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Well Screen Analysis Report, Revision 2

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EXECUTIVE SUMMARY

From 1998 through 2006, 42 wells have been drilled, completed and sampled for hydrogeologic characterization beneath the Pajarito Plateau, either as part of the “Hydrogeologic Workplan” or as part of corrective measures. Concerns about the reliability or representativeness of the groundwater quality data obtained from these wells stem from the potential for residual drilling fluids and additives to mask the present and future detection of contaminants. This report is Revision 2 of the original ”Well Screen Analysis Report,” which provided results of a preliminary geochemical evaluation of well screens in the 33 wells that had been completed and sampled as of August 2005. This revision incorporates comments and recommendations of the New Mexico Environment Department in its direction to modify the report. As in Revision 1, this revision also presents the evaluation of characterization samples from all of the characterization wells, including several completed and sampled since August 2005.

The primary purpose of this report is to evaluate whether screens in characterization wells are capable of producing data that are reliable and representative of the intermediate-depth groundwater and the regional aquifer. In so doing, this report first establishes a set of geochemical criteria against which to compare the water chemistry measured at each screen. This comparison results in a systematic identification of residual drilling effects present in the screen interval each time that it was sampled. The evaluation outcomes for the most recent samples from each screen, as of December 2006, are used to determine the reliability of water-quality data for analytes of interest from each screen at this time and to flag impacted analytes in water-quality samples potentially compromised by residual drilling artifacts. Of the impacted screens, the report identifies those that appear to be cleaning up over time and those that are the most problematic. It also establishes a technical basis for real-time screening of new data for reliability. In addition, Revision 2 compares screen evaluation results to those presented in Revision 0, identifies apparent differences and trends in groundwater chemistry, and offers potential explanations for them.

The original version of this report was used as one basis for prioritizing the wells and screens that may require rehabilitation. Revision 2 now focuses on establishing a clear and consistent technical framework for evaluating historic and new water-quality data for representativeness. Details of the evaluation approach, such as indicator species, associated test thresholds, and the list of chemicals that may be affected by residual drilling effects, are likely to continue to be modified in the future. However, the basic framework and the philosophy that underlie the approach are not expected to change.

This report provides an evaluation of water-quality (geochemical) data for samples collected from deep (>200 ft) wells as of December 2006. The wells evaluated in this report include 38 wells constructed under the auspices of the “Hydrogeologic Workplan,” as well as 4 wells installed as part of a corrective measures study in Cañon de Valle. Within the 42 wells are 95 individual screens. Of these screens, 80 were functional and 15 were dry or plugged at the time that this analysis was conducted. Each of the functional screens was analyzed independently for this report.

The screen evaluation addresses only the potential geochemical impacts of products used in drilling. Drilling products are defined as the primary drilling fluids (polymer-based fluids and bentonite mud) and associated drilling additives placed or circulated in the borehole during drilling operations. Drilling and construction of monitoring wells within perched intermediate zones at depths greater than 100 ft or within the regional aquifer require the use of drilling fluids to ensure borehole stability and lubricity. This report presents a comprehensive picture of drilling fluid use in the evaluated wells (Table 4-20 and Figure 4-1). It is outside the scope of this report to address questions concerning the need for, or the appropriateness of, specific drilling methods and fluids. It is also outside the scope of this report to evaluate any changes to the physical integrity of the well screens and casings resulting from drilling, construction, or development activities.

This report does not examine whether the use of drilling fluids impacted achievement of the characterization objectives of the “Hydrogeologic Workplan,” or whether these wells are suitable for use as monitoring wells under the March 1, 2005, Compliance Order on Consent (Consent Order).

The initial motivation for revising the original report was to address comments of the NMED. A reanalysis of the geochemical data set used in Revision 0, augmented by a more comprehensive data set and additional screens, was performed using additional geochemical indicators for residual drilling effects. The results were presented in Revision 1. The most significant change in the evaluation protocol was a consolidation of the separate components of the tiered geochemical approach used in the original report, in which the application of criteria was determined based upon which primary drilling fluid was used in the screen interval. The revised approach used in Revisions 1 and 2 integrates the potential residual effects of both bentonite and organic drilling fluids into a single set of test criteria that are applied to all screens, regardless of the drilling fluid actually used.

The evaluation in Revisions 1and 2 used revised background values from an expanded set of 30 background locations, as reported in the “Groundwater Background Investigation Report, Revision 2.” Use of revised background values, along with their detailed statistical characterization, allowed for fine-tuning of test threshold values for geochemical indicators. Overall, the use of these revised threshold values actually increased the number of tests passed for many indicator analytes as well as improving the internal consistency among test outcomes.

Revision 2 addresses comments made by NMED in its direction to modify the report. This revision uses the same data set as used in Revision 1, the same evaluation protocol, and the same six test categories. These modifications are minor and are primarily for clarification. The major difference between Revision 1 and Revision 2 is removal of the qualitative assignment of well screens to a rating system, while retaining the quantitative measure of reliability in the number of test categories passed by a particular sample. Removal of the rating system increases the versatility of the assessment process for area-specific evaluations having monitoring objectives for particular suites of contaminants.

Many of the findings of Revision 0 are still true in Revisions 1 and 2:

- The most common drilling artifact is the presence of reducing conditions.
- Single-screen wells show the least impact from residual drilling fluids.
- The majority of the screens in multiple-screen wells appear to be impacted by residual drilling fluids, although nearly all multiple-screen wells have at least one screen interval showing no impacts, or only minor ones.

About one-third of the most recent water-quality samples from the evaluated screens appear capable of providing technically defensible water-quality data for all analytes of interest.

A preliminary conclusion in Revision 0 was that some screens appeared to be improving over time. This overall trend is not only confirmed by the outcomes of the evaluation protocol presented in Revisions 1 and 2 but also made more apparent because of the improved assessment methodology, inclusion of a greatly expanded database, and the passage of time. Nearly 25% of the screens improved over the period covered by this report, whereas previously, the number of sampling events available for many of these screens had been too few to establish definitive trends for them.

As shown in Figure ES-1, 31% (25 screens out of 80) are characterized by oxidizing conditions and show no residual impacts from the use of drilling fluids. Another 26% (21 screens) show an impact for one or two categories. All but three of these 21 screens are also characterized by oxidizing conditions, and the most common residual drilling effect for the 18 oxidizing screen intervals is the presence of organic fluids.

Of the other three screens showing only a low degree of impact, one is characterized by nitrate-reducing conditions, and two others by manganese-reducing conditions. Single-screen wells show the fewest number of impacts overall.

A higher frequency of residual drilling effects are present in the remaining 43% of the screens (34 out of 80), which are generally characterized by iron-reducing and sulfate-reducing conditions, most commonly accompanied by residual organic fluids and/or unstable carbonate mineralogy. Twenty screens (25%) exhibit symptoms of three to five residual drilling effects; 11 of these screens have developed iron-reducing or sulfate-reducing conditions. Eighteen percent (14 screens) are affected by six or more categories of residual drilling effects.

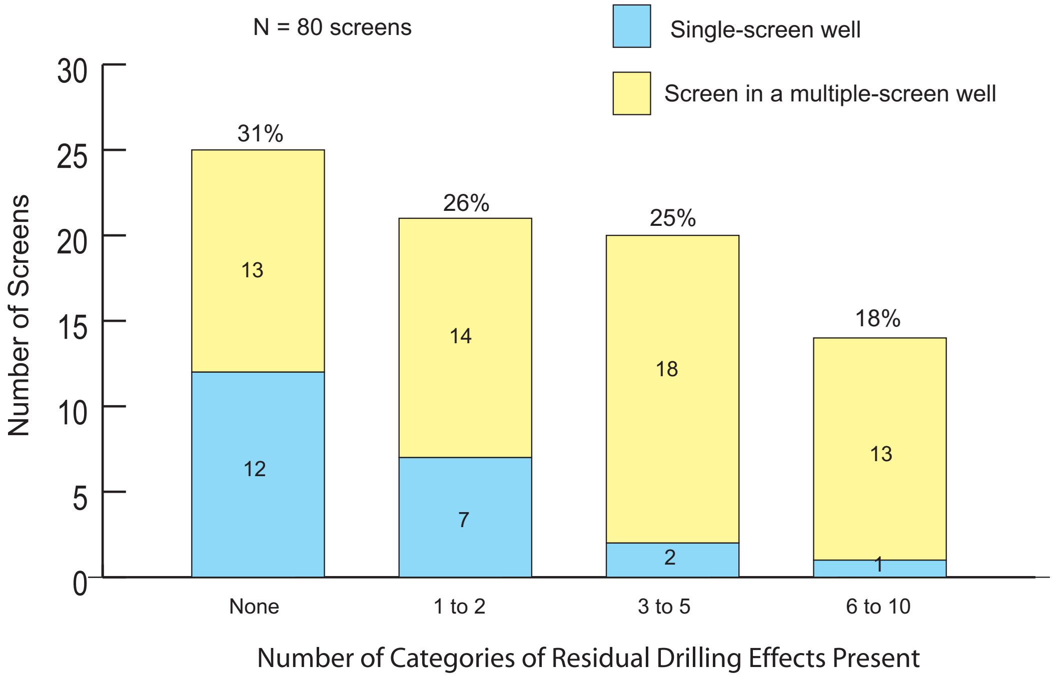

Figure ES-1. Number of categories of residual drilling effects present in the most recent sample from each screen (as of December 31, 2006)

CONTENTS

Figures

Tables

Appendixes

Appendix A Relevant Analytes and Chemicals of Potential Concern

Appendix A Tables

Appendix B Drilling Methods and Dates, Screen Descriptions, and Sampling Events

Appendix B Tables

Appendix C Water-Quality Data Used for Screen Assessments

Appendix C Tables

Appendix D Comparison of Water-Quality Data with Test Criteria

Appendix D Figures

Appendix D Tables

Appendix E Screen Assessment Results

Appendix E Tables

Appendix F Principal Component Analysis: Correlation Matrices, Factor Loadings, and Stations Used for Comparison with Regional Characterization Wells

Appendix F Tables

Acronyms and Abbreviations

AE	alcohol ethoxylate
AES	alcohol ethoxylate sulfate
AOC	area of concern
ASTM	American Society for Testing and Materials
ATSDR	Agency for Toxic Substances and Disease Registry
CA	cluster analysis
CAS	Chemical Abstracts Service
CMC	critical micelle concentration
Consent Order	Compliance Order on Consent
COPC	chemical of potential concern
CRDL	contract-required detection limit
DL	detection limit
DNX	hexahydro-1,3-nitroso-5-nitro-1,3,5-triazine
DO	dissolved oxygen
DOC	dissolved organic carbon
DOE	Department of Energy (U.S.)
DQO	data quality objective
DRO	diesel-range organic
ECR	Environmental Characterization and Remediation Group (former LANL group)
EES	Earth and Environmental Sciences (LANL division)
EES-6	Hydrology, Geochemistry, and Geology (an EES group)
EFDB	Environmental Fate Data Base
Eh	oxidation-reduction potential
ECR	Environmental Characterization and Remediation (former LANL group)
ENV	Environmental Stewardship (former LANL division)
EP	Environmental Programs (LANL directorate)
EPA	Environmental Protection Agency (U.S.)

ERDB	Environmental Restoration [Project] database (LANL database)
ER ID	Environmental Restoration [Project] identifier
ERS	Environmental Remediation and Surveillance Program (former LANL program)
ERSS	Environment and Remediation Support Services (LANL division)
ES-PPP	Environmental Stewardship-Pathways Protection Program (LANL)
ESP	Environmental Surveillance Program (LANL)
EXTOXNET	Extension Toxicology Network
F	filtered (sample)
f_{OC}	fraction of organic carbon
GC-MS	gas chromatography-mass spectrometry
GGRL	Geochemistry and Geomaterials Research Laboratory (LANL)
GSWSED	Groundwater, Surface Water, and Sediment Monitoring Program
HCA	hierarchical cluster analysis
HE	high explosive(s)
HEXP	high explosive degradation products
HMX	high-melting explosive
HSDB	Hazardous Substances Data Bank
ICP	inductively coupled plasma
IDL	instrument detection limit
IFWGMP	interim facility-wide groundwater monitoring plan
LANL	Los Alamos National Laboratory
K_d	distribution coefficient
KMC	K-means cluster
K_{OC}	organic carbon partition coefficient
MDA	material disposal area
MDA	minimum detectable activity
MDL	method detection limit
MGA	modified granular acid

MS	mass spectrometry
MSDS	material safety data sheet
NMED	New Mexico Environment Department
NMED-OB	New Mexico Environment Department DOE Oversight Bureau
NNMCAB	Northern New Mexico Citizen’s Advisory Board
NPL	National Priority List
NTU	nephelometric turbidity unit
OPPT	Office of Pollution Prevention and Toxicity (EPA)
ORP	oxidation-reduction potential
PAH	polynuclear aromatic hydrocarbon
PC	principal component
PCA	principal component analysis
PCB	polychlorinated biphenyl
PCOC	potential contaminant of concern
PETN	pentaerythriotol tetranitrate
PIP	Pesticide Information Profile
pH	negative log of the hydrogen concentration in a solution
PM	Pajarito Mesa
PHPA	partially hydrolyzed polyacrylamide/polyacrylate
pzc	point of zero charge
QA	quality assurance
QAP	Quality Assurance Program
QC	quality control
QP	quality procedure
R	regional (characterization well identifier)
R	rejected (when referring to data qualification code)
RCRA	Resource Conservation and Recovery Act
RDX	research department explosive (cyclonite)

redox	oxidation reduction
RN	registry number
RPF	Records Processing Facility (LANL)
RRES	Risk Reduction and Environmental Stewardship (former LANL division)
SOP	standard operating procedure
SOW	statement of work
SRC	Syracuse Research Corporation
SU	standard units
SVOC	semivolatile organic compound
SWMU	solid waste management unit
TA	technical area
TDS	total dissolved solids
TKN	total Kjeldahl nitrogen
TNT	trinitrotoluene
TOC	total organic carbon
TOXNET	Toxicology Data Network
TPH	total petroleum hydrocarbon
TR	timed release
U	undetected (when referring to data qualification code)
UF	nonfiltered (sample)
USGS	United States Geological Survey
VOC	volatile organic compound
WQDB	Water Quality Database
WQH	Water Quality & Hydrology (former LANL group)
WRC	White Rock Canyon
WWW	World Wide Web

Elemental and Chemical Nomenclature

Americium	Am	Neptunium	Np
Ammonia (as Nitrogen)	NH_3-N	Nickel	Ni
Antimony	Sb	Nitrate (as Nitrogen)	NO_3-N
Arsenic	As	Nitrite (as Nitrogen)	NO_2-N
Barium	Ba	Nitrogen	N
Beryllium	Be	Oxygen	O
Bicarbonate	HCO_3	Phosphorus	P
Boron	B	Phosphate (as Phosphorus)	PO_4-P
Bromine	Br	Plutonium	Pu
Cadmium	Cd	Potassium	K
Calcium	Ca	Radium	Ra
Calcium carbonate	$CaCO_3$	Selenium	Se
Carbon	C	Silicon	Si
Cerium	Ce	Silver	Ag
Cesium	Cs	Sodium	Na
Chlorine	Cl	Strontium	Sr
Chromium	Cr	Sulfate	SO_4
Cobalt	Co	Sulfur	S
Copper	Cu	Technetium	Tc
Carbonate	CO_3	Thallium	Tl
Europium	Eu	Thorium	Th
Hydrogen	H	Tin	Sn
Iron	Fe	Tritium	^3H
Lanthanum	La	Uranium	U
Lead	Pb	Vanadium	V
Lithium	Li	Zinc	Zn
Magnesium	Mg		
Manganese	Mn		
Mercury	Hg		
Molybdenum	Mo		
Neodymium	Nd		

1.0 INTRODUCTION

From 1998 through 2006, 42 wells have been drilled and completed for hydrogeologic characterization beneath the Pajarito Plateau as part of the Los Alamos National Laboratory (LANL or the Laboratory) "Hydrogeologic Workplan" (LANL 1998, 059599) or as part of corrective measures. Of the 42 wells, 7 have been completed in perched intermediate zones, 25 have screens in the regional aquifer, and the remaining 10 have screens in both perched intermediate zones and the regional aquifer. Concerns about the reliability or representativeness of the groundwater quality data obtained from these wells stem from the potential for residual drilling fluids and additives to mask the present and future detection of contaminants, as discussed in characterization well geochemistry reports (listed in section 7.3) and by Gilkeson (Gilkeson 2004, 088728). LANL responded to the concerns raised by Gilkeson by presenting hydrogeological and geochemical data collected at selected wells (LANL 2004, 088420). The U.S. Department of Energy (DOE) then requested LANL to provide an in-depth analysis of all screens in wells constructed under the "Hydrogeologic Workplan" that were completed within intermediate perched zones or in the regional aquifer. The U.S. Environmental Protection Agency (EPA) reviewed the criteria selected by the Laboratory for its approach to evaluating the representativeness of water quality data (EPA 2005, 090545). Revision 0 of the 2005 "Well Screen Analysis Report" (WSAR) (LANL 2005, 091121) responded to DOE's request by providing results of a geochemical evaluation of well screens in the 33 wells that had been completed and sampled as of August 2005. Revision 1 (LANL 2007, 095043) updated the report to include wells completed since 2005 and incorporated comments and recommendations of the New Mexico Environment Department (NMED) (NMED 2006, 094373). Revision 1 also reflected an evolution in the process of evaluating well screens.

This report is Revision 2, which has been prepared to respond to NMED's direction (NMED 2007, 095493) to modify Revision 1. This response contains data on radioactive materials, including source, special nuclear, and byproduct material. Information on radioactive materials and radionuclides, including the results of sampling and analysis of radioactive constituents, is voluntarily provided to NMED in accordance with U.S. Department of Energy policy.

1.1 Purpose

The primary purpose of this report is the evaluation of whether screens in characterization wells are capable of producing data that are reliable and representative of the predrilling conditions within intermediate-depth groundwater and the regional aquifer. In so doing, this report first establishes a set of geochemical criteria against which to compare the water chemistry measured at each screen. This comparison results in a quantitative estimate of the extent to which the data are judged as being reliable or representative of predrilling groundwater geochemistry. Results for the most recent samples from each screen as of December 2006 are used to define screens that produce reliable water-quality data and those for which data are potentially compromised by residual drilling artifacts. Of the impacted screens, the report identifies those that appear to be cleaning up over time and those that are the most problematic.

The results of this report are being used as the basis of prioritization of wells and screens that may require rehabilitation, if selected for monitoring (LANL 2006, 092535). The methodology for screen assessment is being used to determine the suitability of wells to monitor constituents as part of corrective measures evaluations for specific areas. The WSAR also provides a technical framework for evaluating historic and new water-quality data for representativeness.

