen Pump (S4) | Yes |
| CdV-R-37-2 (S2 to S4) | No-purge Westbay | EZ-MUD, QUIK-FOAM | Yes | Single Screen Pump (S2) | No |
| R-5 (S3 & S4) [CP] | No-purge Westbay | EZ-MUD, QUIK-FOAM | No | No | No |
| R-7 S3 | No-purge Westbay | EZ-MUD, QUIK-FOAM | No | No | No |
| R-8 (S1 & S2) | No-purge Westbay | EZ-MUD, QUIK-FOAM | No | No | No |
| R-14 (S1 & S2) | No-purge Westbay | QUIK-FOAM, Bentonite Mud | Yes | Single Screen Pump (S1) | Yes |
| R-16 (S2 to S4) | No-purge Westbay | EZ-MUD, QUIK-FOAM, Bentonite Mud | Yes | Dual Screen Pump (S2 & S4) | Yes (S2) & No (S4) |
| R-19 (S3 to S7) | No-purge Westbay | EZ-MUD, QUIK-FOAM | No | No | No |
| R-20 (S1 to S3) [CP] | No-purge Westbay | QUIK-FOAM, Bentonite Mud | Yes | Dual Screen Pump (S1 & S2) | No |
| R-22 (S1 to S5) [CP] | No-purge Westbay | EZ-MUD, QUIK-FOAM | Yes | No | Unknown |
| R-25 (S5 to S9) [CP] | No-purge Westbay | EZ-MUD, QUIK-FOAM | No | No | No |
| R-31 (S2 to S5) | No-purge Westbay | EZ-MUD, QUIK-FOAM | No | No | No |
| R-32 (S1 to S3) | No-purge Westbay | EZ-MUD, QUIK-FOAM, Bentonite Mud | Yes | Single Screen Pump (S1) | Yes |
| R-33 (S1 & S2) | Low-Flow Barcad | EZ-MUD, QUIK-FOAM | Yes | Dual Screen Pump (S1 & S2) | Yes |
| R-54 S1 [CP?] | Dual Screen Baski | Hammer Oil | No | No | No |
| R-61 S1 & S2 [CP] | Dual Screen Baski | Hammer Oil | Yes | No | No |

[CP] - Contamination Present

## *Key Findings*

**Nine of 16 screens (56%) of multiscreen wells have undergone rehabilitation.**

**Five of 16 screens (31%) of multiscreen wells provide representative samples.**

**Five of 16 screens (31%) of multiscreen wells are in a contaminant plume.**

**Eleven of 110 screens (67 wells) contain residual drilling fluids (10%).**

# Summary of Impacted Monitoring Wells Completed in the Regional Aquifer, Los Alamos National Laboratory, New Mexico

| Impacted Well Screens | Original Completion | Primary Residual Drilling Fluids | Rehab Attempted | Conversion | Representative Samples |
|---|---|---|---|---|---|
| **Regional Aquifer Screens** | | | | | |
| CdV-R-15-3 (S4 to S6) | No-purge Westbay | EZ-MUD, QUIK-FOAM, Bentonite Mud | Yes | Single Screen Pump (S4) | Yes |
| CdV-R-37-2 (S2 to S4) | No-purge Westbay | EZ-MUD, QUIK-FOAM | Yes | Single Screen Pump (S2) | No |
| R-5 (S3 & S4) [CP] | No-purge Westbay | EZ-MUD, QUIK-FOAM | No | No | No |
| R-7 S3 | No-purge Westbay | EZ-MUD, QUIK-FOAM | No | No | No |
| R-8 (S1 & S2) | No-purge Westbay | EZ-MUD, QUIK-FOAM | No | No | No |
| R-14 (S1 & S2) | No-purge Westbay | QUIK-FOAM, Bentonite Mud | Yes | Single Screen Pump (S1) | Yes |
| R-16 (S2 to S4) | No-purge Westbay | EZ-MUD, QUIK-FOAM, Bentonite Mud | Yes | Dual Screen Pump (S2 & S4) | Yes (S2) & No (S4) |
| R-19 (S3 to S7) | No-purge Westbay | EZ-MUD, QUIK-FOAM | No | No | No |
| R-20 (S1 to S3) [CP] | No-purge Westbay | QUIK-FOAM, Bentonite Mud | Yes | Dual Screen Pump (S1 & S2) | No |
| R-22 (S1 to S5) [CP] | No-purge Westbay | EZ-MUD, QUIK-FOAM | Yes | No | Unknown |
| R-25 (S5 to S9) [CP] | No-purge Westbay | EZ-MUD, QUIK-FOAM | No | No | No |
| R-31 (S2 to S5) | No-purge Westbay | EZ-MUD, QUIK-FOAM | No | No | No |
| R-32 (S1 to S3) | No-purge Westbay | EZ-MUD, QUIK-FOAM, Bentonite Mud | Yes | Single Screen Pump (S1) | Yes |
| R-33 (S1 & S2) | Low-Flow Barcad | EZ-MUD, QUIK-FOAM | Yes | Dual Screen Pump (S1 & S2) | Yes |
| R-54 S1 [CP?] | Dual Screen Baski | Hammer Oil | No | No | No |
| R-61 S1 & S2 [CP] | Dual Screen Baski | Hammer Oil | Yes | No | No |

[CP] -Within Contaminant Plume

## *Key Findings*

**Nine of 16 screens (56%) of multiscreen wells have undergone rehabilitation.**

**Five of 16 screens (31%) of multiscreen wells provide representative samples.**

**Five of 16 screens (31%) of multiscreen wells are in a contaminant plume.**

**Eleven of 110 screens (67 wells) contain residual drilling fluids (10%).**

# Summary and Conclusions

- **Complete removal of residual drilling fluids from monitoring wells is essential in obtaining long-term, representative groundwater samples needed for geochemical and risk analysis.**
- **Success of well rehabilitation depends on site-specific hydraulic properties of each saturated zone; type, mass, and reactivity of residual drilling fluid; and method and duration of well development.**
- **Approximately 31% of multiscreen monitoring wells have been successfully remediated.**