1.2 Scope

This report describes an assessment protocol applied to water-quality (geochemical) data for samples collected from deep wells as of December 31, 2006. Figure 1-1 shows locations of wells and springs in the Los Alamos area that are the focus of this report. The wells evaluated in this report include 38 wells constructed under the auspices of the “Hydrogeologic Workplan” (LANL 1998, 059599), as well as four wells installed as part of a corrective measures study in Cañon de Valle associated with solid waste management unit (SWMU) 16-021(c), the 260 outfall. Within the 42 wells are 95 individual screens. Of these screens, 80 were functional and 15 were dry, plugged, or had not yet been sampled at the time that this analysis was conducted. Each of the functional screens was analyzed independently for this report.

The screen evaluation primarily addresses the impacts of fluids used in drilling. Drilling fluids can be defined as fluids—and associated drilling additives—placed or circulated in the drilled hole during drilling operations. Drilling and construction of monitoring wells within perched intermediate zones at depths greater than 100 ft or within the regional aquifer require the use of drilling fluids to ensure borehole stability and lubricity. Drilling fluids perform functions that include cleaning cuttings off of the bit and the bottom of the borehole, transporting cuttings to the surface, providing borehole stability, cooling the bit, and lubricating the drill string. Rotary drilling to these depths is not possible without the use of drilling fluids, without incurring substantial risk to the successful completion of the boreholes and installation of the wells. This is particularly true for the complex hydrogeology of the Pajarito Plateau. In addition to chemical products used during drilling, this report also considers effects of chemical products used during well construction and development. It is outside the scope of this report to address questions concerning the need for, or the appropriateness of, specific drilling methods and fluids.

Finally, this revision also evaluates water-quality samples for effects from metal corrosion of well casings and screens.

1.2.1 Revision 1 Modifications

Revision 1 (LANL 2007, 095043) was prepared to address comments from the NMED (NMED 2006, 094373) and to make other improvements. A reanalysis of the data used in the original report—as well as analysis of new data acquired after that report was prepared—was performed using additional geochemical indicators for groups of analytes. The usefulness and limitations of the indicators were discussed. Although well corrosion is not relevant to the potential impact of drilling fluids, corrosion influences water quality; therefore, indicators of well corrosion were added to the analysis in Revision 1. Additional clarification was provided for the principal component analysis (PCA) in section 5. Although not related to an NMED comment, the most significant change in Revision 1 was the abandonment of the original report’s tiered geochemical approach which focused on evaluating water-quality samples for residual inorganic constituents from bentonite mud, residual organic constituents from drilling polymers, and development of reducing conditions from biodegradation of the organic drilling products. In Revision 1, development of a single systematic set of evaluation criteria recognized the potential effects of drilling products commonly used in concert with the primary drilling fluids. This efficiency allows for improved automation of the approach. Revision 1 implementedestablished the technical basis for an automation algorithm developed specifically to evaluate historic and current groundwater-quality data with respect to representativeness and to assign qualification flags to samples in LANL’s Water Quality Database (WQDB) to indicate those with potential drilling fluid effects.

Revision 1 evaluated a more extensive data set than the original report, by including data that were collected between the data cutoff of August 2005 for Revision 0 and December 2006.

1.2.2 Revision 2 Modifications

Revision 2 addresses comments made by NMED in its direction to modify the report (NMED 2007, 095493). This revision uses the same data set as used in Revision 1, the same evaluation protocol, and the same six test categories. These modifications are minor and are primarily for clarification. The major difference between Revision 1 and Revision 2 is removal of the qualitative assignment of well screens to a rating system. Revision 2 does, however, retain the quantitative measure of reliability in the number of test categories passed by a particular sample. Removal of the rating system increases the versatility of the assessment process for area-specific evaluations having monitoring objectives for particular suites of contaminants; removal of the rating system also decreases the likelihood that a screen's water quality reliability may be misinterpreted due to the impression inherent in a qualitative descriptor.

1.2.3 Topics Outside the Scope of This Report

This report does not examine whether the use of drilling fluids affected the achievement of the characterization objectives of the "Hydrogeologic Workplan," or whether these wells are suitable for use as monitoring wells under the March 1, 2005, Compliance Order on Consent (Consent Order) signed by the NMED, the DOE, and the University of California. The latter will be achieved through area-specific evaluations.

Other related issues that lie outside the scope of this report include specifying actions to be taken for analytes judged as unreliable or not representative of predrilling conditions,

- predicting when an impacted screen may be able to provide chemical data that are reliable and representative of predrilling conditions,
- specifying corrective actions to be taken if a screen is judged as unlikely to produce reliable or representative water-quality samples in the foreseeable future,
- discussing methods for rehabilitating impacted well screens, which is the subject of a separate evaluation, and
- discussing additional factors that may contribute to well screen performance, such as well construction methods and permeability of the geologic formation.

1.3 Organization of the Report

Revision 2 retains the same organization as that of Revision 1. Section 2 describes the methodology and sources used to locate and compile information needed to conduct this analysis, including the development of a list of relevant analytes and their chemical characteristics, well-drilling histories and screen-construction details, and background water-quality parameters that define predrilling groundwater conditions.

Section 3 presents the assumptions used in developing and applying the geochemical criteria used to evaluate water-quality data and identify potentially impacted analytes for individual screens.

Section 4 presents the detailed technical basis of the evaluation process. As a preface for the discussion of the evaluation criteria, section 4.1 summarizes the well drilling, construction, and development methods that were used, and section 4.2 describes groundwater sampling suites, sampling protocols, and sampling frequencies. Sections 4.3 through 4.9 present the methodologies used in the screen evaluation and the analysis of the 80 functioning well screens placed in saturated zones. A new section 4.10 outlines the protocol used to identify analytes impacted by residual drilling effects. Section 4.11 discusses caveats and limitations on the applicability of indicators.

Section 5 presents the results of a separately conducted, multivariate statistical approach to evaluating water-quality data through a statistical PCA.

Finally, section 6 summarizes the well screen analysis, conclusions of this report, lessons learned, and potential next steps.

Supporting data and information used to compile this report are provided in the following appendixes:

- Appendix A—chemical characteristics for the analytes and drilling products considered relevant to this analysis, along with chemicals of potential concern (COPCs).
- Appendix B—well and screen characteristics, including timelines for drilling and development.
- Appendix C—available water-quality data for the geochemical indicator species. Revision 0 of the report included the last three eligible samples (as of August 2005) from each screen. Revision 1 extended the original data set to include sample data available as of December 2006. Revision 2 uses the same data set as Revision 1.
- Appendix D—plots that compare the screen data from Appendix C to each of the geochemical test criteria.
- Appendix E—results of the screen assessment for 393 samples from the 80 screens and an average score for each screen, as well as for the most recent sample from each screen. These tables are used to prepare the summary figures and to identify trends discussed in section 6.
- Appendix F—details of the PCA, including correlation matrices, factor loadings, and a list of stations used for comparison with the characterization wells.

1.4 Quality Assurance

This evaluation uses validated data that are acquired and reviewed following formal, EPA/LANL-approved quality assurance (QA) procedures as outlined in this section. All groundwater monitoring is conducted as an integrated activity that uses the same personnel, standard operating procedures (SOPs), laboratory analysis contracts, and data-management systems (LANL 2006, 094147). Monitoring is conducted under procedures that implement the requirements of the program-specific QA project plan ("Quality Assurance Project Plan for the Groundwater, Surface Water, and Sediment Monitoring Program," RRES-WQH-QAPP-GSWSED, R1, located at http://erinternal.lanl.gov/procedures/WQH/QAPP_GSWSED.pdf)

LANL field procedures generally follow guidelines of U.S. Geological Survey (USGS) water-sample collection methods and industrial standards common to environmental sample collection and field measurements, including the collection of field blanks and field duplicates and use of trip blanks. Sample collection, preservation, and measurement of field parameters for groundwater are conducted according to SOPs and quality procedures (QPs) (current versions listed in section 7.4). Field data protocols are discussed in section 4.2.1. Field data have inherent uncertainties, regardless of compliance, particularly with dissolved oxygen (DO), oxidation-reduction potential (ORP), and sulfide. However, it is assumed that these field data are reliable qualitative indicators of oxidation reduction (redox), even if they have quantitative uncertainties (see section 3.0).

Chemical analyses of water samples use commonly accepted analytical methods required under federal regulations such as the Clean Water Act and approved by EPA. Statements of work (SOWs) for contract analytical services that support monitoring activities specify QA guidelines for the contract laboratories, including specific requirements and guidelines for analyzing groundwater samples.

Chemical data are posted on LANL's publicly accessible WQDB web site (http://wqdbworld.lanl.gov) after receipt. These data undergo several stages of review for validation and verification, with their current review status indicated by preliminary and provisional flags in the WQDB. Data verification evaluates the completeness, correctness, consistency, and compliance of a laboratory analytical data package against specific documentation protocols or contract requirements; data validation involves a standardized review of the analytical data against a set of criteria (QP-5.13, R0, Analytical Data Verification/Validation Process). (Note that this procedure was replaced by an Environmental Programs [EP] Environment and Remediation Support Services [ERSS] SOP [EP-ERSS-SOP-5013] on 2/9/2007.) These criteria are tailored to specific analytical suites and techniques, based on national guidelines for data review (EPA 1994, 048639; EPA 1999, 066649), and augmented with other guidance in the case of radionuclides (as referenced in Environmental Stewardship (ENV) Environmental Characterization and Remediation (ECR) SOP-15.06, Routine Validation of Gamma Spectroscopy Data). SOPs are used to identify the need to apply specific qualifier flags and reason codes to the reported results.

2.0 DATA INPUTS

2.1 Well Drilling and Screen Construction Information

Information about drilling methods and associated fluids or additives potentially present in individual well screen intervals was extracted from well completion reports (listed in section 7.2). In some cases, drilling logbooks were also consulted to verify or augment information in the reports. Extracted information about drilling and screen characteristics has been tabulated and is shown in Appendix B (Tables B-1, B-2, B-4, and B-5). Table B-3 describes drilling product characteristics and the quantities that are typically used, based on technical specifications, material safety data sheets (MSDSs), and other publicly available product-marketing literature.

2.2 Groundwater Chemistry Data for Screens

Groundwater data used in this report (see Appendix C) were extracted from Environmental Programs (EP) Directorate databases and field notes. The primary electronic data archive and source is the WQDB (http://wqdbworld.lanl.gov/), a publicly accessible repository of water-chemistry data obtained as part of characterization, investigation, surveillance, and monitoring of LANL on-site operations. The WQDB only reports data qualifiers for data received from external analytical laboratories. Field data are not amenable to the same level of qualification, beyond verification of instrument calibrations and checks.

Before water samples are collected from single-screen wells for analysis, the screen interval is purged and field parameters are monitored (e.g., pH, turbidity, DO) until they have adequately stabilized so as to minimize effects of screen construction materials on the water. These pre-sampling field data are recorded in field notebooks and on forms. Westbay systems in multiple-screen wells are not capable of purging because there is no internal screen volume to be purged; the sampling port accesses groundwater in the inner annulus between the screen and the sampling system. In lieu of purging, however, the sample collector records field parameters for every sample "pull," of which there may be five or more per sampling event. For a short period of time, these sets of pre-sampling field measurements were entered into an electronic EP database maintained separately from the WQDB. Some field data not yet available in the WQDB were taken from this secondary source, as noted in Appendix C. Section 4.2 provides a more detailed discussion of these field data.

Not all field data are available in electronic format. Purge volumes are recorded in the field, but are not entered into an electronic database. The purge volumes listed in Appendix C were taken from the original field data sheets.

2.3 Background Groundwater Chemistry

The evaluation process used in this report compares selected geochemical indicators for each individual screen against the range of background concentrations that are assumed to encompass predrilling conditions at that screen. Water-quality data that fall outside the range, and that cannot be attributed to the presence of a contaminant plume (see section 2.4), may then be identified as potentially unreliable or not representative of predrilling conditions. The list of indicators used for this comparison—about 30—is neither exhaustive nor comprehensive. The evaluation process is not intended to replace detailed geochemical evaluations such as those presented in characterization well geochemistry reports (listed in section 7.3), but to provide a reasonably simple, efficient, transparent, and consistent process for identifying analytical data that may be unreliable or not representative of predrilling conditions. Consequently, the evaluation method has been constructed by selecting key indicator analytes and parameters to test for the presence or absence of specific geochemical conditions that are known to affect water quality.

Background concentrations used for this comparison have been taken from the “Groundwater Background Investigation Report, Revision 2” (LANL 2007, 094856). The Laboratory updated its determination of the range of background concentrations of inorganic and selected organic compounds and radionuclides within alluvial and perched intermediate groundwater and the regional aquifer. The report provides analytical results and statistical distributions for 30 background stations that were sampled multiple times. The sampling stations consisted of springs discharging within the Sierra de los Valles and White Rock Canyon, supply wells, and monitoring wells completed within the regional aquifer and perched intermediate groundwater zones. Tables 4-3a and 4-3b of this report list ranges and mean background values for key indicator species used in this report.

The ideal approach to determining representative water quality would be to compare water-chemistry data for each screen against background concentrations specific to the formation lithology in which the screen is located. However, this level of distinction for background groundwater chemistry does not exist and is unlikely to ever exist at this level of detail. Consequently, in this report, the range of background concentrations is limited to that defined in the “Groundwater Background Investigation Report, Revision 2” (LANL 2007, 094856) for the regional aquifer and perched intermediate zones.

2.4 Contaminant Plumes

The applicability of specific geochemical indicator tests may be limited if a contaminant plume is present at the sampled location because a constituent in the plume may mask the condition of concern, producing a biased, misleading, or apparently inconsistent outcome. This caveat is particularly relevant for mobile contaminants that are also used as indicator species: chloride, perchlorate, chromate, nitrate, and sulfate. Table 2-1 tabulates some of the indicators that may have limited applicability to evaluation of water samples from specific screens due to the known presence of a contaminant plume containing that species. The compilation of this list focused solely on identifying plume constituents detected at concentrations that could change test outcomes. If the test outcome would be the same irrespective of whether the constituent was present or absent from the plume, then it was not addressed.

Compiled information relevant to the delineation of plume locations and constituents is found in well completion reports, well geochemistry reports, the annual "Environmental Surveillance Report," corrective measures studies reports, specific investigation reports (e.g., chromium investigation), and records of discharges from past and present sewage treatment plants. Confirmatory data are sometimes available from upgradient wells. Table 2-1 lists an indicator as present in the plume at the screen if the following conditions are met:

- The constituent exceeds background levels established for local groundwater
- A credible source for the constituent is present in the watershed, upgradient of the screen
- The constituent is expected to be mobile in local groundwater
- There is an overall high level of confidence that the constituent is present in the plume

Largely beyond the scope of this activity, although a significant consideration, is the identification of constituents that may not be present in the plume at its point of origin, but which attain elevated concentrations along the flowpath due to geochemical interactions between the plume and the formation minerals. An example of this scenario would be the dissolution of carbonate minerals by an acidic discharge, which could result in down-gradient increases in carbonate alkalinity, calcium, barium, and strontium, even if these constituents were not present in the original discharge.

2.5 Determination of Relevant Analytes

Table 2-2 lists LANL-relevant contaminants for each well according to the watershed in which the well is located, based on operational histories, disposal practices, and site-specific investigations. More comprehensive lists of relevant analytes and COPCs, organized by analyte suite, are presented in Appendix A (Tables A-1 through A-8). The list of analytes is intended to be conservatively broad to ensure the inclusion of key indicator species as well as COPCs across the facility. Thus, the analyte list includes some or all of the following:

- general chemical analytes that are commonly used to characterize groundwater quality,
- analytes that are covered by regulatory standards and that have been detected consistently in sediments or water (including alluvial groundwater, springs, and surface water base flow) in watersheds affected by LANL operations,
- analytes identified by the evaluation of Laboratory SWMUs, areas of concern (AOCs), or other considerations,
- analytes that are covered by regulatory standards and for which analysis has not been previously conducted or for which data are insufficient, and
- analytes specifically identified in the Consent Order.

The median groundwater compositions of the regional aquifer and the intermediate perched zone (LANL 2007, 094856, Tables 4.2-2 and 4.2-3) were used as input for speciation calculations, using the computer code PHREEQC (Parkhurst and Appelo 1999, 095402) for the inorganic analytes selected as relevant to this report (Longmire and Fabryka-Martin 2007, 095818). The speciation results are provided in Appendix A, Tables A-1 (general inorganic analytes), A-2 (metal analytes), and A-3 (radionuclides). These speciation calculations serve as the basis for determining which analytes could be impacted by drilling artifacts and under what conditions, as described in greater detail throughout section 4.

2.6 Chemical Characteristics of Analytes and Drilling Fluids

Information on analyte characteristics tabulated in Appendix A, such as adsorption and aqueous speciation, was retrieved from a systematic search of online databases publicly accessible through the World Wide Web (WWW), as well as standard reference documents. The user can generally search these databases by chemical or other name, chemical name fragment, Chemical Abstracts Service (CAS) registry number (RN), and subject terms. The following databases were searched to compile the bulk of the analyte characteristics required for this report:

- The Hazardous Substances Data Bank (HSDB) provides comprehensive, peer-reviewed toxicology data for about 5000 potentially hazardous chemicals, and is one of a cluster of actively maintained chemical databases on the National Library of Medicine's Toxicology Data Network (TOXNET) (http://toxnet.nlm.nih.gov/).
- The Environmental Fate Data Base (EFDB) is provided by the Syracuse Research Corporation (SRC). CHEMFATE (http://www.syrres.com/esc/efdb.htm) is part of EFDB and provides systematic tabulations of available data for up to 25 categories of environmental fate and physical/chemical properties of individual chemical compounds.
- The Extension Toxicology Network (EXTOXNET) Infobase (http://extoxnet.orst.edu/) develops and makes available pesticide information profiles (PIPs), which include over 170 insecticides, herbicides, fungicides, and other classes of pesticides.
- The Agency for Toxic Substances and Disease Registry (ATSDR 2005, 090525) has developed toxicological profile information sheets (http://www.atsdr.cdc.gov/toxprofiles/) for over 250 hazardous substances found at National Priority List (NPL) sites as well as for other substances related to federal sites.

Searches were also augmented by obtaining review articles or research results provided in peer-reviewed publications. For example, the databases listed above do not always contain quantitative information for some of the less common organic analytes or high-explosive (HE) degradation products. Also, specific publications often contain information or data that are more directly relevant to the water-quality effects of drilling fluids. In particular, laboratory and field investigations related to the design and performance of geologic repositories have resulted in a huge data set on the adsorption behavior of metals and radionuclides in subsurface waters, much of it specific to their adsorption onto bentonite clay (e.g., see data sources for Tables A-9, A-11, and A-12).

Physical and chemical characteristics of drilling products are provided in Appendix A, Tables A-9 through A-13. These tables address

- the mineralogical composition and adsorption characteristics of bentonite clay,
- water-soluble constituents of 12 commonly used well-drilling and development products, and
- chemical structures of constituents in the two primary organic drilling products used during drilling of the characterization wells.

3.0 ASSUMPTIONS

The following assumptions underlie this evaluation of the screen water-quality data:

- Groundwater within perched intermediate zones and the regional aquifer is overall aerobic (i.e., DO is present). Figure 3-1 presents a schematic of the conceptual model of natural groundwater chemistry for the Laboratory and surrounding areas. Supporting information for the assumption of oxidizing predrilling groundwater conditions comes from "Los Alamos National Laboratory's Hydrogeologic Studies of the Pajarito Plateau: A Synthesis of Hydrogeologic Workplan Activities (1998–2004)" (Collins et al. 2005, 092028):

  - ❖ the ubiquitous presence of oxidized forms of dissolved nitrogen (nitrate), sulfur (sulfate), and DO
  - ❖ the presence of manganese dioxide and ferric (oxy)hydroxide in borehole geologic samples
  - ❖ the absence of sulfides
  - ❖ low dissolved concentrations of iron and manganese (generally less than 0.1 mg/L)
  - ❖ oxidizing conditions measured in groundwater samples collected within areas of recharge (Sierra de los Valles), along groundwater flow paths (Pajarito Plateau), and from part of the discharge zone (White Rock Canyon springs)
  - ❖ detection of contaminants stable in oxidized forms, including nitrate, perchlorate, chromate, molybdate, sulfate, and uranium(VI), in groundwater at the Laboratory

- Review of three or more characterization and surveillance sample events for a screen is necessary to yield a screen assessment outcome with a moderate to high level of confidence. A high level of confidence means that the outcome of the assessment is approximately the same for all of the most recent sample events, or that the outcomes define a consistent trend over time.
- The level of confidence in the outcome of the assessment is indicated as low if one or more of the following conditions exist: (a) data are available for less than three sampling events; (b) some key data are not available for the assessment; (c) data for the most recent sampling event were obtained more than a year prior to this assessment; or (d) results from the assessment are internally inconsistent, e.g., with respect to apparent reducing-oxidizing conditions.
- The suite of positively charged inorganic analytes that adsorb onto bentonite also adsorb onto iron and manganese (oxy)hydroxides and vice versa, depending on pH and the adsorbent's point of zero charge (pzc).
- Neutral organic compounds are assumed not to adsorb onto iron and manganese (oxy)hydroxides that possess either a net negative or net positive surface charge.
- Residual bentonite mud used for drilling contains about 0.1% solid organic carbon. This assumption is made for the purpose of evaluating adsorption sites for organic contaminants.
- The effective distribution coefficient (K_d) for an organic species adsorbing onto bentonite can be estimated from the species' organic carbon partition coefficient (K_{oc}) by multiplying K_{oc} by the fraction of organic carbon in the bentonite (0.001).
- All organic analytes can be potentially impacted if reducing conditions develop in the vicinity of the screen as a direct or indirect result of residual drilling fluids. Organic chemicals undergo oxidation-reduction reactions under a wide range of conditions, including aerobic (oxygen present) and anaerobic (oxygen-absent) conditions. Although degradation kinetic rates can be extremely slow for some organic analytes in the absence of appropriate microbial populations, the evident presence of anaerobic water in several screens strongly indicates that the residence time of groundwater in the impacted zone is apparently long enough for bacteria to carry out a sequence of metabolic activities, causing the aerobic groundwater to become anaerobic.
- Field-based measurements of DO, sulfide, and ORP provide reliable qualitative indicators for the presence of reducing conditions, although not necessarily of the absence of such conditions

unless appropriate precautions are taken to prevent exposure of the sample to the atmosphere. This assumption is a consequence of the logical expectation that, under reducing conditions, a low to moderate concentration of dissolved oxygen in a bailed or pumped water sample can only be increased—not decreased—upon exposure to the atmosphere, and that the concentration of dissolved sulfide can only decrease (by outgassing or by its oxidation to sulfate), not increase. The same assumption applies to ORP measurements, i.e., that the ORP measured in a reducing water sample can only increase upon exposure to the atmosphere. Consequently, low to moderate ORP and DO values are interpreted as upper limits for actual in situ conditions, and the measured sulfide concentration is considered a lower limit.

Note: Although one would be wrong to conclude that reducing conditions are absent if these field-based redox indicators passed their associated tests, it is important to recognize that this limitation—that a drilling effect is absent if one of the associated indicator passes its test—applies to all indicators. This limitation is the primary reason for examining multiple indicators for the same condition and should not be taken as a reason to remove a less-than-perfect indicator from consideration.

- Some organic species and radionuclides adsorb so strongly to clays, including bentonite, that they are rarely detected in groundwater. As a result, we are not aware of any suitable indicator species that are routinely measured and that can be used to evaluate with confidence whether or not nondetects of these strongly adsorbing species are reliable and representative of predrilling conditions. Consequently, if a sample passes all applicable test criteria for which suitable data are available, such that no strong evidence is found for the presence of residual drilling-fluid effects, then it is assumed that no further evaluation is needed for the reliability and representativeness of water-quality data from that screen for that sample.

4.0 DATA QUALIFICATION PROCESS TO IDENTIFY IMPACTED SCREENS

4.1 Drilling Methods and Impacts

4.1.1 Well Drilling and Construction Methods

A general familiarity with well drilling and construction methods and products is necessary in order to develop and implement a reliable protocol for detecting whether or not groundwater chemistry has been impacted by these activities. LANL has adopted a graded approach for its drilling operations, with the objective of minimizing the introduction of fluids and materials downhole to those needed to complete drilling operations in a timely and effective manner. The use of some type of drilling fluid is generally necessary to cool the drillbit and to lift cuttings from the hole. Two common drilling methods are used at LANL: mud rotary and air rotary (Figure 4-1). The mud-rotary method uses a water-based slurry of bentonite mud, to which soda ash (sodium carbonate) is usually added to increase the fluid pH and to suppress flocculation of the clay particles by calcium. At deeper depths, or if borehole walls become unstable and subject to sloughing or cave-ins, then an organic polymer such as EZ-MUD is added. The polymer serves several purposes, the primary one being to help build the wall cake in order to reduce filtrate loss into the formation. Polymer also coats the clay particles so as to minimize flocculation and clumping.

An air-rotary method uses air as the primary component of the drilling fluid. For shallow boreholes, e.g., depths of 30 ft or less, air alone may be adequate for this purpose. For deeper depths, a fluid with better lift capability is needed, and mixing air with water extends the fluid's effective working depth to about a hundred feet. To lift cuttings from depths up to a few hundred feet, a surfactant such as QUIK-FOAM may be added to the air-water mix to stiffen it. Finally, at greater depths, or if borehole walls are unstable, then a polymer such as EZ-MUD may be added to the air-foam mix. It forms a thin polymeric film coating on the borehole walls that acts to minimize fluid loss to the formation and thereby improves the fluid's lift capability.

A variety of other drilling products is often needed to advance the borehole and to prevent sticking and other problems (Figure 4-1). Chief among these products are lost circulation materials (used to plug openings in the borehole wall and minimize loss of drilling fluids into the formation) and casing lubricant such as TORKease. The significance of the fact that a variety of drilling products are often introduced into a borehole besides bentonite and polymers is made more apparent in sections 4.4 and 4.5 when this information is used to identify potentially useful indicators of residual drilling products.

In wells constructed prior to 2002, a solution of EZ-MUD was used to transport the annular bentonite fill through the tremie pipe. Adding the polymer delayed the swelling of the clay. During this same period of the drilling program, PEL-PLUG was used.

Appendix B, Table B-1, tabulates well drilling, construction, and development histories for the wells evaluated in this report. Table B-2 briefly describes the drilling methods and materials used in each well. The earliest wells were drilled using air-rotary drilling methods with casing advance and the minimal use of fluids other than air. Because of significant problems associated with stuck casing, unstable boreholes, and lost circulation, drilling fluids were used to improve lubricity, borehole stabilization, and cuttings circulation. Continuing drilling problems made total reliance on air-rotary drilling with casing advance impractical for meeting drilling objectives. It became apparent that the depth of the wells and the difficult drilling environment, including substantial heterogeneity in physical rock properties, required that additional drilling techniques be employed in order to penetrate and respond to the complex hydrogeologic conditions that characterize the Pajarito Plateau. All of the drilling methods used by LANL are in accordance with standard industry practice and are described by the American Society for Testing and Materials (ASTM). The drilling methods used by LANL are also among those specified in the Consent Order.

As indicated in Appendix B, Table B-2, all of the wells used some type of downhole material to assist in drilling. Organic fluids, primarily EZ-MUD and QUIK-FOAM, were used in all but two wells. In addition, sodium-bentonite drilling mud was used in twelve well-screen intervals. A variety of other materials was also added to many of the wells (Table B-2). A description of these products, their uses, and the typical amount added per 100 gal. of injection water is provided in Table B-3.

4.1.2 Well Development Methods

Well development is the combination of processes used to mitigate aquifer damage, including that of the borehole wall during well drilling, and to remove suspended sediments. Well development removes fluids used during drilling and can restore or improve porosity and permeability of the formation materials around the well screen. A secondary function of well development is to settle the annular fill to a stable position. Ultimately the well, when fully developed, will yield groundwater samples that are representative of predrilling conditions. Well-development procedures at LANL are consistent with industry standards and with the Consent Order. As of July 2000, the Laboratory defined an upper limit of 2 mg/L of total organic carbon as one of the performance criteria for satisfactory well development.

SOPs and/or drilling workplans prescribe the development process to be followed and specify water quality parameters as performance criteria. To monitor the effectiveness of well development, a suite of groundwater parameters is measured throughout the development process.

> *The primary objective of well development is to remove suspended sediment from the water until turbidity is less than 5 nephelometric turbidity units (NTUs) for three consecutive samples. Additional water quality parameters to be measured during development include pH, temperature, specific conductance, and total organic carbon (TOC). If the NTU standard isn't attainable, an alternate standard of stabilization of pH, temperature, and conductivity, and TOC levels less than 2.0 ppm must be achieved before termination of development procedures. Water samples will be collected daily in 40-ml septum vials and 250-ml poly bottles and transferred to the Earth and Environmental Science Division's Hydrology, Geochemistry, and Geology (EES-6) Group for TOC and anion analyses. Samples will be submitted unfiltered and without acid preservatives. (Kleinfelder 2005, 094909, p. 9)*

Groundwater samples are collected immediately after well development and analyzed for the full suite of inorganic constituents and organic constituents, including acetate and formate, which are breakdown products of EZ-MUD. Additional analyses are performed by external laboratories for isopropyl alcohol, the primary constituent in QUIK-FOAM, and/or acetone (initial oxidation product of isopropyl alcohol).

As the drilling program progressed, the tendency was to use rod-based slotted screens in preference to pipe-based slotted screens. Rod-based screens allow more effective development of the screen interval because they have twice as much open area and less of a tendency to allow pockets of drilling fluid to collect behind the screen.

New well development procedures were implemented in 2002, based on recommendations made by Powell and Schafer (2002, 090523). The new procedures emphasize development immediately following well installation to remove the wall cake from the borehole. As described in characterization well completion reports (listed in section 7.2), additional development techniques involved

- initial surging with a bailer during well construction to settle filter pack around the screen,
- using packers to isolate screens to pump directly from that interval in the multiple-screened well installations,
- using standard development chemicals to break down the additives used during drilling,
- jetting at well R-16, and
- removing significantly large volumes of groundwater during the pumping phase of well development. An average of 135% or more groundwater was removed than was added in the multiple-screened wells drilled in 2002 and later.

These new development procedures have been conducted under the drilling contractor's internal field procedure and not under a LANL procedure. The formal documentation of development procedures for a given well is reported in the drilling workplan (e.g., Kleinfelder 2005, 094909 for R-10 and R-10a). The well completion reports (listed in section 7.2) also document the procedure that is followed, along with any deviations from the workplan, and present the monitoring data for field parameters. To assess the effectiveness of the improved development protocol, data for the final measurements of turbidity and TOC following development are tabulated for each screen in Table 4-1. Also on that table are listed data for these parameters as measured for the most recent sampling event in Table C-3. This comparison reveals that desired target values for turbidity (<5 NTU) and TOC (<2 mg/L) have not always been attained by the end of development. For example, R-2, for which development was completed in December 2003, had a final turbidity of 11 NTU and TOC of 2.2 mg/L.

The influence of well-development protocols on present-day screen conditions was examined by tabulating the presence of residual drilling effects and redox conditions for the most recent sample from each screen as a function of three surrogate measures for the effectiveness of development in removing residual drilling fluids from a screen. The surrogates are the TOC attained by the end of development (Figure 4-2a), the year in which development was completed (Figure 4-2b), and the elapsed time between completion of drilling and end of well development (Figure 4-2c). Figure 4-2a shows that slightly less than one-half of the 80 screens included in this report had achieved TOC <2 mg/L by the end of development. (Note that the majority of these screens were developed prior to establishment of the TOC monitoring guideline.) However, from this plot there appears to be little correlation between the level of TOC achieved and the present-day reliability of the water-quality samples from that screen. The most striking trend is observed when current screen conditions are mapped against the year in which development was completed (Figure 4-2b). Screens in which development was completed in 2003 or later show an improved track record as compared with screens developed prior to 2003. This apparent improvement is attributed to the cumulative effect of multiple factors: implementing additional development criteria, modifying drilling practices to minimize fluid use and loss into the formation, switching to rod-based screens, and—perhaps most importantly—switching to a much higher proportion of single-screen and dual-screen wells rather than multiple-screen wells.

The lack of correlation between ending TOC and present conditions in a screen implies that a significant inventory of residual organic drilling fluid component may remain in a screen interval even after development, and yet not be directly detectable from groundwater samples. This conceptual model, which is described later in section 4.5, assumes that some proportion of the organic constituents used in a borehole adsorbs or partitions strongly onto geologic material or onto cellulosic lost-circulation material, and that these organic constituents may not be detected in water-quality samples simply because they have been immobilized or trapped and are only negligibly soluble. However, their presence can be inferred from the subsequent development of reducing conditions and lingering elevated concentrations of biodegradation products, as discussed in section 4.5.

Polymer-based fluids, such as EZ-MUD and TORKease, have been used in nearly all of the characterization wells within the scope of this report to provide lubrication between the casing advance system and the borehole wall, stiffen the air-foam mix, or enhance the bentonite-based drilling fluid. Downhole drilling products are analyzed for inorganic chemicals to evaluate their potential to impact groundwater chemistry. Results of this characterization and evaluation are presented in section 4.4 (for inorganic constituents) and section 4.5 (for organic constituents). Once the regional water table was encountered, the use of additives was greatly reduced so as to minimize the impact on groundwater chemistry. Well-development methods were further revised to address the use of bentonite-based drilling fluids. Additional time and effort were spent in removing residual bentonite and minimizing adverse impacts to groundwater chemistry and formation properties.

4.2 Groundwater Sample Collection

4.2.1 Collection Protocol

SOPs for sampling groundwater have undergone multiple revisions to reflect technical and Laboratory organizational changes during the period of record addressed in this report. A list of applicable procedures governing the collection of groundwater samples is presented in section 7.4. This section briefly reviews how the sample collection protocol has evolved over time. Table B-5 lists which of the methods described below were used to collect each of the water-quality samples evaluated in this report.

<u>Single-screen wells</u>

One aspect of sample collection that has been revised over the past decade is the conditions by which the field sampling team determines when the screen interval has been adequately purged. In characterization wells that use submersible pumps to retrieve water samples from intermediate or regional groundwater (16 wells, identified in Tables B-5 and C-2), purging and sampling has been previously performed in accordance with the procedure ENV-ECR SOP-6.01, Purging and Sampling Methods for Single Completion Wells, prepared in 1992. Prior to the collection of groundwater samples, three conditions had to be met: (1) a minimum of three casing volumes of water must be purged; (2) field chemical parameters must stabilize; and (3) turbidity must be stable or less than 5 NTU. Field parameters are considered stabilized when pH varies by less than 0.2 units or the variation in the other parameters over a series of four readings is within ten percent.

In 2004, the Risk Reduction and Environmental Stewardship (RRES) Division's Water Quality & Hydrology (WQH) Group, in a procedure titled "Groundwater Sampling Using Submersible Pumps" (RRES-WQH-SOP-049), adopted the purging criteria of (1) a minimum of three casing volumes of water extracted at a low flow rate; or (2) after purging one casing volume withdrawn at a low flow rate, drawdown, turbidity (and dissolved oxygen, if measured) have stabilized. The effective date of RRES-WQH-SOP-049 is July 21, 2004; however, the draft SOP was implemented prior to document finalization. Depending on the sampling date and well-specific field parameter conditions, from one to three casing volumes of water may have been purged prior to the collection of groundwater samples. Under special conditions (e.g., where field parameters have not stabilized after purging three casing volumes of water or low flow conditions limit the volume available for purging), sample collection has deviated from the SOP and has occurred as directed by the leader of the project for which the samples were intended. Such deviations can be seen in the purge volumes documented in Table C-2. For example, MCOBT-4.4, which is sampled using a submersible pump, was purged of 3 casing volumes of water for the samples collected in 2003, but only 1 casing volume or less in subsequent years The cause for this deviation was the dropping water level in this perched intermediate aquifer; in June 2005, the volume of water obtained was insufficient even to submit for all of the desired analyses.

Specific governing SOPs and volumes of water purged prior to each sampling event covered by this report are presented in Table C-2.

The standards and procedures for measuring field parameters are presented in ENV-DO-203, Field Water Quality Analyses, which became effective July 2005, superseding both RRES-WQH-SOP-054.1 and ENV-ECR-SOP-6.02, Field Water Quality Analyses System. The use of flow-through cells (a closed chamber that allows the continuous flow of water over measurement probes while preventing atmospheric influence) has occurred historically, but not consistently, for the measurement of field parameters at single-screen wells that are sampled using submersible pumps. Beginning with sampling rounds conducted in late 2003 to early 2004, the use of flow-through cells for the collection of field parameter data at wells using submersible pumps became routine.

Multiple-screen wells

Wells equipped with a Westbay system (identified in Table B-1) have been historically sampled in accordance with ENV-ECR-SOP-6.32, Multi-Level Groundwater Sampling of Monitoring Wells—Westbay MP System, and ENV-WQH-SOP-050, Groundwater Sampling Using Westbay System, which are similar procedures prepared by Laboratory groups RRES-ECR and ENV-WQH, respectively. Water samples from Westbay systems have been collected in accordance with ENV-WQH-SOP-050.3 since December 2005.