# Summary and Conclusions

- **Reduction of DO, $NO_3^-$, $CrO_4^{2-}$, $SO_4^{2-}$, and $UO_2(CO_3)_2^{2-}$ has been observed at multiscreen monitoring wells containing residual organic drilling fluids.**
- **Reductive dissolution of $MnO_2$, FeOOH, and/or $Fe(OH)_3$ and reductive precipitation of $Cr(OH)_3$am and $UO_2$ most likely have taken place under natural and contaminated conditions.**
- **Dissolution of calcium carbonate (calcite) most likely has occurred during oxidation of residual organic drilling fluids under elevated partial pressure of $CO_2$ gas.**
- **Desorption of trace elements (Ni, Zn) from FeOOH and/or $Fe(OH)_3$ most likely has occurred during reductive dissolution of these adsorbents.**

# Supplemental Material

# Analytical Methods

***Major Ions***

**Ion chromatography, titration, and inductively coupled plasma-optical emission spectroscopy**

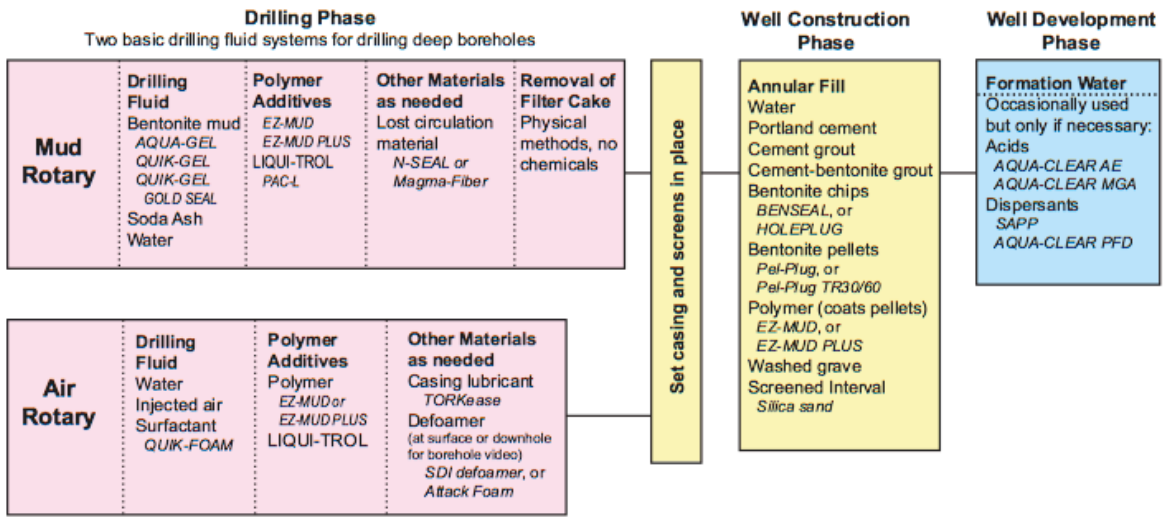
***Trace Elements***

**Inductively coupled plasma-optical emission spectroscopy and (high resolution) inductively coupled plasma-mass spectrometry**

***Field Parameters***

**Dissolved oxygen, pH, ORP, temperature, specific conductance, and turbidity**

# Typical Sequence of Drilling Fluid Use, Los Alamos National Laboratory, New Mexico (LANL, 2007)



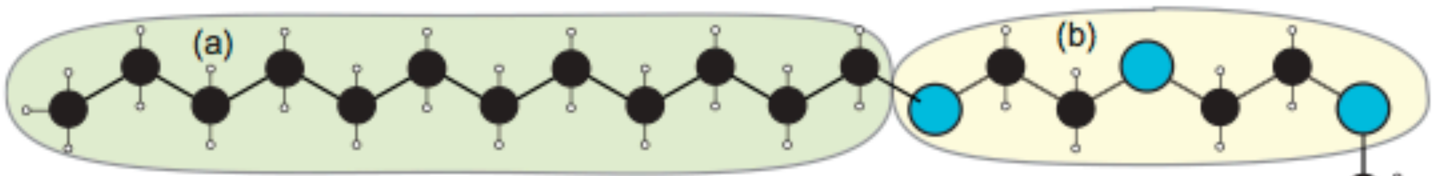

Note: This sketch clarifies, in a highly generalized way, the sequence in which chemicals are used to drill, complete, and develop a well, and the types of chemicals used in each of these phases. However, not all materials listed are used in all wells. Just as geologic formations vary widely in their properties, so does every well involve a unique combination of drilling materials added in varying amounts and at different times in the process.

**Figure 4-1. Typical sequence of drilling fluid use**

# Chemistry of an Anionic Surfactant (QUIK-FOAM®) (LANL, 2007)

(a1) This long hydrocarbon chain is the uncharged hydrophobic end of the surfactant molesule. The first stage of biodegradation probably involves detachment of this chain by hydrolysis. This process requires microbial activity to break the first carbon–carbon bond.

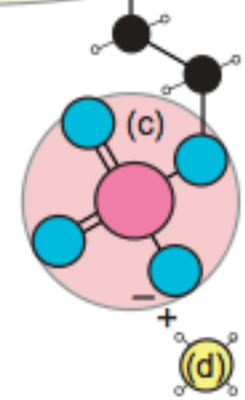
(b) The central ethylene oxide portion of the molecule, once detached from the long-chain hydrocarbon and sulfonate groups, biodegrades first into alcohols. Its ultimate breakdown products are carbon dioxide and water, thereby increasing carbonate alkalinity.

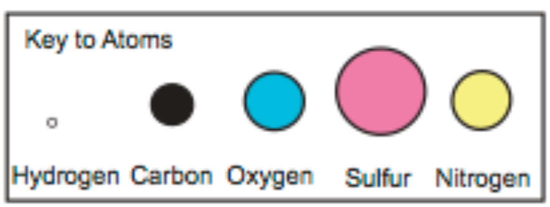



(a2) Following the initial separation of the long chain from the rest of the molecule, the chain is gradually broken down into ever-smaller hydrocarbon chains. The final degradation products are carbon dioxide and water, which increases carbonate alkalinity.

(c) This is the hydrophilic end of the surfactant molecule. The anionic sulfonate group requires microbial action for biodegradation, ultimately to sulfate ($SO_4^{2-}$).

(d) The ammonium ($NH_4^+$) counterion leaches into the groundwater, and may be replaced by other more-strongly adsorbing cation species.




Note: An example of an alcohol ethoxy sulfate (AES) is sodium laureth sulfate. The structure and biodegradation mechanisms for the surfactant in QUIK-FOAM are expected to be similar to those depicted for this widely-studied AES. In the molecule sketched above, ammonium has been substituted for sodium as the counterion, to more closely parallel the QUIK-FOAM surfactant's composition.