As described in ENV-WQH-SOP-050, fifteen steps are involved in taking samples with the Westbay sampler: (1) surface function tests are performed; (2) the sampler probe is placed on the well head and the surface function tests are documented (in all steps, documentation occurs on the Groundwater Sampling Field Data Sheet); (3) air is evacuated from stainless-steel sample bottles with a vacuum pump to 2–4 psi and the pressure is documented; (4) the sampler probe and bottles are tripped in using a casing log and table as a reference; (5) the sampler probe is landed at the desired port, the location and pressure inside the casing is documented; (6) the sampler probe is attached to the monitoring port and the zone pressure is recorded; (7) the water sample is collected at the port by opening the sampler valve; when the pressure stabilizes, the zone pressure with the valve open is recorded; (8) the sampling valve is closed and the shoe is retracted, the internal pressure is recorded; (9) the sampler probe is raised and the landing arm is retracted, the sampler probe and stainless-steel sample bottles are tripped out; (10) the sample bottles are disconnected from the sample probe, excess pressure can be vented from the last bottle in the string; (11) the water is transferred to sample containers and the volume of sample water retrieved is recorded; (12) the samples collected for volatile organic compound analysis have several sub-steps to ensure the absence of bubbles in the sample bottle; (13) steps 1–12 are repeated as needed to collect the appropriate volume of water for sampling requirements from each port; (14) samples are collected using a 0.45 µm pore size filter; and (15) field chemistry measurements or field parameters are collected on each run, the information is recorded, and the water used for field measurements is discarded upon completion.

R-33 is an exception to this standardized description of sample collection from multiple-screen wells. R-33 is sampled using a BARCAD system that applies pressurized gas in cycles to push and extract the water column into a sampling chamber. Bore volumes are not removed from R-33 prior to sampling. BARCAD sampling is performed per a draft SOP.

Comparison of field parameters obtained during sampling

To evaluate how these different sampling protocols might affect the reliability of water-quality data, field parameter data obtained during purging of two single-completion wells are compared to field data obtained for each consecutive “sample pull” from two BARCAD screens and two Westbay screens (Figures 4-3a and 4-3b). The samples selected for this comparison are evaluated in detail later in this report. The ending field parameter values are listed in Table C-3, and other water-quality data (post-purging in the case of R-2, R-33, and MCOBT-4.4) are listed in Tables C-4, C-5, and C-6.

An important question is the extent to which purging before sampling affects the quality or reliability of the water-quality data. To address this question, field data are plotted in Figure 4-3b for two sampling events at MCOBT-4.4, both involving purging using a submersible pump. The purge volume for the March 2005 sample was 48 gal., equivalent to 2.2 casing volumes, while that for the June 2005 sample was only 6 gal. (0.3 casing volumes). Figure 4-3b shows that pH, DO, temperature, turbidity, and conductivity were monitored for over 50 minutes before collection of a water-quality sample for analysis. ORP data are available throughout the purging period for the June 2005 event, but are only available for the first 10 minutes for the March 2005 event. Approximate lengths of time involved for stabilization of the individual field parameters are:

- conductivity, 5 minutes, following which it remains relatively invariant for the remainder of the purge time
- pH, 35 minutes
- ORP, 45 minutes for the June 2005 event
- temperature and turbidity, indeterminate

Overall, however, no systematic difference is obvious when field data from the two sampling events are compared. Any differences in water quality parameters that might arise due to differences in purging volumes or rates are presumably largely masked by natural variability induced by the dropping water levels in this perched water system.

The other five samples examined are all collected from the regional aquifer and are plotted together on Figure 4-3a. The purge volume for R-2, which is sampled with a submersible pump, was 108 gal. for the August 2005 event, equivalent to 2.9 casing volumes. Field data are shown on the same plots for two BARCAD screens (R-33, Screens 1 and 2), and two Westbay screens (R-22, Screen 2 and 4), for sample events in June and July 2005. Again, no systematic difference is readily apparent when field data from these different sampling systems are compared.

4.2.2 Analytical Suites

Once a well is completed and developed, it initially undergoes characterization sampling. Analytes for characterization sampling are designed to detect changes in ambient water chemistry or the presence of Laboratory contaminants, and therefore involve generally comprehensive analytical suites. Following completion of the two to four characterization rounds, ongoing sampling is conducted in accordance with an approved monitoring plan. Analytical suites for surveillance monitoring are generally much less extensive than those analyzed during characterization sampling. Analytes are specified in the monitoring plan for each well based on possible source terms from the Laboratory. The need to monitor for a broad range of analytes is driven by detecting changes in ambient conditions, monitoring movement of environmental constituents of interest, regulatory requirements monitoring, and monitoring to assess the effectiveness of remedial actions. The frequency of sampling is also specified in the monitoring plan, and may range from quarterly to annually or even triennially.

The analytical suites for groundwater samples are periodically updated in response to information gained from site investigations and from changes in regulatory requirements. The suites currently defined in the WQDB are the following:

- Dioxins and furans
- Diesel-range organics (DRO)
- General parameters and inorganic species
- Herbicides
- HE and HE degradation products (HEXP)
- Metals
- Organochlorine pesticides and polychlorinated biphenyls (PCBs)
- Radionuclides
- Semivolatile organic compounds (SVOCs)
- Volatile organic compounds (VOCs)

SVOC and VOC suites overlap with one another, as do the DRO compounds and herbicide suites. Several analytes are measured or reported under more than one description, e.g., as an individual chemical as well as part of a total concentration for a particular category. Thus, even though a sample might not have been submitted for analysis of a particular analytical suite, analytes from that suite may still have been measured.

4.3 Water-Quality Assessment Methodology

4.3.1 General Evaluation Protocol

The original version of this report used a tiered geochemical approach that applied sets of evaluation criteria to each screen depending upon whether or not it was drilled using bentonite mud, organic polymers, or both. The current report establishes the groundwork for a more thorough, systematic, consistent, and transparent approach that automates the first step of the data qualification process. Figure 4-4 shows the sequence of steps envisioned for the qualification process. Once a water sample is selected for evaluation of drilling impacts through implementation of the WQDB's in-progress Data Qualification Module (step 1 in Figure 4-4), the next step will be automated application of the full set of water-quality test criteria for which suitable data are available in the WQDB.

The automated portion of the evaluation process (step 2 in Figure 4-4) relies upon the data qualifier codes reported by the analytical laboratory to determine whether to consider the analyte as detected or not detected. In the first stage of the well screen evaluation process, validation codes assigned through the data verification/validation process are not taken into consideration. This approach ensures that all water-quality data are treated on an equal basis by being taken at face value, as received from the analytical laboratory. The analytes that are most affected by this approach of not using verification/ validation codes at this early step in the evaluation process are the trace metals, especially zinc, but also chromium and molybdenum.

Subsequent to the automated initial screening, manual checks are conducted to ensure the validity of the automated test outcomes (step 3 in Figure 4-4).

If a local contaminant plume is present, or if the previous steps identify the potential for residual drilling effects, then a more in-depth technical review of the evaluation outcomes is almost always warranted (step 4 in Figure 4-4):

- checking for internal consistency among the test outcomes (e.g., indicators of redox conditions, indicators of residual drilling products)
- taking into account site-specific factors that may limit the applicability of a particular test criterion to a water sample
- identifying geochemical conditions that negate an underlying assumption for one or more test criteria.

Once the test criteria outcomes have been satisfactorily reviewed for a water sample such that residual drilling effects can be specified with confidence (step 5 in Figure 4-4), the final step in the data assessment protocol is to identify analytes for which the reported data are potentially unreliable as a result of the drilling effects. This aspect is also automated for producing the initial list of potentially affected analytes (step 6 in Figure 4-4). Following another review for correctness, the affected analytes are then assigned a flag in the WQDB indicating the reported data have a high probability of not being representative of predrilling groundwater conditions due to residual drilling effects.

4.3.2 Categories of Drilling Effects

One of the main objectives of this revised report is to establish and document the technical basis for the methodology used to evaluate groundwater chemistry data for representativeness relative to background and/or predrilling conditions. As a convenient framework, the effects of drilling fluids and development fluids on water chemistry in the vicinity of a well screen are classified as follows throughout this report (Figure 4-5 and Table 4-2), as well as throughout Appendixes A through E:

- Category A—Residual water-soluble inorganic components (section 4.4)
- Category B—Residual organic components (section 4.5)
- Category C—Modification of in situ redox conditions (section 4.6)
- Category D—Modification of surface-active mineral surfaces (section 4.7)
- Category E—Changes in carbonate mineral stability (section 4.8)
- Category F—Corrosion of stainless-steel well components (section 4.9)

A set of questions and test criteria have been developed to determine whether specific groundwater samples collected from single and multiple-screen wells are representative of predrilling conditions. The ability of a given well to detect the presence of contaminants, without interference from residual drilling or development fluids, is also an essential end point to this analysis. The remainder of this section discusses each of the different categories of drilling-derived effects in detail. Conceptual models are presented for the initial cause and evolution of each condition over time. Indicator species are selected based on characterization data or geochemical relationships well-established in the scientific literature. The last subsection for each category summarizes the results when the test criteria for that category are applied to the water-quality data from the 80 screens included in this report.

Section 4.10 summarizes the geochemical impacts of each individual drilling fluid and reiterates the geochemical indicators selected to identify when those impacts are present in a water sample. Section 4.11 identifies limitations or conditions under which the reliability of a particular indicator could be in question.

4.3.3 Considerations for Selection of Indicators

Ideally, test questions and indicator species should possess the following qualities:

- Transparency. The underlying logic for the indicator's selection should be quickly evident to users.
- Simplicity. Measured data should be directly comparable to a numerical threshold without any intermediate calculation required.
- Data availability. The data should be available for the majority of sampling events, past and present.
- Reliability. The measured data should have a high degree of reliability relative to whether they are above or below the specified threshold level. For indicators of residual drilling products, this aspect requires taking into account the extent to which the product is typically diluted when it is used.
- Specificity. The test questions for a condition should be sufficiently specific that they can be applied to all samples regardless of the type of drilling fluid used, with minimal risk of falsely identifying conditions that are "known" to be absent because a particular drilling fluid was not used at that location.

No single indicator can embody all of the above desired qualities. The last quality—specificity—is the most difficult to ensure because multiple factors usually affect the concentration of an analyte.

Consequently, a concerted effort has been made to include multiple indicators for each condition so that an outcome is not overly reliant upon a single indicator. In addition, outcomes for a sample may require a closer review by a subject-matter expert under the following conditions, in order to determine the applicability of specific tests and their default threshold values:

- the sample’s pH or alkalinity lies outside the normal range of background groundwaters,
- the sample’s test outcomes appear internally inconsistent, or
- one of the indicator species is suspected of being present in a local contaminant plume, and could be biasing the test outcome.

The threshold values for each test condition are based primarily on background concentrations of inorganic, radionuclide, and natural organic solutes characteristic of the regional aquifer and perched intermediate zones (Tables 4-3a and 4-3b). If geochemical evidence indicates the presence of one or more of the above drilling-related conditions when a sample was collected, then the protocol described in section 4.10 is followed to identify groundwater constituents that are probably impacted by the presence of those conditions. Data-quality flags (such as those listed in Table 4-4) are then assigned to these constituents in the WQDB. The purpose of these flags is to indicate to the data user which analyte concentrations may not be representative of predrilling conditions due to residual drilling fluid effects.

If a sample passes all test criteria, and if no strong evidence is found for drilling-fluid effects, then the screen assessment for that sample is completed, and no further evaluation is needed of that particular sample for data reliability and representativeness.

4.3.4 Organization and Presentation of Data and Test Outcomes

The data qualification process is documented at several levels of detail in this report, by both tabular and graphical means. The raw water-quality data used for the assessment of the 80 screens covered by this report are listed in Appendix C:

- Table C-3 for general water quality indicators (tritium, pH, alkalinity, and turbidity)
- Table C-4 for organic indicators
- Table C-5 for general inorganic indicators, other than trace metals, and
- Table C-6 for trace metal indicators.

The data listed in these tables are also shown on separate plots for each indicator in Appendix D, in alphabetical order by analyte name. These plots make it easier for the user to judge the credibility of the test itself as well as that of the threshold values, for example, whether the threshold values may be overly stringent or overly lax to define a pass/fail condition with confidence. These plots are also useful for conducting a quick visual check for correlations among indicators, so as to test some aspect of a conceptual model.

Tables C-3 to C-6 also list the outcome for each test applied to each sample: pass, fail, indeterminate, or not applicable. Table C-7 summarizes the number of tests passed and failed for each sample, so as to provide a quick basis for identifying overall water-quality trends. Failed criteria for each individual water sample are also tabulated in Table C-8, according to the category to which the test is assigned. This tabulation provides a convenient means by which one can scan the outcomes for correlations among indicators.

Table E-1 consolidates the individual test outcomes, omitting the raw data and showing only the pass/fail outcomes grouped by category so as to provide another way to visually recognize correlations among indicator outcomes. By examining such tables for common relationships, one develops a sense for the level of confidence to assign to each outcome.

The most condensed summary of sample outcomes is provided in Table E-2, which calculates a composite score for each screen based on all the sample events included in this report. A comparison between the composite score and the score for the most recent sample provides the basis for characterizing each screen's evaluation in terms of three descriptors, which are described in more detail in the introductory text for Appendix E:

- an overall composite score that expresses the percent of the applicable criteria met by the screen's water samples;
- the trend in the screen's condition with respect to water-quality impacts of residual drilling fluids (stable, improving, worsening, variable, or indeterminate); and
- the level of confidence in the outcome of the evaluation (high, moderate, or low).

4.4 Category A—Residual Water-Soluble Inorganic Constituents

4.4.1 Conceptual Model

This section first outlines how inorganic water-soluble constituents in drilling, construction, and development fluids may affect water quality. The primary drilling products that release water-soluble inorganic constituents to groundwater during use are not only bentonite drilling muds, but also acids, polymers in organic drilling fluids, soda ash, and lost-circulation materials. These materials are combined into a single class for the following reasons:

- Multiple products are often used in the same borehole interval, as illustrated by the variety of organic and inorganic drilling chemicals used in several screen intervals that were drilled using bentonite mud (Table 4-5).
- Based on simple laboratory leaching tests, discussed in subsection 4.4.2, these products share many of the same indicator species such that it would be difficult to determine which particular product was responsible for an anomalous chemical signal. For example, sodium and sulfate are indicator species for several drilling or development products other than bentonite mud.
- Ultimately, the biodegradable organic drilling products break down into inorganic species, such as sulfate from the Quik-Foam surfactant and dissolved nitrogen (via an intermediate degradation product, ammonia) from the EZ-Mud polymer.

Figure 4-6 depicts the geochemical conceptual model for the impacts of bentonite mud on water quality. Attention is focused on bentonite mud because this product is used in the largest quantity and initially dominates the water chemistry near the screen. The two major processes of interest are (1) desorption (leaching) of soluble inorganic constituents associated with bentonite, and (2) adsorption of metals, radionuclides, and organic compounds to the bentonite. (This second aspect is covered later in section 4.7.) The bentonite mud used to drill LANL wells, and in fact used for the majority of wells throughout the United States, is derived from Wyoming bentonite, which contains about 75% montmorillonite clay (Table A-9). Wyoming bentonite has a large specific surface area on the order of 600 m^2/g and a cation exchange capacity of about 80 milliequivalents (meq) per 100 g (Lajudie et al. 1995, 090542; Langmuir 1997, 056037). Over half of the ion-exchange sites are occupied by sodium cations (Table A-9). When this bentonite is mixed with water to form the drilling mud, large quantities of sodium and other soluble mineral impurities such as sulfate, nitrate, and chloride are leached into solution (Table A-9). Assuming a make-up rate of 25 lb of bentonite per 100 gal. of water (Table B-3), the initial concentration of total dissolved solids in the mud mix would be on the order of 77,500 mg/L (calculated from data for QUIK-GEL in Table 4-6), which is more than 500 times greater than the median total dissolved solids (TDS) of groundwater in the regional aquifer (145 mg/L calculated from data in Table 4.2-3 of LANL 2007, 094856). One of the objectives of well development is to retrieve as much of these solutes as possible from the saturated zone.

4.4.2 Selection of Indicator Species and Test Criteria

The water-soluble inorganic constituents of several drilling fluids used to drill LANL boreholes were characterized by staff at the LANL Geological and Geochemical Research Laboratory (GGRL) by diluting or leaching each with deionized water, and then analyzing the filtered solutions (Table 4-6). Table A-10 presents a more complete listing of the GGRL leaching data, including some drilling products not included in Table 4-6. These analytical results then provided the basis for estimating initial concentrations in the drilling solution used downhole, assuming each drilling fluid was diluted with an appropriate volume of local groundwater (Table 4-7). The two-fold objective of these calculations is (a) to identify analytes whose concentrations could be significantly increased by the presence of residual drilling fluid at the end of well development, and (b) to identify a set of key indicator species for these residual drilling fluids. The last row of Table 4-7 summarizes the results of this evaluation, identifying several soluble inorganic ions as indicator species based on the predicted magnitude of the increases in groundwater concentration. For example:

- QUIK-GEL and AQUA-GEL Gold Seal bentonite drilling muds—Na, alkalinity, SO_4, and Cl
- PAC-L, a cellulose polymer often added to drilling mud to minimize loss into the formation—Na, alkalinity, Cl, F, and PO_4

The presence of such analytes above background levels for local groundwater provides evidence of desorption processes taking place with residual drilling products, provided that these constituents are not present at a given well site as a result of local contaminant plumes. Sodium, phosphate, sulfate, and chloride are commonly present in plumes local to Los Alamos. The selection and application of multiple indicators is one of the main strategies used to minimize the potential for misinterpreting an anomalous geochemical signal, or the potential for an indicator's presence to be masked or ambiguous due to natural variability in background levels or due to inadequate development of a screen interval to remove residual chemicals. Based on estimated concentrations in Table 4-7, for example, calculated initial concentrations for sodium and sulfate in the drilling mud prepared using Quik-Gel exceed median concentrations in the regional aquifer, on average, by factors of 13 (sodium) and 100 (sulfate).

Such increases above background concentrations are illustrated by the geochemical trend plots for calcium, chloride, fluoride, sulfate, sodium, phosphate, alkalinity, and pH in Screens 2, 3, and 4 of characterization well R-16 (Figure 4-7). This multiple-screen well was drilled with bentonite mud, as well as drilling fluid additives and post-drilling chemicals including Liqui-Trol, Magma Fiber, N-Seal, PAC-L, and soda ash (Table B-2). Concentrations that plot above the grey-shaded regions for each indicator in Figure 4-7 are above background levels for the native groundwater, and are interpreted as residual constituents of drilling fluids not completely removed from the screen interval. Concentrations at background levels in Screen 2 (blue squares in Figure 4-7) indicate that the water-soluble constituents leached from these drilling products were mostly removed from this screen during well development. Screen 4 (red squares) shows greatly elevated concentrations of calcium, sulfate, sodium, and phosphate, which are slowly returning to background values, although at very different rates because of dilution and other geochemical processes. Screen 3 (black squares) appears to be intermediate between these two extremes. The last two samples plotted are data for samples collected in November and December 2006, showing the effectiveness of the recent screen rehabilitation pilot project in expediting a return to predrilling water-quality conditions. The dramatic increase in phosphate and alkalinity in Screen 4 immediately after the rehabilitation activities suggests that the bulk of the residual drilling fluids left in R-16 resided in the vicinity of this screen.

4.4.3 Application of Criteria to Water-Quality Samples

Screening questions, assessment criteria, and test outcomes for this category are presented in Table 4-8. Water-quality data from all of the screens included in this report were compared against the criteria listed in Table 4-8. Measured concentrations in samples from 80 screens are plotted in Appendix D. The details of this comparison are tabulated in Appendixes C and E.

Figure 4-8 summarizes the results of this analysis. Key findings for the most recent sample event include the following:

- The 5 selected indicators for residual inorganic constituents (chloride, fluoride, sulfate, sodium, phosphate), along with alkalinity and pH, are within background levels for 40% (32) of the 80 well screens, indicating the probable absence of significant residual inorganic drilling constituents from these screens.
- Among the 22 single-screen wells, 12 (55%) passed all tests for residual inorganic constituents of drilling fluids, including pH and alkalinity. Among the 58 screens in multiple-screen wells, the proportion of screens passing all tests was only 34% (20 screens).
- Of the 52% (42) of the screens that failed at least 1 of the 5 indicators, 22 (52% of 42) only fail 1 indicator, 11 (26% of 42) fail 2 indicators, 6 (14% of 42) fail 3 indicators, and 3 fail 4–5 indicators.
- From the bottom histogram of Figure 4-8, the most frequent indicator failed is chloride (20 screens, which comprises 48% of the 42 screens that failed 1 or more tests).
- The next 3 most frequently failed tests are those for fluoride (19 screens, 45% of 42), sodium (15 screens), and sulfate (11 screens).
- The test with the fewest number of failed samples is phosphate (9 screens, 21% of 42), possibly reflecting its limited presence in the most commonly used downhole drilling products.

The above outcomes take into account that a test may not be applicable if the constituent is known to be present in a contaminant plume intercepted by the screen. However, some of the remaining instances of elevated concentrations may also be attributed to the presence of an unknown plume or—more likely—to the unknown presence of a constituent in a known plume. This caveat is particularly likely to apply to some of the cases of elevated alkalinity, chloride, fluoride, and sodium concentrations.

If the evalution presented in this section concludes that residual inorganic components of drilling products are present in the water sample from a screen interval, then the protocol outlined in section 4.10 for Category A is followed to identify those analytes that are likely to be impacted.

4.5 Category B—Residual Organic Components of Drilling Fluids and Additives

In parallel with Category A for residual inorganic constituents of drilling fluids, Category B addresses the presence of residual organic constituents. The two dominant organic-based drilling fluids used in LANL wells are EZ-MUD and QUIK-FOAM. The main active ingredients in QUIK-FOAM belong to a class of anionic surfactants known as alcohol ethoxylate sulfates (AES). These molecules are moderately long carbon chains (ranging from 11 to 18 carbon atoms) bonded to several ethoxylate groups and ending with a negatively charged sulfate group (Pojana et al. 2004, 094487). The charge-balancing cation associated with the sulfate group is usually sodium, magnesium, or ammonium. Active ingredients in EZ-MUD are extremely long carbon chains of repeating sequences of polyacrylamide and acrylic acid units.

Several other organic drilling products are also routinely used in drilling—such as Liqui-Trol, N-Seal, PAC-L, SDI defoamer, and TORKease—as well as organic components in largely inorganic products. For example, QUIK-GEL bentonite drilling mud is coated with polyacrylate polymer (Wisconsin Department of Natural Resources 2006, 094912).

4.5.1 Conceptual Model

Figure 4-9 shows an idealized geochemical conceptual model for the water-quality impacts of organic polymer-based drilling fluid. Biodegradation of these compounds causes elevated concentrations of organic carbon and ammonia. The general sequence for biodegradation of AES chemicals is well known because of their widespread use in commercial products such as shampoos and detergents, and numerous studies of their environmental fate in surface waters (Scott and Jones 2000, 094913). Ultimately, the organic parts of these molecules are broken down and oxidized to carbon dioxide. However, the biological half-lives for the initial compounds or their derivatives range from a few hours to several years. Although well characterized for surface environments, biodegradation rates for these products in groundwater are poorly known and extremely sensitive to site-specific conditions (Scott and Jones 2000, 094913). Key factors which affect the rate include the types of microbes already present at the site, the extent to which the various microbial populations are acclimated to their food sources, and particularly whether the microbes require aerobic conditions to actively degrade the organic molecule. While acetone and isopropyl alcohol generally biodegrade fairly quickly to concentrations that are below detection (e.g., within 1 yr), EZ-MUD and EZ-MUD PLUS undergo slow natural degradation on the order of 2 to 3 yr (Simpson 2001, 094859). Under anaerobic (reducing) conditions, the biodegradation rate for surfactants is likely to be significantly slower (Scott and Jones 2000, 094913). Hence, if residual surfactants remain in a screen interval, biodegradation of residual surfactants may not progress significantly until oxidizing conditions are restored.

To envision a typical sequence for biodegradation, schematic sketches of the major QUIK-FOAM and EZ-MUD organic components are presented in Figures 4-10 and 4-11. The precise structure of the QUIK-FOAM surfactant is not known, but it is undoubtedly similar to that shown in Figure 4-10 for another anionic surfactant, sodium laureth sulfate, a common ingredient in hair shampoo (Robison 2006, 094883). An important characteristic of this molecule that has major consequences for its effects on water chemistry is the fact that it has an uncharged hydrophobic end, a hydrophilic negatively-charged end, and a positively-charged cation (NH_4^+ in Figure 4-10) to balance the molecule's negative charge. The first and immediate effect on water quality is leaching of the counterion (NH_4^+). The second step is detachment of the long hydrophobic hydrocarbon chain from the other half of the molecule (step a1 in Figure 4-10). This initial carbon-bonding breaking requires microbial activity and occurs rapidly (on the order of several days) under aerobic conditions (Pojana et al. 2004, 094487; Ying 2006, 094486). Biodegradation of the residual hydrophilic group proceeds more slowly. Eventually, microbes break up the long molecule into ever-smaller segments. Its ultimate breakdown products are inorganic carbon and sulfate. However, this process probably takes several years to go to completion if reducing conditions are present.

The different parts of the surfactant molecule can be expected to biodegrade at very different rates, and possibly not simultaneously. Although microbes often live in symbiotic colonies, each targeting a different species for its food source, they can also be antagonistic toward one another, incapable of coexistence.

Microbial activity is also generally sensitive to other geochemical conditions. For example, one of the microbial species that converts the sulfonate group to sulfate requires dissolved oxygen to be present, and so is inactive under reducing conditions.

Figure 4-11 depicts an isolated segment of the repetitive structure of the polyacrylamide that constitutes the main ingredient in EZ-MUD and EZ-MUD PLUS. This extremely long polymer has a molecular weight on the order of 4,000,000–6,000,000 for EZ-MUD and 15,000,000 for EZ-MUD PLUS (Simpson 2001, 094859). Such a large size makes it unlikely that this molecule will penetrate very far into a formation during drilling, except in lost circulation zones or in formations with high porosity or that are fractured. Its ultimate biodegradation products are ammonia, inorganic carbon, and water but, like the QUIK-FOAM surfactant, its degradation rate is not expected necessarily to proceed rapidly in groundwater.

Figure 4-12 shows some of the potential interactions between anionic surfactants, such as those in QUIK-FOAM, and constituents in groundwater. The most significant of these interactions, relative to their potential effects on the transport characteristics of analytes of concern, are discussed below.

- Positively charged metal and radionuclide cations may bind to the negatively charged end of the surfactant, thereby potentially changing the mobility of these cations.
- Hydrophobic organic species, such as aromatic hydrocarbons and pesticides, may associate with the hydrophobic end of the surfactant molecule, also modifying their mobility.
- Although AES surfactants are not expected to adsorb onto organic-free clays, soils or sediments, they may adsorb onto geologic materials (or onto lost-circulation materials) that contain organic carbon(Cano and Dorn 1996, 094899) (Cano and Dorn 1996, 094860) (Salloum et al. 2000, 094896) (Ying 2006, 094486). Partition coefficients reported for adsorption of 1 mg/L of nonionic alcohol ethoxylates (AE) onto natural geologic media containing 0.3 to 2.2% organic carbon ranged up to 2100 mL/g, attaining equilibrium within a few hours (Cano and Dorn 1996, 094899).
- Surfactant molecules may adsorb onto stable metal oxides and modify the mineral’s surface characteristics (Cserháti et al. 2002, 094904). For example, the surfactant may create an organic film that can adsorb other organic species, or provide a platform for a microbial population.
- The surfactant molecule may adsorb onto organic surfaces, including microbes, rendering the molecule immobile such that its presence is not directly detectable in a groundwater sample. It presence may either enhance or suppress microbial activity.
- At concentrations on the order of tens to hundreds of mg/L, anionic surfactants may form a spherical aggregate similar to micelles, also called surfactant colloids or solloids (Cserháti et al. 2002, 094904) (Salloum et al. 2000, 094896) (Ying 2006, 094486). The concentration at which this occurs is known as the “critical micelle concentration” (CMC) and is characteristic of that specific surfactant. In water, the hydrophobic part of the molecules turns inward, towards the center of the solloid. Other hydrophobic organic compounds may then partition into the center of the solloid, thereby enhancing the solubility of sparingly soluble organic compounds in water, as well as affecting biodegradation rates of these hydrophobic compounds (Valsaraj and Thibodeaux 1989, 094895).
- The solloid may clog pore openings, reducing hydraulic conductivity and creating micro-environments with redox and geochemical characteristics significantly different from that of the bulk groundwater.
- Some anionic surfactants precipitate as calcium salts (Rouse et al. 1996, 095728).

- Until they finally break down altogether, organic molecules may serve as low but constant in situ sources of organic nitrogen (TKN), ammonia, and organic and inorganic carbon to the groundwater.

Also shown in Figure 4-9 are the effects of residual organic drilling fluids on the redox state of the groundwater and on the characteristics of surface-active minerals in the vicinity of the well. This aspect is covered separately in section 4.6.

4.5.2 Selection of Indicator Species and Test Threshold Values

EZ-MUD PLUS consists of a high molecular-weight copolymer made up of a carbon framework containing nitrogen functional groups (Longmire 2002, 072800), suspended in a solution of long-chain hydrocarbons (Larson 2006, 094892) (Robison 2006, 094891) (Table 4-9). It serves as a flocculating aid for precipitation of suspended solids from the drilling solution. QUIK-FOAM consists of AES, surfactants that serve as a high-expansion foaming agent. As received from the manufacturer, the surfactants are dissolved or suspended in an aqueous solution containing isopropyl alcohol, acetone, and ethanol (Larson 2006, 094892) (Robison 2006, 094891) (Table 4-9). Acetone is also an oxidation product of isopropyl alcohol and is routinely analyzed as part of VOC analysis using gas chromatography-mass spectrometry (GC-MS). Characterization data in Tables 4-9 and 4-10 confirm that the best organic indicators for residual organic drilling components are dissolved organic carbon (DOC), TOC, total Kjeldahl nitrogen (TKN), and ammonia. These same indicators are also suitable for the organic components associated with the use of inorganic products such as bentonite drilling muds (Table 4-10). Acetone is a good indicator to monitor the effectiveness of well development, and to assess the prevailing biodegradation conditions based on the acetone’s rate of disappearance.

The effectiveness of the first three indicators is demonstrated in Figure 4-13, again using the example of R-16. Like Figure 4-7, these plots also start with the first characterization sample in March 2004 and track each indicator’s concentration up through mid-October 2006, the most recent sampling event for which analyses of these indicators are available. As a result of its short biodegradation half-life and the ease with which it is removed from a formation during well development, acetone is below detection in all 3 screens even at the time of the first characterization sample, which occurred more than a year after development was completed in December 2002. Other than slightly elevated TOC concentrations, water samples from Screen 2 (blue points) pass nearly all of the tests for all of the events and also show significant improvement following the pilot rehabilitation activities. At the other extreme, water samples from Screen 4 (red points) fail all tests except acetone, and remain slightly elevated in TOC and ammonia concentrations even after the rehabilitation activities. The most dramatic shift is observed in water samples from Screen 3 (black points), which initially show the highest concentrations of TKN and ammonia, but these concentrations approach background levels within 15 months in this screen. TOC, TKN and ammonia remain steadily elevated in screen 4 (red points) for over two years until finally being brought under control by corrective measures taken under the pilot rehabilitation effort in July and August 2006.

4.5.3 Application of Criteria to Water-Quality Samples

Screening questions, assessment criteria, and consequence of response for this category are presented in Table 4-11. Water-quality data from all of the screens included in this report were compared against the criteria listed in Table 4-11. The details of this comparison are tabulated in Tables C-4 and E-1. Measured concentrations for the 80 screens are plotted in Appendix D. Figure 4-14 summarizes the results of this analysis. Key findings for the most recent sample event for which data are available for each indicator include the following:

- The four selected indicators (TOC, TKN, ammonia, and acetone) for residual organic drilling fluids are below the test thresholds for 52% (42) of the 80 well screens, indicating the likely absence of significant residual organic drilling constituents from these screens.
- Among the 22 single-screen wells, 15 (68%) passed all tests for residual organic constituents of drilling fluids. Among the 58 screens in multiple-screen wells, the proportion passing all residual organic tests was 47% (27 screens).
- Of the 38 screens that failed at least 1 indicator, 28 (74% of 38) only fail 1 indicator, 8 (21% of 38) fail 2 indicators, and 8 (21% of 38) fail 3 indicators.
- From the bottom histogram of Figure 4-14, the most frequent indicators failed are TOC (24 screens) and ammonia (22 screens), which comprise 63% and 58%, respectively, of the 38 screens that failed one or more tests.
- Of the 38 screens that failed at least one test, 8 screens (21% of 38) failed TKN.

The test with the fewest number of failed samples is acetone (3 screens, 8% of 38), reflecting the effectiveness of its removal during well development and the quick biodegradation of any residual concentrations in the screen interval.

If the evalution presented in this section concludes that residual organic components of drilling products are present in the water sample from a screen interval, then the protocol outlined in section 4.10 for Category B is followed to identify those analytes that are likely to be impacted.

4.6 Category C—Modification of In situ Redox Conditions

The residual organic drilling fluids provide a rich source of food for small but ubiquitous native microbial populations in the aquifer. The activities of these sub-micron organisms have dramatic and long-term effects on the water chemistry and mineralogy in the vicinity of the well. As depicted in Figure 4-9, their feasting results in the sequential reduction of dissolved oxygen, nitrate, manganese(IV), chromium(VI), iron(III), uranium(VI), and sulfate and creates anaerobic conditions around the well, resulting in significant shifts in the types and reactivities of mineral phases with which the water is in contact.

4.6.1 Conceptual Model

Table 4-12 provides information on selected theoretical redox couples that are relevant to the screen assessment, either as indicator species (e.g., dissolved oxygen, nitrate, manganese, iron, sulfate, and bicarbonate) of in situ conditions, or as COPCs that are redox-sensitive such as perchlorate, chromate, uranium, and plutonium. Table 4-13 classifies inorganic and organic solutes according to the type of reducing condition that would affect their concentrations, either directly in response to the electrochemical potential of the water, or indirectly through interactions with newly-formed reactive mineral surfaces. Strongly reducing conditions, such as those observed during sulfate reduction to hydrogen sulfide, affect a greater number of inorganic and organic analyte suites, whereas aerobic conditions (dissolved oxygen present) representative of natural and site conditions have the least impact on analyte suites.

The following discussion focuses on redox processes that both occur naturally and in the presence of residual organic drilling constituents. Redox reactions provide essential information on evaluating geochemical and biochemical impacts from residual drilling fluids on groundwater chemistry and aquifer mineralogy. Determining and monitoring redox chemistry provides important insights as to the extent that groundwater is approaching its predrilling conditions.

Plausible oxidation-reduction reactions occurring under natural conditions and during the breakdown or oxidation of residual organic species are shown in Figure 4-15, and redox criteria for assessing screens are shown in Figure 4-16. Overall oxidizing conditions are characterized by positive Eh values and overall reducing conditions are characterized by negative Eh values. Dissolved oxygen, nitrate, manganese, iron, and sulfate are naturally occurring solutes that undergo reduction in the presence of in situ aerobic and anaerobic microbes and different forms of dissolved and suspended organic carbon. The solubilities of naturally occurring minerals present in aquifer material, including manganese dioxide and ferric (oxy)hydroxide, generally increase under reducing conditions in the presence of organic carbon (Figure 4-9). As in situ microbes consume residual organic drilling constituents such as hydrocarbons, alcohols, surfactants, or polymers that serve as a food source, the following sequence of highly generalized geochemical events is initiated:

- Initially, DO is reduced to water.
- Nitrate is reduced to nitrogen gas (denitrification), and dissolved nitrate concentrations drop below detection.
- Manganese dioxide (mineral) is reduced to dissolved manganese(II), which increases in concentration.
- Chromate is reduced to chromium(III) and may precipitate as chromium hydroxide [$Cr(OH)_3$]
- Ferric (oxy)hydroxide is reduced to dissolved iron(II), which increases in concentration.
- Sulfate is reduced to dissolved sulfide, which may lead to precipitation of metal sulfides.

  Note: Once a screen interval reaches this stage, its rate of recovery is usually substantially slowed. In the absence of rehabilitation efforts, the screen's recovery to oxidizing conditions is likely to take several years. This aspect of the conceptual model is represented in Figure 4-9 by the second lower loop along the path of redox evolution in a screen interval in which residual organic drilling products are present.
- Finally, methanogenic conditions may develop if sulfate supplies are depleted and dissolved carbon dioxide becomes the dominant terminal electron-acceptor, being reduced to methane as bacteria continue metabolizing the residual organic carbon. Although sulfate-reducing conditions have developed in several screen intervals, there is as yet no evidence for the subsequent development of methanogenic conditions at these locations. Nonetheless, this end stage is mentioned to ensure a comprehensive identification of all potential drilling-induced conditions that could impact the reliability and representativeness of water-quality samples.

This conceptual model is illustrated by the geochemical trends plotted in Figure 4-17 for wells R-18 and R-20 Screens 1 and 3. Well R-18 illustrates conditions typical for a well providing reliable and representative water-quality samples free of any residual effects from drilling and construction or of a contaminant plume. Samples from this well show iron, nitrate, and sulfate concentrations that are consistent with oxidizing conditions in the regional aquifer; R-18 passes all of the tests in Category B for residual organics for which data are available (Tables C-3), indicating that no residual organic fluids remain in the formation to initiate reducing conditions. In contrast, Well R-20 Screens 1 and 3 both demonstrate variable degrees of reducing conditions during their first 4 sampling events, evidenced by low nitrate (Figure 4-16c), elevated iron (Figure 4-17), and, in the case of Screen 3, negligibly low sulfate (Figure 4-17). Reduction of iron(III), nitrate, and sulfate has taken place because of the presence of residual organic drilling fluids in these intervals of well R-20. Prior to the start of pilot rehabilitation activities at this well in June 2006, ammonia and TOC concentrations still exceeded the upper threshold limits in all 3 of the screens in R-20, despite the fact that 3-1/2 years had passed since the completion of well development (in December 2002).