# CHEMISTRY OF ANIONIC SURFACTANTS

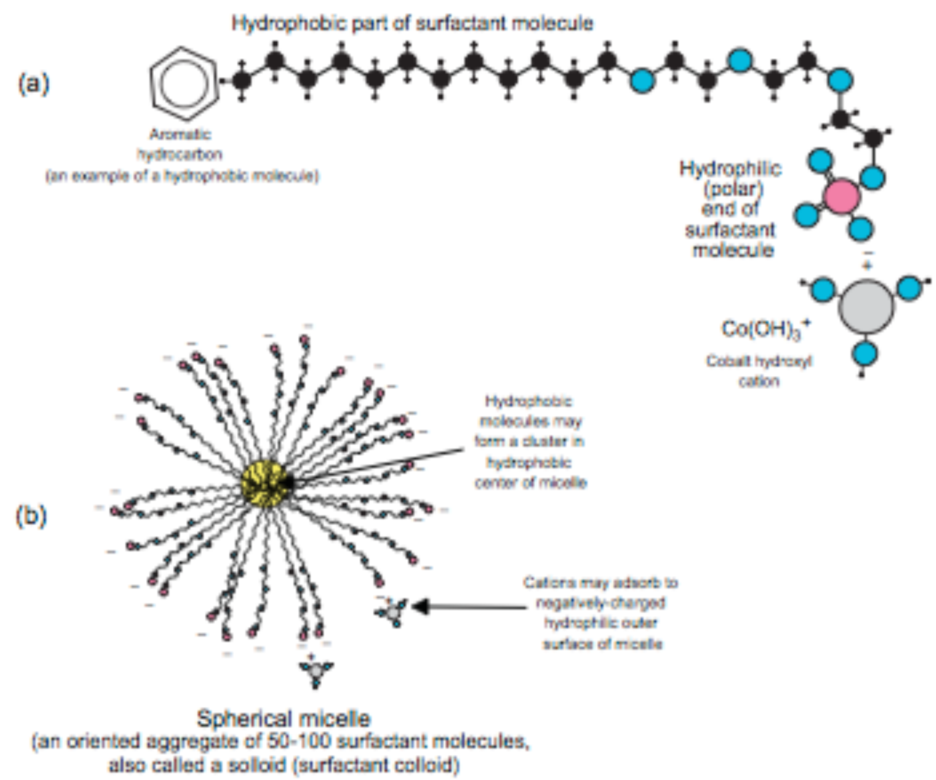
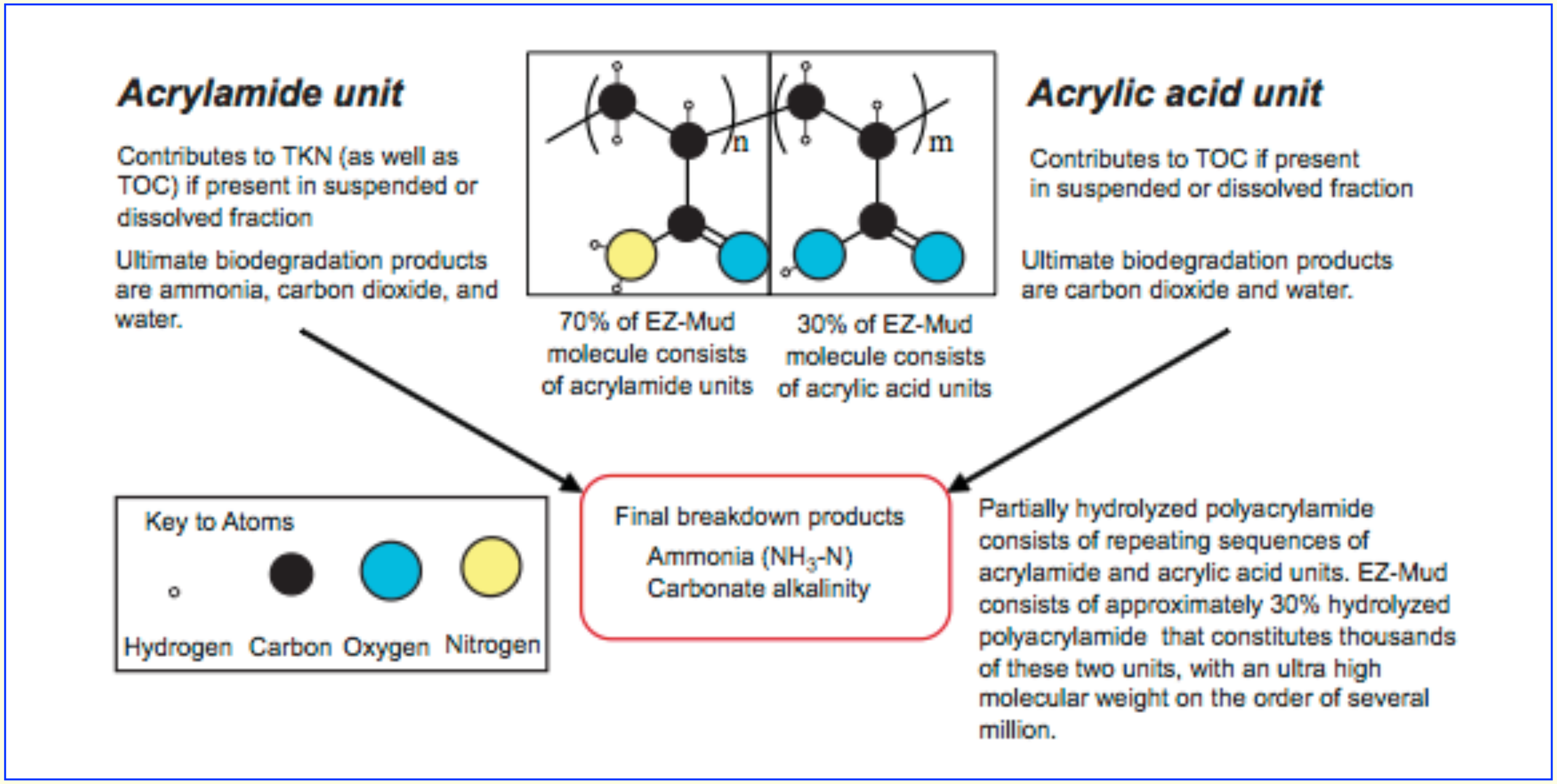