Molybdenum concentrations are expected to wax and wane as groundwater passes through increasingly negative redox stages. Under oxidizing conditions (DO present), molybdenum (VI) forms stable and soluble molybdate (MoO_4^{2-}) anions (Table A-2). In the regional aquifer, molybdate is present only at low concentrations, often below the detection limit (median 1 µg/L, maximum 4 µg/L, 49% nondetects, Table 4-3a). In addition to being a constituent leached from bentonite products (section 4.10.2), molybdenum concentrations may rise sharply when iron (III) is reduced to iron (II) (about 14 mV, Table 4-12), thereby releasing into solution those metal ions (including molybdenum) adsorbed onto ferric (oxy)hydroxides. Molybdate (MoO_4^{2-}) is reduced to molybdenum (IV) at about -203 mV (Table 4-12). Finally, when sulfate is reduced to sulfide (about -217 mV), concentrations of molybdenum once again drop to negligibly low values when it precipitates as molybdenum sulfide (MoS_2). This conceptual model for geochemical interrelationships among molybdenum, iron, and sulfate as reducing conditions evolve is supported by geochemical trends in dissolved metals, sulfate, and sulfide for water-quality samples from screen 3 in R-20 as well as from other screens. Such trends may provide a means for identifying those screens in which iron-and sulfate-reducing conditions have resulted in significant transformation of reactive-phase iron minerals adjacent to an impacted well screen (EPA 2006, 094894).

Although methanogenic conditions cannot be ruled out, sulfate reduction represents the strongest reducing conditions readily observable in wells impacted by organic drilling fluid. Under this condition, nearly all of the analyte suites (general chemistry, metals, radionuclides, HE compounds, and other organic suites) are significantly impacted (Table 4-13). The list of affected analytes is slightly shortened under the less severe condition of iron and manganese reduction (Table 4-13). Nitrate and dissolved oxygen reduction have most analyte suites not impacted by residual organic drilling fluid, excluding part of the general inorganic suite and all SVOC and VOC suites. A completely restored well produces water with measurable dissolved oxygen (>2 mg/L), dissolved iron and manganese concentrations near or below the detection limit, and nitrate and sulfate concentrations within the range of background or representative of site conditions. Under these aerobic conditions, none of the various analyte suites are expected to be compromised by any residual organic drilling fluid (Table 4-13).

Organic components of drilling products eventually oxidize to carbon dioxide and water, producing elevated alkalinity. Field measurements of dissolved oxygen and analyses of total carbonate alkalinity, dissolved nitrate, manganese, uranium, iron, and sulfate support the sequence of these redox reactions. These various indicators provide direct and quantitative evidence for the breakdown of organic-based drilling fluid and the well's progress toward restoring its predrilling geochemical conditions. Total carbonate alkalinity is denoted as alkalinity in this report.

Analytical results for organic contaminants, such as chlorinated solvents, aromatic hydrocarbons, HE compounds, aliphatic hydrocarbons, and PAHs, that may undergo biological transformations induced by residual drilling fluid may not provide representative results (Table 4-13). Native microbes use residual organic carbon from drilling fluids as a substrate or food source, in the form of an electron donor, and anthropogenic organic compounds listed above can serve as terminal electron acceptors. The electron acceptors become reduced as the residual organic drilling fluid oxidizes to carbonate alkalinity. These include chlorinated aliphatic hydrocarbons and HE compounds.

In situ microbes also consume organic contaminants directly, in which the organic compounds eventually oxidize to total carbonate alkalinity and water. These include PAHs, benzene, toluene, xylene isomers, and ethylbenzene. Organic contaminants affected by biodegradation induced by residual organic drilling fluid would decrease in concentration over time. Predrilling conditions occur when mobile organic contaminants and carbonate alkalinity show consistent trends in groundwater.

4.6.2 Selection of Indicator Species and Test Threshold Values

Redox indicators for water samples are selected based on theoretical calculations as well as practical concerns (see Table 4-12). As shown in Figure 4-16, selected indicators include ten that participate in or respond directly to redox reactions (dissolved oxygen, nitrate, manganese, iron, uranium, perchlorate, chromium, sulfate, sulfide, and ORP), as well as two indicators (nickel and molybdenum) which may reflect redox conditions through their take-up and release from Fe- or Mn-bearing minerals dissolved or transformed by shifting redox conditions (Davranche and Bollinger 2000, 094906) (Davranche and Bollinger 2000, 094908). These species were added in order to be able to detect iron-reducing or sulfate-reducing conditions in situations where the reduction of these species leads to a change in mineralogy—such as formation of iron sulfides or iron carbonates—instead of increasing dissolved iron concentrations (EPA 2006, 094894). The addition of molybdenum in particular was suggested by the statistical association between its concentrations and those of iron and manganese in the multivariate statistical analysis presented in section 5 and interpreted in section 5.4.

Although field measurements of DO and ORP are assumed to be uncertain and potentially biased on the high (oxidizing) side relative to in situ conditions, nonetheless these data provide a backup method for detecting sulfate-reducing or nitrate-reducing conditions in a water sample when such conditions may be obscured by the presence of a contaminant plume.

4.6.3 Application of Criteria to Water-Quality Samples

Screening questions, assessment criteria, and the consequence of response for redox conditions are provided in Table 4-14. Water-quality data from all of the screens included in this report were compared against the criteria listed in Table 4-14. The details of this comparison are tabulated in Tables C-5 and C-6, and summarized in Tables C-7 and E-1. Measured data for samples from the 80 screens are plotted in Appendix D.

Figure 4-18 summarizes the results of this analysis, prior to thorough review of the applicability and validity of test criteria for all of the screens and samples. Key observations for this preliminary view of redox test outcomes for the most recent sample event are provided below:

- No indicators of reducing conditions are observed in the most recent sample from 28 (35%) of the 80 screens, indicating the presence of oxidizing conditions in these screens. Twelve of these are single-screen wells, and sixteen are screens in multiple-screen wells.
- Fifty-two (65%) of the 80 screens failed at least one redox test, including ten single-screen wells.
- Thirteen (16%) of the 80 screens failed at least one of the three tests for sulfate-reducing conditions. Two new single-screen wells failed solely on the basis of field parameters (sulfide in R-3i and ORP in R-24).
- Note: It is possible, but not confirmed, that sulfide may be a degradation product of QuikFoam surfactants, in which case this analyte may not be an appropriate indicator for reducing conditions in R-3i.
- Twenty-eight (35%) of the 80 screens failed the test for iron-reducing conditions, based solely on elevated iron concentrations. One is a single-screen well (R-6i) and the remainder are screens in multiple-screen wells.
- Thirty-one (39%) of the 80 screens failed the test for manganese-reducing conditions, based solely on elevated manganese concentrations. Two of these are single-screen wells (R-6 and R-9).

- Nine screens (11%) failed the test for perchlorate-reducing conditions. One is a single-screen well (R-3i) and the rest are screens in multiple-screen wells.
- Fourteen (17.5%) of the 80 screens failed the test for uranium-reducing conditions. All are screens in multiple-screen wells.
- Twenty (25%) of the 80 screens failed at least one of the two tests for nitrate-reducing conditions. All are screens in multiple-screen wells. One screen (R-20, screen 3) failed solely on the basis of low DO.
- Thirteen (16%) of the 80 screens had elevated concentrations of nickel, and thirteen (16%) had elevated concentrations of molybdenum. The conceptual model proposes that these metals are released into solution when oxidized iron or manganese minerals dissolve or convert to reduced mineral phases including sulfides or carbonates. However, elevated molybdenum concentrations could also result from its presence in a contaminant plume or as an impurity leached from bentonite drilling mud (as discussed in section 4.10).

At first glance, some of these results appear internally inconsistent because the number of screens showing nitrate-reducing conditions should be at least as great as, if not greater than, the proportions showing sulfate-, iron-, or manganese-reducing conditions. This apparent discrepancy is a consequence of several factors, for example,

- nitrate-reducing conditions may be obscured by the presence of a nitrate contaminant plume at several locations;
- the test threshold for nitrate-reducing conditions does not capture those screens in which this condition is in early (developing) or late (recovering) stages; or
- there could be other sources or geochemical reactions involving sulfide, iron, or manganese which the current conceptual model does not adequately take into account.

Figure 4-18b classifies the most recent samples included in this report according to the redox state that is most consistent with the analytical data, using expert judgment to place heavier reliance on those indicators which are considered most reliable, and to discount those indicators which are likely being affected by other factors (as discussed in section 4.11), including the effects of a contaminant plume. This qualitative evaluation results in the following snapshot of redox conditions in the 80 screens as of December 2006:

- Forty-four (55%) of the 80 screens are fully oxidizing. This total includes 20 of the 22 single-screen wells and 24 of the screens in the multiple-screen wells.
- Only 10 (12.5%) of the 80 screens appear to be squarely in the nitrate-reducing and manganese-reducing categories, in the broad Eh zone between fully oxidizing conditions and iron-reducing conditions. Apparently, this redox state is relatively unstable, and geochemical conditions tend to evolve either to more oxic or more reducing conditions. This distribution probably reflects the prominent role of iron-bearing minerals in controlling the water's redox chemistry.
- Sixteen (20%) of the 80 screens are iron-reducing. All are screens in multiple-screen wells.
- Ten (12.5%) of the 80 screens are sulfate-reducing. This total includes one single-screen well (R-24), which shows elevated manganese and molybdenum levels as well as other signs of reducing conditions. As in the case of nitrate-reducing and manganese-reducing conditions, the sulfate-reducing state may also be unstable, and once the available sulfate is depleted, iron-bearing minerals then establish the water's more stable redox chemistry.

If the evalution presented in this section concludes that reducing conditions have developed in the screen interval as a result of drilling product use, then the protocol outlined in section 4.10 for Category C is followed to identify those analytes that are likely to be impacted.

4.7 Category D—Modification of Surface-Active Mineral Surfaces

Surface-active minerals have charged surfaces that attract and retain oppositely-charged metal counter-ions. In the saturated zones beneath the Parajito Plateau, the most common surface-active minerals are native calcium carbonate, clays, and iron (oxy)hydroxides. Analytes adsorb onto a specific mineral surface by ion exchange or formation of a surface complex. In the case of many organic species, retention by a mineral surface may simply be a consequence of the organic compound's hydrophobic characteristic. Under some conditions, adsorption is reversible; in other cases, it is essentially permanent.

Drilling fluids can alter the type, quantity, and distribution of surface-active minerals directly as through the injection of bentonite clays during drilling, or indirectly by initiating the alteration, dissolution, or precipitation of mineral phases. The category of effects addressed by this section is limited to alumino-silicate minerals, and focuses primarily on bentonite drilling clay. Residual drilling effects on iron/manganese-bearing mineral phases are incorporated into Category C as redox effects (section 4.6), and changes in carbonate mineral stabilities induced by residual drilling fluids are addressed in section 4.8 (Category E).

4.7.1 Conceptual Model

In addition to providing a source of inorganic species to the groundwater, as discussed in section 4.4, bentonite drilling mud also affects groundwater quality by removing solutes from solution through adsorption (Figure 4-6). Bentonite is negatively charged at pH >2. Anions adsorb poorly onto bentonite at neutral pHs. Cationic metals that may adsorb onto sodium bentonite include beryllium, cadmium, cobalt, iron, manganese, nickel, silver, strontium, thallium, and zinc. Many other trace metals are not expected to adsorb because they are generally present as neutral species or as anions (Longmire and Fabryka-Martin 2007, 095818). Many organic constituents also adsorb strongly onto bentonite or partition onto the small but significant fraction of organic carbon compounds that commonly coat parts of the clay surface. Table 4-15 summarizes information on the adsorptive behavior of inorganic and organic adsorbates onto sodium bentonite drilling mud. An adsorbate having a K_d less than 1 mL/g is considered as not adsorbing onto bentonite and as not impacted by its presence in the screen interval. At the other extreme, an adsorbate having a K_d greater than 1000 is considered to be very strongly adsorbed.

4.7.2 Selection of Indicator Species and Test Threshold Values

The high adsorption capacity of bentonite for cations is addressed in Table 4-16, which considers uranium, strontium, and barium as key analytes for evaluating the adsorption capacity of bentonite for some of the inorganic (cationic) chemicals that are present in local groundwaters. Concentrations of analytes that are less than their respective minimum background levels for predrilling conditions may suggest that adsorption processes have taken place with residual bentonite.

Zinc was selected as a conceptually conservative indicator for evaluating the adsorption of cesium-137 onto residual bentonite, based on a literature-derived mean K_d of 2400 mL/g for zinc and 1900 mL/g for cesium (Table A-11) (Sheppard and Thibault 1990, 090541). Zinc is stable predominantly as Zn^{2+}, which adsorbs to a greater extent than monovalent cations, including Cs^+. These adsorption data were compiled for clay-rich soil. Zinc is typically analyzed using inductively coupled plasma (argon)-mass spectrometry (ICP-MS), and this analyte is detected in groundwater samples. If dissolved zinc is detected in groundwater and it adsorbs more strongly than cesium, based on literature-derived K_d values, then it is reasonable to assume that a nondetect of cesium-137 is reliable and not attributable to removal from solution because of adsorption onto residual bentonite.

A potential limitation in the suitabilities of barium and zinc as indicators of adsorption for other dissolved species results from the tendency of these two metals to form anionic and neutral carbonate complexes at elevated pH and alkalinities, in which case they would not necessarily be expected to adsorb as strongly (if at all) onto bentonite.

The compilation of K_d values by Sheppard and Thibault (1990, 090541, Table 3) suggests that cobalt may sorb more strongly onto loam and agricultural soils than does zinc. However, the geochemical conditions under which this occurs are not representative of groundwater beneath the Pajarito Plateau. The more appropriate reference for local conditions is Bradbury and Baeyens (2005, 094905), which shows that zinc sorbs more strongly than cobalt onto montmorillonite in a neutral pH, low-TDS solution. However, the relative affinity of zinc for montmorillonite may be very sensitive to alkalinity because of the tendency for zinc to form a neutral carbonate complex ($ZnCO_3$) at even slightly elevated alkalinities (Longmire and Fabryka-Martin 2007, 095818).

Radionuclides, including americium-241, cerium-139/141/144, plutonium-238/239/240, and radium-226/228 may also strongly adsorb onto bentonite (Table A-12). However, these radionuclides—as well as their candidate natural indicators [e.g., lanthanides (Coppin et al. 2002, 094907) (Bradbury and Baeyens 2005, 094905)]—also adsorb very strongly onto clay minerals and iron (oxy)hydroxides that occur naturally along active flow paths in most host rocks that underlie the Pajarito Plateau. Consequently, it cannot be distinguished whether the absence of a strongly sorbing species from a water sample is attributable to its true absence, to adsorption onto residual bentonite drilling mud, or to adsorption onto native minerals in the formation.

The propensity for HE compounds and degradation products to adsorb or partition onto residual bentonite is based on their estimated K_d values. Compounds with K_d values greater than 1 mL/g are considered to adsorb onto residual bentonite, assuming that the organic carbon content associated with bentonite is 0.1% or higher. Table 4-15 shows that HE compounds with K_d values >1 mL/g are high-melting explosive (HMX), pentaerythriotol tetranitrate (PETN), tetryl, and trinitrotoluene (TNT). Solid organic carbon is considered to be the dominant adsorbent for these hydrophobic compounds. Appendix A, Table A-4 tabulates K_{OC} and K_d values for HE compounds and related degradation products.

The same approach is used to estimate the adsorption or partitioning tendencies of organic analytes: herbicides, pesticides, PCBs, dioxins, furans, VOCs, SVOCs, long-chain aliphatic hydrocarbons, aromatic compounds, and polynuclear aromatic compounds. Appendix A, Table A-5, provides information on K_{OC} and K_d values for dioxins, furans, pesticides, and PCBs and shows that all of these have K_d values >1 mL/g and are considered to be possibly impacted by residual bentonite through adsorption processes.

Most herbicides are not considered to adsorb or partition onto solid organic carbon or bentonite, based on literature-derived K_d values (<1 mL/g) provided in Appendix A, Table A-6. These constituents generally are not impacted by residual bentonite through adsorption processes. Glyphosate, paraquat, picloram, T[2,4,5-], and TP[2,4,5-], however, have calculated K_d values >1 mL/g, and adsorption onto solid organic carbon and bentonite is a conservative assumption.

Constituents of diesel fuel, including long-chain aliphatics and polynuclear aromatic hydrocarbons (PAHs), are considered to adsorb or partition onto both solid organic carbon and bentonite, based on literature-derived K_d values provided in Appendix A, Table A-7. These constituents are potentially impacted by residual bentonite through adsorption processes. The hydrocarbon solution in which

EZ-MUD copolymers are suspended falls into this category, as may some of the intermediate breakdown products of QUIK-FOAM surfactants.

Adsorption parameters (K_{OC} and K_d) for VOCs and SVOCs are provided in Appendix A, Table A-8. Most of these organic compounds are characterized by K_d values <1 mL/g, and adsorption onto residual bentonite is not significant. Acetone, isopropyl alcohol, and ethanol are in this category; these three are the VOC constituents of the aqueous solution containing QUIK-FOAM surfactants. Several compounds, including meta-dichlorobenzene[1,3-], para-dichlorobenzene[1,4-], trichlorobenzene[1,2,3 and 1,2,4-], benzidine, bis(2-ethylhexyl)phthalate, butylbenzylphthalate, carbazole, chloronaphalene[2-], and other organic compounds, however, have K_d values >1 mL/g. These compounds are predicted to adsorb onto solid organic carbon and bentonite.

4.7.3 Application of Criteria to Water-Quality Samples

Water-quality data from sampling events in the 12 screens drilled primarily using bentonite mud were compared against the four Category D criteria listed in Table 4-16. Data for these four indicators are plotted for all 80 screens in Appendix D. Details of this comparison are tabulated in Tables C-5 (for barium) and C-6 (for strontium, uranium, and zinc), and are summarized in Table C-7.