**Figure 4-12** **Schematics of potential interactions between anionic surfactants and constituents in groundwater: (a) interactions with hydrophobic and hydrophilic ends of a surfactant molecule, and (b) interactions with a surfactant micelle**

# Chemistry of Polyacrylamide-Polyacrylate Copolymer (EZMUD®) (Longmire, 2002; LANL, 2007)



# Summary of Monitoring Wells Completed in Perched-Intermediate Zones, Los Alamos National Laboratory, New Mexico

| Impacted Well Screens | Original Completion | Primary Residual Drilling Fluids | Rehabilitated | Conversion | Representative Samples |
|---|---|---|---|---|---|
| **Intermediate Aquifer Screens** | | | | | |
| R-5 S2 [CP] | No-purge Westbay | EZ-MUD, QUIK-FOAM | No | No | No |
| R-9i (S1 & S2) [CP] | No-purge Westbay | EZ-MUD, QUIK-FOAM | No | No | No |
| R-12 (S1 & S2) [CP] | No-purge Westbay | EZ-MUD, QUIK-FOAM | Yes | Dual Screen Pump (S1 & S2) | No |
| R-19 S2 | No-purge Westbay | EZ-MUD, QUIK-FOAM | No | No | No |
| R-25 (S1 to S4) [CP] | No-purge Westbay | EZ-MUD, QUIK-FOAM | No | No | No |
| R-26 S1 | No-purge Westbay | EZ-MUD, QUIK-FOAM, Bentonite Mud | Yes | Single Screen Pump | Yes |
| R-40i [CP] | Single Screen | QUIK-FOAM | No | No | No |
| R-55i [CP] | Single Screen | Hammer Oil | No | No | No |

[CP] - Contamination Present

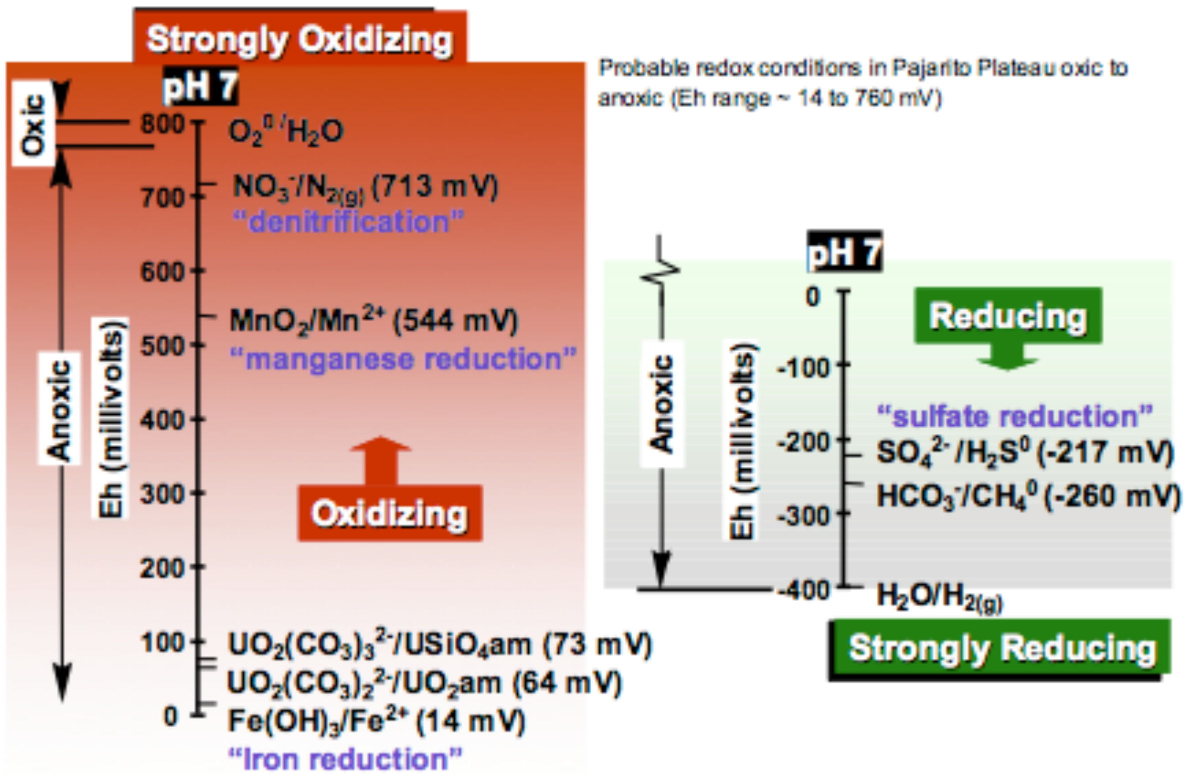
## *Key Findings*

**Two of 8 screens (25%) of multiscreen wells have undergone rehabilitation.**

**One of 8 screens (12%) of multiscreen wells provide representative samples.**

**Six of 8 screens (75%) of multiscreen wells are in a contaminant plume.**

# Selected Redox Couples (at pH7 and 25C) for the Pajarito Plateau and Surrounding Areas, New Mexico



# Redox Reaction Sequences and Redox Ladder in Natural Systems

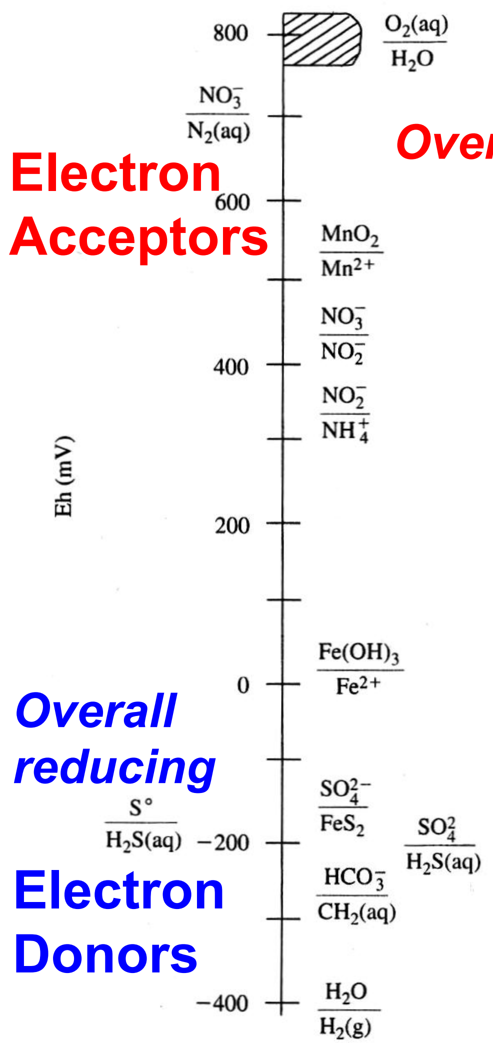
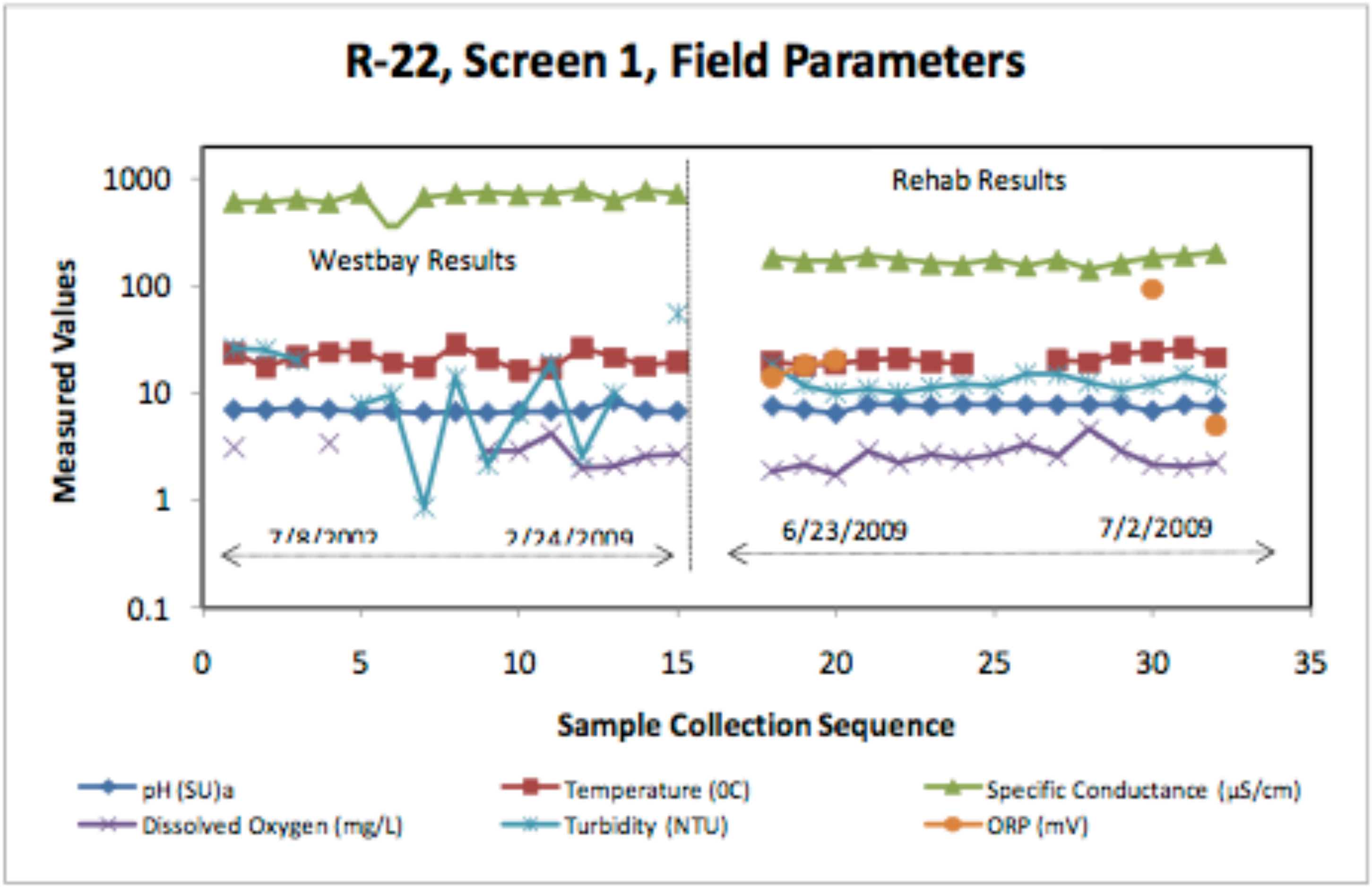