In the previous version of this report, tests for adsorption were only applied to water samples from screen intervals in which bentonite drilling mud was known to have been used. Table B-2 documents that bentonite mud was used to drill 3 single-screen wells (R-2, R-4, and R-6), and 10 screen intervals in 4 multiple-screen wells (R-14 screens 1 and 2, R-16 screens 1 to 3, R-20 screens 1 to 3, and R-32 screens 1 and 3). Bentonite-rich annular fill was also inadvertently emplaced in close proximity to the screen in R-13 and to screen 5 in CdV-R-15-3. These 15 screens would have the greatest likelihood of showing any geochemical effects of adsorption onto residual bentonite clays, if present. Key observations for the most recent sample events from these 15 screens include the following:

- One hundred percent of the 15 screens listed above (4 single-screen wells, 11 screens in multiple-screen wells) provide reliable detections of strontium. Therefore, strontium-90, if present, should also be reliably detected.
- One hundred percent of the 15 well screens provide reliable detections of barium and hence data for those metals for which barium can be considered a suitable indicator should also be reliably detected, if present.
- One hundred percent of the 15 well screens provide reliable detections of zinc and hence data for those metals and radionuclides for which zinc can be considered a suitable indicator should also be reliably detected, if present.
- Seventy-three percent (11) of the 15 well screens (4 single-screen wells, 7 screens in multiple-screen wells) provide reliable detections of uranium. Uranium is below detection in water samples from the remaining 4 screens (all in multiple-screen wells), but this condition is attributed to the very reducing environments that have developed at these screens.

Because of the absence of suitable indicators, it was not possible to evaluate the well-screen intervals drilled using bentonite for the reliability of data for organic species or for strongly adsorbing radionuclides.

If adsorption onto residual bentonite mud were a significant mechanism for the above detection rate for uranium, then one might expect a higher detection frequency for uranium in water samples from screens in which the drilling mud was not used. This hypothesis was tested by applying the same four test criteria to the 65 screens that were not drilled with bentonite mud. Key observations for the most recent sample event include the following:

- Ninety-two percent of the screens (18 single-screen, 42 of the 47 screens in multiple-screen wells) provide reliable detection of strontium and therefore, strontium-90, if present, should be detected. The detection rate was 100% for the screens drilled using bentonite mud.
- All but one of the 65 well screens provide reliable detections of barium and hence also of those metals for which barium can be considered a suitable indicator. The detection rate was 100% for the screens drilled with bentonite.
- One hundred percent of the well screens provide reliable detections of those metals for which zinc can be considered a suitable indicator. The detection rate was also 100% for the screens drilled with bentonite.
- Eighty percent of the wells (18 single-screen, 34 of the 47 screens in multiple-screen wells) provide reliable detections of uranium. For 12 of the 13 screens that did not provide detections of uranium, this condition is attributed to the reducing environments that have developed at these screens. The detection rate was 73% for the screens in which residual bentonite may have been present.

This comparison of test outcomes for adsorption indicators demonstrates residual bentonite most likely has a negligible effect on concentrations of these particular adsorbing species in regional groundwater. Other geochemical processes, not adsorption onto bentonite, are the dominant controls for dissolved concentrations of these species: specifically, reducing conditions and carbonate alkalinity. The first aspect was discussed in section 4.6, and the second is discussed in the following section.

If the evalution presented in this section concludes that adsorption onto residual drilling clays is occurring in a screen interval, then the protocol outlined in section 4.10 for Category D is followed to identify those analytes that are likely to be impacted. On the other hand, if a sample passes all test criteria in all applicable categories such that no strong evidence is found for residual drilling-fluid effects, then no further evaluation is needed for the reliability and representativeness of water-quality data from that screen for that sample.

4.8 Category E—Changes in Carbonate Mineral Stability

4.8.1 Conceptual Model

Barium, alkalinity, and strontium span a large range of concentrations in the screens included in this report, extending to very highly elevated levels (Appendix D). A comprehensive conceptual model that accounts for the major sources for these species and the geochemical processes that control their distribution in an impacted screen interval has not yet been fully developed. Nonetheless it is important to develop a better understanding of these controls because of the dominating role of carbonate species in controlling aquifer mineralogy, groundwater geochemistry, and transport characteristics of COPCs.

The multivariate statistical analysis presented in section 5 and interpreted in section 5.4 reveals a strong statistical association among barium, strontium, and alkalinity, together with boron, calcium, chloride, and magnesium. Relative contributions from several potential sources need to be considered:

- To what extent could association of the cations be explained as a consequence of being leached or dissolved from drilling products (e.g., see leach results for these species in Table A-10)?

- To what extent could association of these species be explained as a consequence of being desorbed or dissolved from the geological formation as a result of a drilling fluid?
- Could the elevated concentrations be an artifact of changes to carbonate mineral solubilities caused by the use of surfactants or other drilling products in an interval?
- To what extent could carbon dioxide generated by biodegradation of residual organic drilling fluids contribute to elevated alkalinities in the screen intervals?

4.8.2 Selection of Indicator Species and Test Threshold Values

Indicator species for changes in carbonate mineral stability (barium, calcium, magnesium, strontium, alkalinity, and pH) were selected based upon their statistical association, which is also apparent in plots showing their relative distributions in the 80 screens covered by this report (Appendix D). Uranium was added to this category of indicators because of the importance of alkalinity and pH in controlling its speciation and, hence, its transport characteristics. Test criteria for barium, magnesium, strontium, and alkalinity are whether the concentrations measured in a water sample are below the upper limits for these species in background groundwater. The criteria for calcium and pH are whether measured concentrations in a water sample fall within the range established for regional background groundwater (Table 4-17).

4.8.3 Application of Criteria to Water-Quality Samples

A comparison against the limits of background concentrations for these indicators is tabulated in Tables C-3 through C-5. Measured data for samples from the 80 screens are plotted in Appendix D figures. The following trends are notable:

- Low pH is seldom observed. Only 25 (6%) occurrences are noted among the 389 sample events (tallied at the bottom of Table C-3 and plotted on Figure D-20). Only in two screens does a low pH appear possibly to be a persistent condition.
- pH above background levels from local groundwater occurs in 38 (10%) of the full sample set.
- Over 30% of the alkalinity data exceed the upper limit for local groundwater (tallied at the bottom of Table C-3 and plotted in Figure D-2). It is unclear the extent to which these excursions are attributable to residual drilling effects, including biodegradation processes, non-representative bounds on natural variability in groundwater alkalinity, or alkalinity data that are not representative of in situ conditions.

Among the four divalent cations (barium, calcium, magnesium, and strontium), based on results tallied at the bottom of Tables C-5 and C-6:

- Calcium shows the largest total proportion of excursions outside the background range (139 out of 379 samples, 37%), most of which are above background limits (103 out of 379, 27%) rather than below them (38 out of 379, 10%).
- Strontium mimics calcium distributions, with its 35% rate of excursions (134 out of 383 samples) dominated by concentrations above (96 out of 383, 25%) the upper limits of its range in local groundwater rather than below (38 out of 383, 10%) its lower limits.
- Barium shows the most frequent excursions above background limits (114 out of 383, 30%). Low barium is rarely observed, with only one occurrence noted among the 383 samples (<0.3%).

- Magnesium shows the smallest (63 out of 381, 17%) proportion of excursions above its range in native groundwaters.

If the evalution presented in this section concludes that the carbonate mineral system in a screen interval is in disequilibrium as a result of drilling fluid use, then the protocol outlined in section 4.10 for Category E is followed to identify those analytes that are likely to be impacted.

4.9 Category F—Corrosion of Stainless-Steel Well Components

4.9.1 Conceptual Model

Below the depth of the surface casing, all R wells are constructed with stainless-steel well casing. The term “stainless steel” refers to iron-based alloys that contain at least 12% chromium. The high chromium content results in the formation of a passive layer on the surface of the steel that resists oxidation. Stainless steel is known for its inertness even under extreme chemical conditions. However, the properties of this metal under physically stressed conditions can be quite different from those when it is not stressed. Corrosion tends to start in the form of pits or microcracks where the metal was subjected to the greatest stress, and grows along intergranular boundaries. The iron in the steel begins to dissolve into solution as the metallic iron species, and is immediately oxidized to ferric hydroxide if dissolved oxygen is present. The iron hydroxide precipitates, removing it from solution (although it may remain suspended in colloidal form), which allows more iron metal to dissolve. This process continues as long as the supply of DO is continually renewed.

As the iron matrix dissolves, other metal components of the stainless steel are also released. The dominant species, in order of decreasing total concentrations, are iron, chromium, and nickel (Herting et al. 2005, 094897) as well as manganese. Under oxidizing conditions, the oxidized forms of chromium and nickel are highly soluble, whereas manganese, like iron, may form an insoluble oxide phase. Other metal components which could be released if present in a particular type of steel include boron, molybdenum, phosphorous, sulfur, vanadium, titanium, niobium, and tungsten.

Beyond the depth of the surface casing, the deeper casing for all of the wells evaluated in this report is composed of Type 304 stainless steel. Its approximate composition is described below (Herting et al. 2006, 094898):

Chromium %	18
Nickel %	9.0
Manganese %	1.1
Silicon %	0.3
Molybdenum %	0.3
Carbon %	0.05
Phosphorus %	0.03
Sulfur %	0.002
Iron %	71

Two general observations made by corrosion researchers is that iron is preferentially released relative to its proportion in the alloy, and that the release rate for each element is higher early in the corrosion process and then decreases with subsequent exposure time to the fluid (Herting et al. 2006, 094898).

4.9.2 Selection of Indicator Species and Test Threshold Values

Indicator species for stainless-steel corrosion are highly elevated total concentrations of iron, chromium, and nickel. To distinguish the effects of stainless-steel corrosion from those of iron-reducing conditions, additional test criteria must also be specified. The test indicators and threshold values are presented in Table 4-18. Stainless steel corrosion is concluded as being present if any of the following combinations of conditions are met:

- Total iron above 0.5 mg/L and a ratio of total to dissolved iron greater than 10,
- Total chromium above the maximum concentration for background groundwater and a ratio of total to dissolved chromium greater than 5, and/or
- Dissolved nickel concentration greater than 0.05 mg/L.

Turbidity greater than 5 NTU is an additional test criterion that is neither required nor sufficient to conclude the presence of corrosion, but which establishes the level of confidence that one should have in the outcome of the other test criteria.

4.9.3 Application of Criteria to Water-Quality Samples

Water-quality data are compared against these 6 test criteria in Appendixes C and D:

- Total iron, and the ratio of total iron to dissolved iron (Table C-6 and Appendix D)
- Total chromium, and the ratio of total chromium to dissolved chromium (Table C-6 and Appendix D)
- Dissolved nickel (Table C-6 and Appendix D)
- Turbidity (Table C-3 and Appendix D)

Test outcomes are tabulated in Table C-7, in the far right-hand column labeled “Category F, Metal Corrosion.” In order for the second set of tests to be applicable, the sample must first show that it meets at least one of the qualifying conditions (i.e., it must fail at least one of these tests) (Figure 4-4). Among the most recent samples from each screen, 18 of the 80 screens meet at least one qualifying condition. Of those 18 screens, five show indications of possible stainless-steel corrosion:

- CdV-16-2(i)r—high iron ratio
- R-19 Screen 7—high total/dissolved iron ratio and high total/dissolved chromium ratio
- R-22 Screen 1—high total/dissolved chromium ratio
- R-25 Screen 1—high total/dissolved iron ratio, high total/dissolved chromium ratio
- R-25 Screen 2—high total/dissolved chromium ratio, high dissolved nickel concentration

The water samples from two of these five screens (R-22 Screen 1 and R-25 Screen 2) also show definite signs of sulfate-reducing conditions, counter to the conceptual model presented in section 4.9.1. These are also the only screens among the set of five with iron ratios that are less than the test threshold. This indicates the need to fine-tune the conceptual model, such as by geochemical modeling of the corrosion environment so as to minimize the potential to misinterpret geochemical conditions.

If the evalution presented in this section concludes that stainless-steel corrosion is affecting the water quality in a screen interval, then the protocol outlined in section 4.10 for Category F is followed to identify those analytes that are likely to be impacted.

4.10 Identification of Analytes Impacted by Residual Drilling Effects

The protocol used to assess whether or not an analyte is likely to be impacted by residual drilling effects parallels that used to evaluate whether or not a particular category of effects is present. This protocol is presented as a flowchart in Figure 4-19 and described below.

4.10.1 Analytes Impacted by Elevated pH or Alkalinity Conditions

This category does not include any test criteria but rather serves as a checkpoint to ensure that underlying assumptions about oxidation state and speciation for inorganic analytes, and for abiotic degradation rates for organic analytes, remain valid at the prevailng pH and alkalinity conditions (Figure 4-19). (Note: The effects of reducing conditions on speciation and degradation rates are addressed separately in Category C.)

For inorganic analytes, Tables A-1 and A-2 list the dominant speciation calculated for median concentrations of analytes in the regional aquifer, which is considered the “base case.” The dominant speciation calculated for median intermediate perched aquifer does not differ significantly from the base case (Longmire and Fabryka-Martin 2007, 095818). Between median and upper threshold limits for background groundwater in the regional aquifer, the dominant oxidation states also remain unaffected. For the general inorganic analytes listed in Table A-1, the dominant species also do not change. However, for the metal analytes in Table A-2, the following shifts in speciation are predicted as pH and alkalinity increase(Longmire and Fabryka-Martin 2007, 095818):

- Beryllium is mostly present as a cation ($BeOH^+$) for the base case, but the neutral species $Be(OH)_2$ becomes increasingly dominant at higher pH values. This shift indicates that beryllium becomes less likely to adsorb onto clays or metal oxides, hydroxides, or other charged mineral surfaces as pH increases above its median value.
- For the base case, cadmium, cobalt, nickel, and zinc are present primarily (>75%) as uncomplexed divalent cations (Cd^{+2}, Co^{+2}, Ni^{+2}, Zn^{+2}). However, as alkalinity increases, the proportion of neutral carbonate complexes for these metals also increases ($CdCO_3$, $CoCO_3$, $NiCO_3$, $ZnCO_3$) to the extent that these carbonate complexes become the dominant species for nickel and zinc at the upper threshold limit for background alkalinity. This shift means that the proportion of these trace metals that adsorb onto charged mineral surfaces will decrease at higher alkalinities. Furthermore, dissolved concentations of these trace metals may even increase if residual drilling effects lead to increased alkalinites and subsequent desorption of these metals.

For some inorganic analytes, the rate of abiotic degradation, such as by hydrolysis, could be sensitive to groundwater pH. This particular aspect is only of significance for those very few cases in which the degradation rate is slow (relative to the species’ residence time in the screen interval) within some part of the range of background pH conditions but considerably greater (relative to the species’ residence time in the screen interval) under lower or higher pH conditions. Such a possibility is not expected to be a significant factor for many (if even any) of the organic analytes listed in Appendix A. Consequently, it has not been addressed in this report but should be considered in site-specific evaluations.

4.10.2 Analytes Impacted by Category A

Effective development of a screen interval normally removes residual mobile constituents of drilling products from the screen interval. However, if the evalution presented in section 4.4 concludes that residual inorganic components of drilling products are present in the screen interval, then an analyte may have the potential to be impacted if (Figure 4-19, evaluation criteria for Category A):

- it is an inorganic constituent of a drilling product used in the well, in a zone in direct hydrologic contact with the screen interval of interest during borehole drilling or well construction; and
- its release from the drilling product could conceivably be significant enough to increase concentrations above predrilling levels such that the water sample cannot provide reliable and representative data for this constituent.

Inorganic constituents of drilling products are tabulated in Table A-10; in the future, this list may be expanded as necessary to include other drilling products. Analytes judged as having the potential to be impacted by the presence of residual inorganic drilling products are marked as such in the right-hand columns of Tables A-1 and A-2. This list of analytes includes the following:

- General inorganics (Table A-1 and Table 4-7)— ammonia, chloride, fluoride, nitrate, phosphorus, sodium, sulfate, sulfide; and
- Trace metals (Tables 4-19 and A-2)—antimony, arsenic, boron, chromium, copper, iron, lead, manganese, mercury, molybdenum, nickel, selenium, strontium, and uranium.

In addition, even if a well has not been drilled using bentonite mud, granular bentonite is used routinely to backfill the annular space between the borehole wall and the well casing so as to isolate the well screens from adjacent formations and from one another. In the absence of information to the contrary, it is reasonable to expect that these trace species could be leached and diffuse into the water near the screen during backfill operations as the bentonite settles in the water column and becomes compacted.

4.10.3 Analytes Impacted by Category B

If the evalution presented in section 4.5 concludes that residual organic components of drilling products are present in the screen interval, then an analyte is considered as possibly being impacted if one of the following conditions is present (Figure 4-19, evaluation criteria for Category B):

(1) An analyte could be impacted if it is either an organic constituent or inorganic degradation product of a drilling product used in the well, and its release from the drilling product could conceivably be significant enough to increase the analyte’s concentration in the local groundwater.

Analytes identified under this criterion are acetone, ammonia, TKN, TOC, alkalinity, sulfate, and sulfide.

(2) An organic analyte could be impacted if the residual surfactant is at or above the surfactant’s CMC, in which case an analyte may be impacted if its organic-carbon partition coefficient (K_{oc}) is > 100.

For the mixture of anionic ethoxylated surfactants in QuikFoam, the effective CMC is estimated to be on the order of 2 mM (Rouse et al. 1996, 095728), Table 1, surfactant 4N), corresponding to about 1200 mg/L (Table A-13) and equivalent to about 600 mg/L TOC. Such a high TOC concentration has not been observed in any post-development water-quality sample and is highly unlikely to be sustained within a properly-developed screen interval. A surfactant’s concentration may also be limited by precipitation with calcium (Rouse et al. 1996, 095728). However, although it is assumed unlikely to be relevant for post-development samples, this aspect has been included to facilitate a comprehensive recognition of all potential mechanisms that may impact water-quality data reliability.

It is assumed that none of the inorganic analytes would be impacted by this category of drilling effects. However, a significant portion of the organic analytes tabulated in Tables A-4 to A-8 have $K_{oc} > 100$. Examples of analytes for which $K_{oc} > 100$ include tetryl, TNT, PCBs, petroleum hydrocarbons (diesel-range organics), PAHs, chlorobenzene, dichlorobenzene, and xylenes.

(3) An organic analyte could be impacted if the concentration of one of the organic indicators is sufficiently high so as to suggest the presence of residual organic carbon immobilized in the formation, in which case an analyte may be impacted if its K_{oc} value is > 300. Such a high K_{oc} value indicates a strong likelihood for it to partition into the immobile organic carbon phase.

A crude approach for estimating the residual fraction of organic carbon (f_{OC}) immobilized in the formation is based on the measured TOC in the water sample and the adsorption coefficient (K_d) of the organic drilling product(s). A value for f_{OC} could be estimated by rearranging the expression for K_d:

$$K_d = S_{rock} / C_w$$

$$S_{rock} = K_d \times C_w$$

in which S_{rock} = mass of organic drilling product sorbed onto rock (mg/kg), and C_w = mass of the organic drilling product in solution (mg/L). As a rough approximation, C_w = 2 x TOC. No K_d values have been found for EZ-Mud or QuikFoam components in the online databases or in the published literature. Presumably, the K_d value is very high for EZ-Mud polymers because of their hydrophobicity, and low for Quik-Foam anionic surfactants because of their negative charge (Ying 2006, 094486, pp 420-421). Assuming K_d = 1000 L/kg and C_w = 10 mg/L as C for the sake of illustrating the approach, then S_{rock} = (1000 kg/L) x (10 mg/L as C) = 10,000 mg/kg as C in the solid phase, i.e., f_{OC} = 0.01, or 1%.