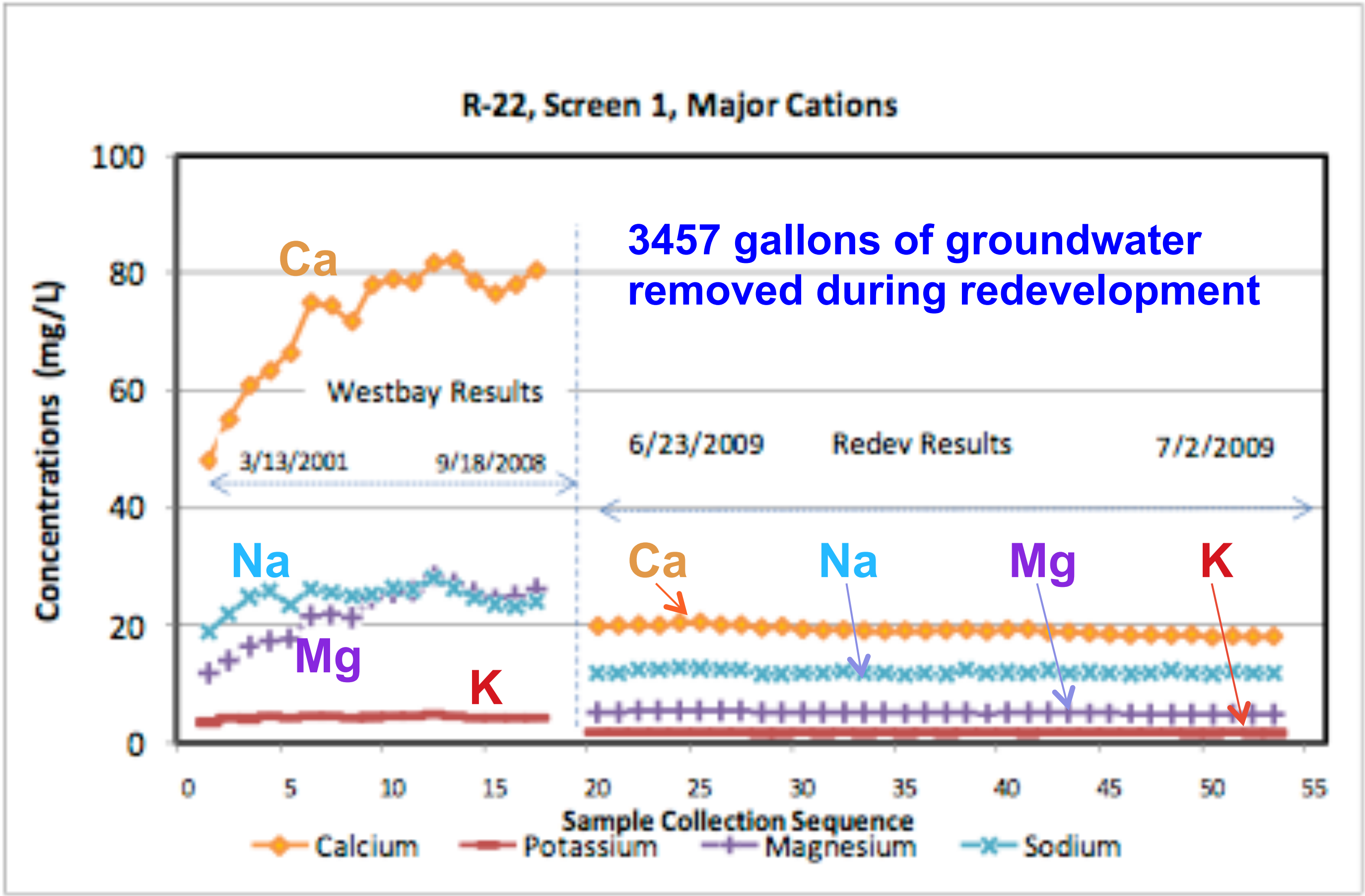

**Figure 11.10** The theoretical Eh (mV) of some important oxidation-reduction couples at equal molar ion concentrations except as indicated below, at pH = 7 and 25°C. Cross-hatched area gives Eh's for $O_2(aq)/H_2O$, where $O_2(aq)$ ranges from 8.25 to 0.01 mg/L. Other conditions are: $NO_3^-/N_2(aq)$ at $N_2(aq) = 14$ mg/L (atmospheric $N_2 = 0.80$ bar), $NO_3^- =$ 62 mg/L; $MnO_2$(pyrolusite)/ $Mn^{2+}$ at $Mn^{2+} = 1$ mg/L; $Fe(OH)_3/Fe^{2+}$ at $Fe^{2+} =$ 1 mg/L assuming $K_{sp}$ for $Fe(OH)_3 = 10^{-38.5}$; $SO_4^{2-}/FeS_2$(pyrite) at $Fe^{2+} = 1$ mg/L and $SO_4^{2-} = 96$ mg/L; and S°(native sulfur)/$H_2S(aq)$ at $H_2S(aq) = 108$ mg/L ($10^{-1.5}$ mol/L). After D. Langmuir, Physical and chemical characteristics of carbonate water. In *Guide to the hydrology of carbonate rocks,* ed. P. E. Lamoreaux, B. M. Wilson, and B. A. Memeon. Copyright 1984 by UNESCO. Used by permission.

**The above figure shows the Eh value at pH 7 and 25°C for important redox couples in natural waters under specified conditions (Langmuir, 1997). Langmuir D., 1997, Aqueous Environmental Geochemistry, Prentice Hall, New Jersey, 600 p.**

# Field Parameters at Regional Aquifer Well R-22, Screen 1 (LANL, 2009)

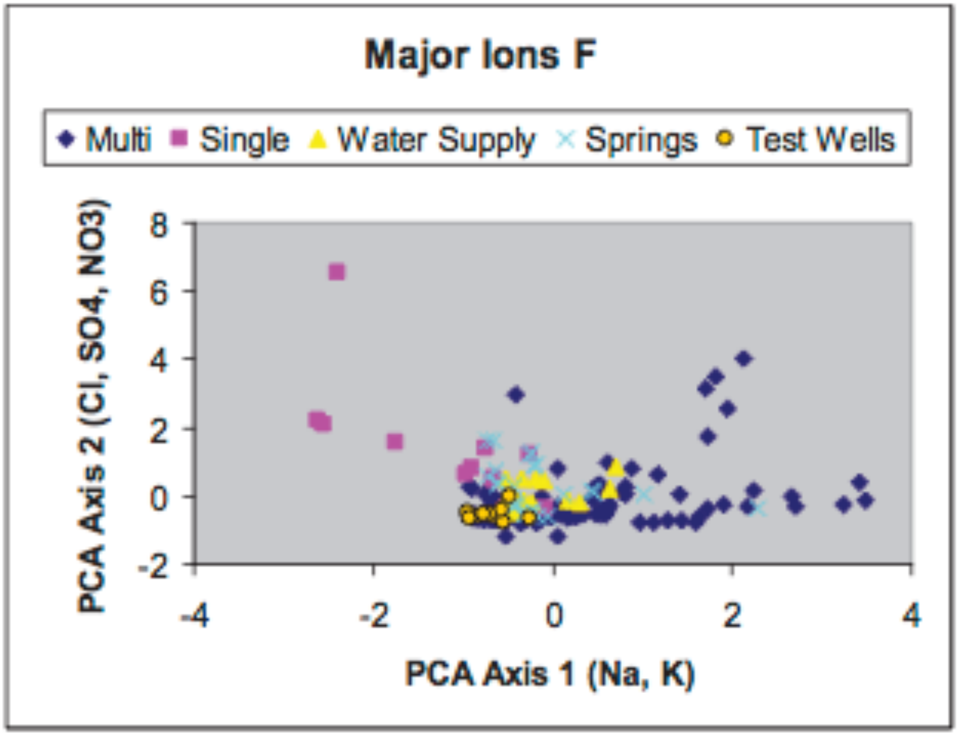


# Concentrations of Dissolved Cations at Regional Aquifer Well R-22, Screen 1 From 2001 to 2009 (LANL, 2009)



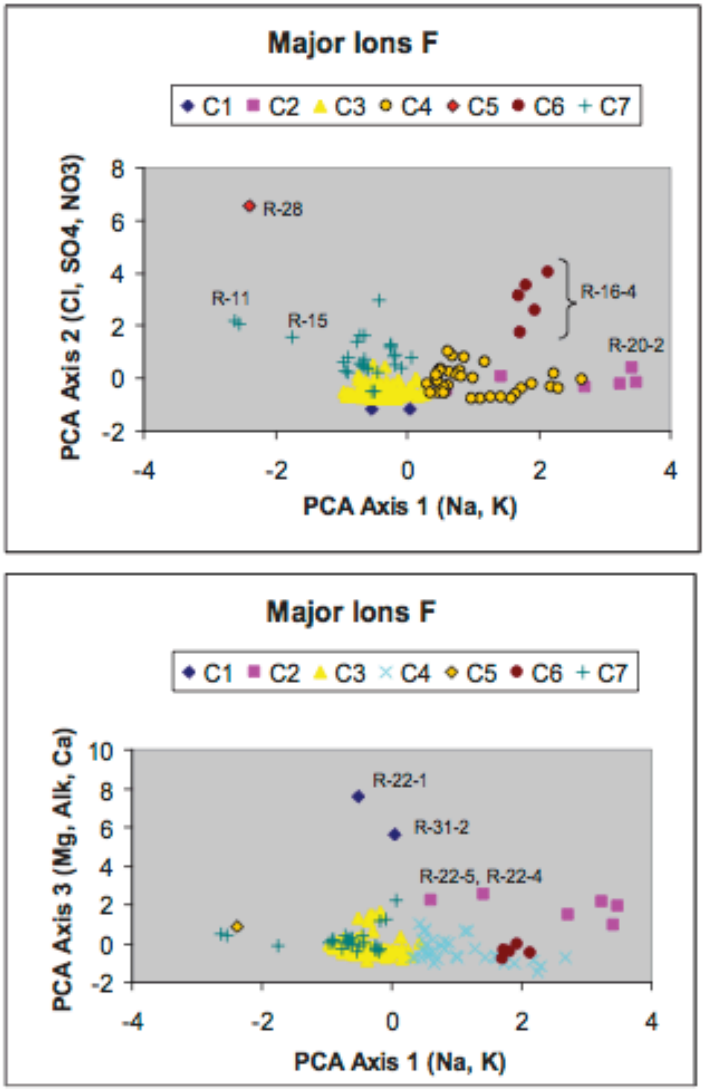

Note: Calcium ($Ca^{2+}$), potassium ($K^{+}$), sodium ($Na^{+}$), and magnesium ($Mg^{2+}$) concentrations during characterization sampling using Westbay equipment (March 2001–September 2008) and during redevelopment (June and July 2009).

# Results of Principal Component Analysis Conducted on Major Ion Solutes, LANL, New Mexico (LANL, 2007)




Tight grouping of test well, water supply and springs samples. Most single-screen wells consistent with these "baseline" stations. A few single-screen wells show elevated nitrate concentrations, which do not appear to be drilling related.

# Results of Principal Component Analysis Conducted on Major Ion Solutes, LANL, New Mexico (LANL, 2007)




*Interpretation:*

C3 = Consistent with White Rock Canyon springs or existing wells

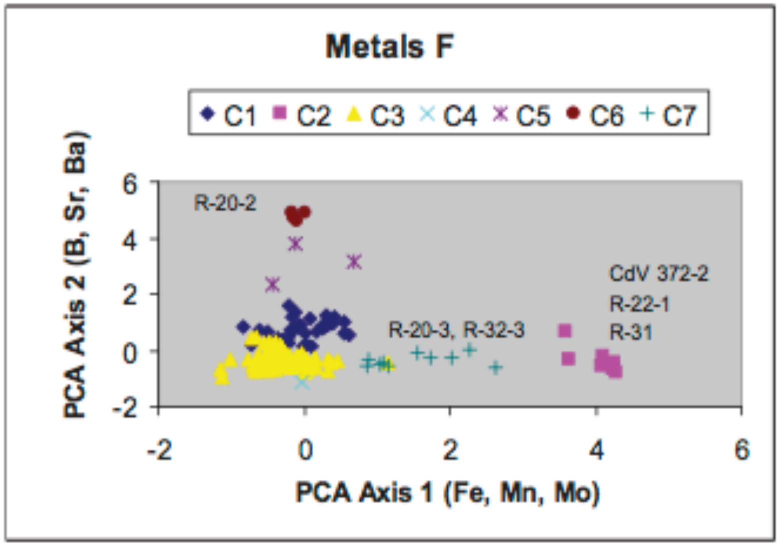
C7 = Possible or slight impacts

C4 = Moderate impacts

C1, C2, C5, C6 = Significant impacts

R-11 and R-15 show elevated $NO_3$ concentrations which do not appear to be drilling related. C7 appears to reflect natural chemical variability within aquifer, rather than drilling impacts.

# Results of Principal Component Analysis Conducted on Trace Solutes, LANL, New Mexico (LANL, 2007)



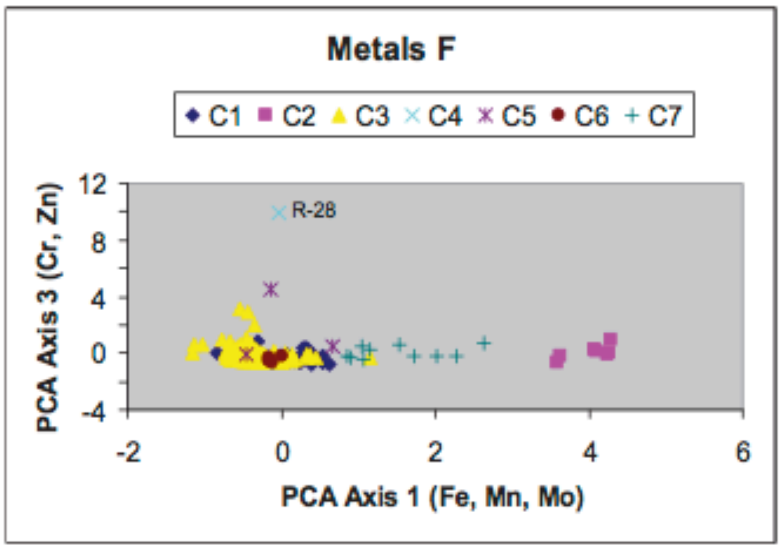

*Interpretation:*

C3 = Consistent with White Rock Canyon springs or existing water-supply wells

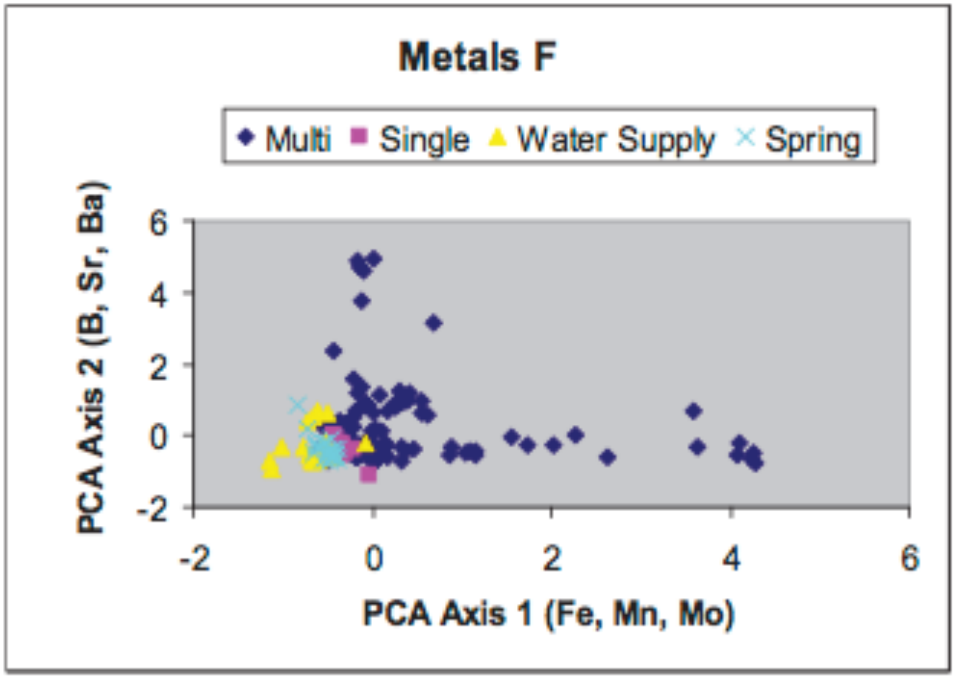
C1 = Possible to slight impacts

C5, C7 = Moderate impacts

C2, C4, C6 = Significant impacts



# Results of Principal Component Analysis Conducted on Trace Solutes, LANL, New Mexico (LANL, 2007)




Water supply wells consistent with springs, indicating minimal or no residual drilling impacts. Many single-screen wells consistent with springs and water-supply wells.

# Photographs of Sulfate-reducing Bacteria Tests for Regional Aquifer Well R-61 (LANL, 2013)

| R-61 Sulfate Reducing Bacteria | Screen 1 | | | Screen 2 | | |
|---|---|---|---|---|---|---|
| | Day 1 | Day 12 | Day 15 | Day 1 | Day 12 | Day 15 |
| May-12 | No Test Done | | | No Test Done | | |
| Nov-12 |  |  |  |  |  |  |
| Feb-13 |  |  |  |  |  |  |

# Results of Biological Activity Reaction Tests for Regional Aquifer Well R-61 (LANL, 2013)

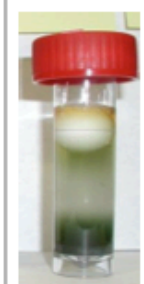
| Well screen | Test Start Date[a] | Purge Volume | Field Parameters at Time of BART Sample Collection | | | | | Aggressivity of Bacterial Populations[b] | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Field pH | Sp Cond (µS/cm) | DO (mg/L) | ORP (mV) | Turbidity (NTU) | Iron-Related Bacteria (IRB-BART) | Slime-forming Bacteria (SLYM-BART) | Sulfate Reducing Bacteria (SRB-BART) |
| R-61 S1 | 5/12/12 | DP + 1CV | 7.0 | 157 | <1 | -42 | 4 | Moderate (Lag = 3 days) | Moderate (Lag = 4 days) | — |
| | 11/15/12 | DP + 1CV | 6.5 | 177 | 4 | 216 | 10 | Moderate (Lag ~ 3 days) | Moderate (Lag ~ 3 days) | Not aggressive (Lag = 11 days) |
| | 2/11/13 | DP + 1CV | 6.7 | 156 | 5 | -66 | 12 | Moderate (Lag = 3 days) | Moderate (Lag = 5 days) | Not aggressive (Lag = 11 days) |
| R-61 S2 | 5/12/12 | DP + 1CV | 6.8 | 220 | <1 | -78 | 1 | Moderate (Lag = 3 days) | Moderate (Lag = 3 days) | — |
| | 11/15/12 | DP + 1CV | 6.4 | 192 | 1 | -90 | 15 | Moderate (Lag ~ 3 days) | Moderate (Lag ~ 3 days) | Not aggressive (Lag = 13 days) |
| | 2/12/13 | DP + 1CV | 6.4 | 213 | 1 | -127 | 9 | Moderate (Lag = 3 days) | Moderate (Lag = 4 days) | Not aggressive (Lag = 13 days) |

Abbreviations: CV = casing volume, DO = dissolved oxygen, DP = drop pipe, Lag = time lag, NTU = nepheletic turbidity unit, ORP = oxidation-reduction potential, S1 = screen 1, S2 = screen 2, Sp Cond = specific conductance

[a] Tests were started on the same day that the sample was collected, with the exception of the samples collected for R-61 S1 and R-61 S2 in May 2012. These samples were collected on 5/9/12 and delivered to the analytical laboratory to start the BART tests on 5/12/12.

[b] Threshold values used to estimate aggressivity for these samples are based on those presented in DBI (2004). Different bacterial populations show characteristic reaction sequences within the various types of tests. The significance or level of aggressivity for each type of bacteria is determined by the reaction type first observed, length of time between the start of the test and the occurrence of the first reaction (time lag), and the sequence and type of subsequent reactions that develop. Threshold time lags shown in this table are for the specific types of reactions observed in the tests summarized in and may not be applicable to tests conducted on other samples. A control sample consisting of sterilized de-ionized water was included in all tests.

# Photographs of Iron-related Bacteria Tests for Regional Aquifer Well R-61 (LANL, 2013)

| R-61 Iron related Bacteria | Screen 1 | | | Screen 2 | | |
|---|---|---|---|---|---|---|
| | Day 1 | Day 6 | Day 10 | Day 1 | Day 6 | Day 10 |
| May-12 |  |  |  |  |  |  |
| Nov-12 |  |  |  |  |  |  |
| Feb-13 |  |  |  |  |  |  |

Acknowledgment: "This material is based upon work supported by the Department of Energy Office of Environmental Management under Award Number *DE-EM0002420*."