The partitioning of an analyte into the sorbed organic fraction is calculated as the product of f_{OC} and K_{OC}. It is assumed that none of the inorganic analytes would be impacted by this category of drilling effects. However, several organic analytes tabulated in Tables A-4 to A-8 have $K_{oc} > 300$. Examples include tetryl, TNT, PCBs, diesel range organics, PAHs, dichlorobenzene, and trichlorobenzene.

The mechanisms described by items 2 and 3 above are not expected to be a significant factor for many of the water-quality samples evaluated in Appendix C. Consequently, they have not been addressed in this report but should be considered in site-specific evaluations.

4.10.4 Analytes Impacted by Category C

If the evalution presented in section 4.6 concludes that reducing conditions are present in the screen interval, then a COPC is considered as possibly being impacted if one of the following conditions is present (Figure 4-19, evaluation criteria for Category C):

(1) An inorganic analyte may be impacted if its dominant oxidation state and/or speciation under the prevailing reducing condition differs from its dominant oxidation state for oxic conditions (dissolved oxygen present above 1 mg/L). The oxidation state determines the analyte’s aqueous speciation and hence its solubility and transport properties.

The effect of reducing conditions on inorganic analytes was evaluated for median background concentrations in the regional aquifer using the geochemical speciation model PHREEQC (Longmire and Fabryka-Martin 2007, 095818). The results are summarized in Table 4-13 and in section 4.6.1.

(2) An inorganic or organic analyte may be impacted if its rate of abiotic degradation (such as by hydrolysis) is sensitive to the redox potential of the groundwater. This particular aspect is only relevant for those cases in which the degradation rate is slow (relative to the species' residence time in the screen interval) under oxic conditions but considerably greater (again, relative to the species' residence time in the screen interval) under reducing conditions. Such a possibility, although probably significant for some analytes, has not been addressed in this report because the reliability and representativeness of the water-quality data for these same analytes are already identified as suspect under one or more of the other evaluation criteria in Category C. Hence, although the mechanisms responsible may differ, the outcome (in terms of flagging suspect water-quality data) is the same.

(3) An inorganic or organic analyte may be impacted if its rate of microbial degradation is increased under reducing condiitons, relative to the rate under oxic conditons. This particular aspect is only relevant for those cases in which the degradation rate is slow (relative to the species' residence time in the screen interval) under oxic conditions but considerably greater (again, relative to the species' residence time in the screen interval) under reducing conditions.

Under reducing conditions (methanogenic), it is assumed that microbial degradation rates of all organic analytes could be significantly impacted (Table 4-13), such that the biodegradation rate could conceivably be enhanced considerably in the vicinity of an impacted screen relative to significantly slower rates under predrilling conditions. This assumption is probably not valid for all organic analytes because for some analytes, the microbial degradation rate would be slower under reducing conditions than under oxic conditions. However, this case-specific aspect is outside the scope of this report.

(4) An inorganic or organic analyte may be impacted if there is a change in the types and capacities of reactive mineral surfaces in the screen interval.

Inorganic COPCs that adsorb onto bentonite (Table 4-15) are assumed likely to adsorb onto Fe-bearing and Mn-bearing minerals as well. Adsorption onto, or desorption from, Mn-bearing or Fe-bearing minerals is assumed to be insignificant for organic COPCs because the primary mechanism for sorption for these neutral species is partitioning into the solid organic-carbon phase, as opposed to attraction to a charged mineral surface as in the case of inorganic ionic COPCs (section 3, fourth and fifth bullets). Some organic chlorinated species are subject to reductive chlorination. However, this mechanism is not addressed in this report because the reliability and representativeness of the water-quality data for these same analytes are already identified as suspect under the previous evaluation criterion.

4.10.5 Analytes Impacted by Category D

As discussed in section 4.7, the evaluation of the likelihood that analyte adsorption onto clays is enhanced by the presence of residual drilling clays in or near a screen interval presents a difficult challenge because of the lack of reliable indicators. Analytes fall into one of two general categories for this evaluation:

(1) Analytes for which a suitable indicator species is available—strontium as an indicator for strontium-90, uranium as an indicator for itself and uranium isotopes, barium and zinc as indicators for selected strongly-sorbing metals and radionuclides listed in Table 4-16.

(2) Organic analyses and most radionuclides that adsorb very strongly to clays including bentonite, and that are rarely detected in groundwater. We are not aware of any suitable indicator species that are routinely measured and that can be used to evaluate with confidence whether or not nondetects of these strongly adsorbing species are reliable and representative of predrilling conditions. For these cases, the protocol outlined in Figure 4-20 is followed:

- ❖ Does the water-quality sample pass all applicable test criteria in all relevant categories for which suitable data are available?
  - — If the sample passes all applicable test criteria, then the next question in the flowchart is evaluated.
  - — If a sample does not pass all tests in all relevant categories, then the water-quality data are considered unreliable or nonrepresentative for this analyte.
- ❖ Is the analyte a COPC for this location? (In this report, an answer in the affirmative has been assumed.)
  - — If the sample is a COPC, then the next question in the flowchart is evaluated.
  - — If a sample is not a COPC, then no further evaluation is needed for the reliability and representativeness of water-quality data for the strongly-sorbing organic analytes and radionuclides from that screen for that sample.
- ❖ Is the analyte detected in the sample?
  - — If the analyte is detected, the data are considered reliable for this analyte.
  - — If the analyte is not detected, the data are considered unreliable or nonrepresentative for this analyte.

4.10.6 Analytes Impacted by Category E

Residual drilling effects on carbonate mineral stability primarily affect alkaline-earth and other trace species that are generally present as divalent cations or complexed with carbonate species under undisturbed conditions. If the evalution presented in section 4.8 concludes that reducing conditions are present in the screen interval, then it is assumed that an inorganic analyte is potenitally impacted if carbonate complexes constitute more than 25% of its total dissolved concentration under oxic conditions (base case and bounding cases) or under the prevailing redox condition of water from the screen interval (Figure 4-19, evaluation criteria for Category E); or if a carbonate mineral containing that analyte significantly changes its degree of under- or over-saturation under the prevailing conditions near the screen as compared to that base-case conditions.

Under the first evaluation criterion, those affected by carbonate disequilibria as a residual drilling effect under oxic conditions are cadmium, cobalt, copper, lead, nickel, uranium, and zinc.

The second evalution criterion requires site-specific geochemical modeling for reliable identification of affected analytes. This modeling is beyond the scope of this report but should be taken into consideration if relevant for a site-specific assessment. In lieu of site-specific modeling, analytes that could be affected under this criterion, and that are not already identified under the first one, are barium, calcium, manganese, and strontium.

It is assumed that no organic analytes are impacted by this category of residual effects.

4.10.7 Analytes Impacted by Category F

If the evalution presented in section 4.9 concludes that reducing conditions are present in the screen interval, then inorganic analytes that could be affected are those comprising the steel corrosion products (iron, chromium, nickel, manganese), and those that adsorb onto, or desorb from, iron colloids (Figure 4-19, evaluation criteria for Category F). Other than those four metals that are corrosion products, this list is assumed to be the same as that for adsorption onto Fe-bearing minerals under Category C (Table 4-13).

The organic analytes are not expected to be affected by steel corrosion or its products because (1) they are not a component of the steel, (b) corrosion only occurs under oxic conditions (i.e., in the presence of dissolved oxygen) (section 4.9.1), and (3) adsorption onto Fe colloids is assumed to be insignificant for organic analytes.

4.11 Caveats and Limitations on the Applicability of Indicators

The overall approach to identifying the residual effects of drilling materials underwent a substantial redesign in Revision 1 to reflect the shift in focus away from identifying impacts from specific drilling products and toward identifying categories of effects, regardless of which specific product or mix of products was primarily responsible for those effects. The restructured approach establishes a better foundation for incorporating future adjustments to the indicators, their test thresholds, and their implications for affected analytes. Table 4-20 presents the full list of indicator species and test threshold values that have been described in this section.

Multiple interfering conditions created by different constituents in drilling fluids make it challenging to determine a single responsible indicator for a well-screen condition. A change in iron mineralogy, for example, cannot be observed directly but can only be inferred from water-quality data. More than one cause could give rise to the identical symptom, but the different causes may have very different long-term prognoses. This ambiguity makes it difficult to predict when or if conditions might change such that the altered mineralogy in the vicinity of a screen will begin to transition back to predrilling conditions.Table 4-21 presents a matrix that summarizes such cross-linkages of cause and effect for each indicator, and that identifies some critical qualifications and limitations that affect the applicability or reliability of a particular indicator for a particular condition.

None of the outcomes using these indicator species is infallible. The common shortcomings of field measurements such as dissolved oxygen are already well recognized in the user community. However, the limitations of other indicators are not as readily apparent or explained. For instance, detection of tritium is generally assumed to indicate the presence of a component of modern water, such that the absence of measurable tritium would appear to rule out the presence of a groundwater contaminant plume as being unlikely. However, there are screens—such as in wells R-10a and R-23—in which modern contamination is obviously present but in which tritium is below detection.

Three additional categories of residual drilling effects are addressed in Revision 1 and in this revision: transformation of iron mineral phases, changes in carbonate mineral stabilities, and corrosion of stainless-steel components. The described protocol identifies those screens in which these effects appear to be present. However, further progress on interpreting the causes and effects of these geochemical shifts outside the range of background conditions requires better knowledge of the co-evolution of geochemical species, and the ability to incorporate consideration of kinetic rates. For example, zinc may be more mobile than assumed in this evaluation as a result of site-specific chemical conditions such as elevated sulfate, carbonate, and phosphate.

Radionuclides, including americium-241, cerium-139/141/144, plutonium-238/239/240, and radium-226/228 may strongly adsorb onto bentonite (Table A-12). However, these radionuclides—as well as their candidate natural indicators [e.g., lanthanides (Coppin et al. 2002, 094907) (Bradbury and Baeyens 2005, 094905)]—also adsorb very strongly onto clay minerals and iron (oxy)hydroxides that occur naturally along active flow paths in most host rocks that underlie the Pajarito Plateau. Consequently, it cannot be distinguished whether the absence of a strongly sorbing species from a water sample is attributable to its true absence, to adsorption onto residual bentonite drilling mud, or to adsorption onto native minerals in the formation. Because of the absence of a suitable indicator, it was not possible to evaluate the well-screen intervals drilled using bentonite for detections of strongly adsorbing radionuclides (or, for that matter, for strongly adsorbing organic species).

Finally, one of the more significant factors of which the data reviewer needs to remain cognizant is the potential effect of a contaminant plume on the reliability of an indicator's test outcome. Several of the selected indicators are also common constituents of contaminant plumes: chloride, perchlorate, chromium, nitrate, sulfate, and possibly alkalinity. Table 2-1 tabulates some of the indicator tests that may have limited applicability to evaluation of water samples from specific screens because of the known presence of a contaminant plume containing that species or including constituents that could affect it.

5.0 MULTIVARIATE STATISTICAL ANALYSIS TO IDENTIFY IMPACTED SCREENS

An exploratory use of multivariate statistical methods was made in 2005 to determine if the wells showing residual drilling effects could be identified. Differences in chemical signatures were investigated between the characterization wells and springs and long-established water supply and test wells in Los Alamos County, using a suite of 9 major ions and 11 metals/trace elements. Multivariate statistical methods, specifically principal component analysis (PCA) and cluster analysis (CA), were used to reduce large amounts of geochemical data in order to elucidate patterns within the data which otherwise might not have been observed.

5.1 Data Set Used in the Analyses

Selected regional aquifer water-quality data for the years 2000–2005 were retrieved from the WQDB. The retrieval comprised data for samples from 28 regional (R) characterization wells, 16 White Rock Canyon springs, and 15 long-established wells. These wells included 10 municipal supply wells (the Guaje Canyon series and the Pajarito Mesa [PM] series) and 5 regional aquifer test wells (TW-3, TW-8, DT-5a, DT-9, and DT-10). Of the 28 R wells used in the data set of 2005, 11 are single-screened, and 17 are equipped with multiple screens. In total, R-well results from 49 discrete screens were considered. All but four of the R wells had been sampled more than once; many had four complete rounds of chemical characterization data. To capture the full extent of water-quality variability in the wells, data from all the rounds were used in the statistical analysis.

Results from the White Rock Canyon springs, municipal water-supply wells, and test wells help in the identification of wells that contain residual drilling fluids. A list of these reference stations is provided in Table F-11. All the spring data are from filtered samples and represent regional aquifer quality unaffected by drilling. The test wells were installed in the early 1960s without drilling muds using cable-tool casing-advance methods. Only major ion chemistry results from the test wells were used in the statistical analyses because the metals data are suspect as a result of oxidation and partial dissolution of casing materials used (hardened steel). The municipal water supply wells were installed in the 1970s and 1980s with drilling muds. Because of the age of the supply wells and large pumpage volumes, however, there should be minimal or no residual drilling effects apparent in these wells. All data from the test and water-supply wells were from nonfiltered samples with turbidity levels below 2 NTUs. Because of the low turbidity and developed nature of the wells, those data were treated as comparable to filtered data (assuming that submicron colloids are absent) and added to the filtered results from the R wells and springs.

The analytes selected for the statistical analyses were limited to those that were routinely tested for in both the R wells and the reference stations. This eliminated some potentially useful identifiers of well construction impacts, such as TOC or TKN, because they were only occasionally analyzed in samples from the R wells and rarely in waters from the reference stations. The principal component analysis requires a fully populated data matrix and samples with missing results would have been excluded from the statistical analysis. Radionuclides also were not included in the exploratory analysis because they are not routinely detected in regional aquifer samples.

Statistical analyses were initially performed on four independent groups of data, distinguished by analytical suite and field preparation:

- Dissolved metal/trace-element concentrations—172 filtered (F) samples
- Total metal/trace-element concentrations—201 nonfiltered (UF) samples
- Dissolved major ion concentrations—166 F samples
- Total major ion concentrations—79 UF samples

These initial analyses were performed with the objective of determining if wells with residual drilling impacts could be identified, along with the analytes that best reflected such impacts. After it was demonstrated that the statistical approach was viable, other analyses were performed using merged data sets that included metals/trace elements as well as major ions. The objectives of the latter phase of analysis were to examine the interrelationships between the metals and major ions, and to examine trends in uranium concentrations.

Analytes with below instrument-detection-limit (IDL) concentrations in more than half of the samples were removed from statistical analysis. Below-detection-limit concentration values were replaced with values equal to half the IDL. The metals/trace elements included in the analyses were boron, barium, chromium, iron, manganese, molybdenum, strontium, vanadium, and zinc. The major ions included in the analyses were calcium, magnesium, sodium, potassium, chloride, sulfate, fluoride, nitrate, and total carbonate alkalinity. All of these constituents could be affected to varying extents by the presence of residual drilling fluids.

5.2 Statistical Analysis

Principal component analysis is a multivariate statistical technique for data reduction and for deciphering patterns with large sets of data (Stetzenbach et al. 2001, 090565). These data are not required to be normally distributed for the analysis. In using PCA, a large data matrix can be reduced to two smaller matrices, one consisting of principal component (PC) scores and the other containing the loadings. The scores help define the chemical signatures for each sample in the data set. The loading identifies the analytes that cause the greatest variance in the data set.

After the principal component scores were calculated, they served as input into CAs to group the results and identify groundwaters that have similar chemical signatures. PCA scores, weighted by their respective loadings, were input into the CA. Principal components with eigenvectors (scaling factors) usually larger than 1 were input into the CA. At a minimum, at least three components were carried forward into the CA. The K-means cluster (KMC) or hierarchical algorithms were used to identify similar clusters of results. For most analyses, it was empirically determined that six or seven clusters adequately represented the spread of data. The statistical software package “Statistica for Windows 7.1” (StatSoft, Inc.) was used for all PCA and CA.

5.3 Key Analytes Identified Through the Analysis

Summary results of the PCA are provided in Table 5-1. Appendix F provides detailed correlation matrices and factor loading matrices for all the separate PCA analyses performed. From the nine major ions and nine metals, the PCA identified the constituents that varied the most in concentration within each of the data sets. For each PCA analysis, the nine major ions were reduced to three PCs (groups of analytes). The nine metals/trace elements also were reduced to three PCs. From 65 to 72 percent of the variance in the data sets was explained by the three factors. The key analytes are identified in Table 5-1, along with the proportional amount of variation in the data set that is explained by the three or four principal components listed in that table. There were considerable similarities between the key analytes identified for the nonfiltered and filtered samples. For metals and trace elements, the key analytes included iron, manganese, barium and strontium.

5.4 Interpretation of the Statistical Analyses

An initial review of the water-quality data sets showed a larger range in chemical concentrations in the R wells than is typically found in the springs or long-established wells. The higher concentrations were associated with the R wells and probably reflect the presence or effects of residual drilling fluids or of local contaminant plumes.

Wells with possible drilling impacts were identified by examining chemical signatures established by the statistical analyses. R wells that are compositionally similar (cluster) to the White Rock Canyon springs or the long-established wells are interpreted to have minimal residual drilling impacts. R wells that are placed in other clusters were interpreted to have possible residual drilling effects.

Figures 5-1 through 5-4 present plots of the first three PCs for each metals or major ions analysis. These three PCs account for the majority of variability in the original data. The PCA scores for each water sample are plotted, and groundwaters that are compositionally similar are shown in the plots as clusters (C1, C2, etc.) identified by the KMC method. Highlighted on the plots are selected wells that reflect the most anomalous chemistry. The top plot in each figure shows the PCA scores grouped according to the type of groundwater source: multiple-screen R wells, single-screen R wells, municipal water-supply wells, White Rock Canyon springs, or test wells.

The interrelationships between metals and major ions in the R wells were examined by merging metals and major ions data sets and by analysis using the hierarchical cluster analysis (HCA) method. The results are shown in tree diagrams, or dendograms, in Figures 5-5 and 5-6. The HCA analysis identified the same highly impacted well screens as did the KMC analyses. The resulting dendogram was interpreted upon visual examination to have classified the nonfiltered recent water samples into four subgroups and the filtered samples into five subgroups (clusters) using 19 parameters (Figures 5-5, 5-6). This is a subjective breakdown but the subgroups serve to further examine the characteristics of the most impacted wells.

Tables 5-2 and 5-3 show the means for each of the parameters produced by the HCA analysis. Both the non-filtered and filtered data sets produced similar sub-groups with comparable compositions. Cluster 1 contains elevated concentrations of carbonate minerals (Ba, Ca, Sr), reducing conditions (elevated Fe, Mn), and elevated sodium. This is consistent with categories A (leachable drilling fluids), C (reducing conditions), and E (precipitation or dissolution of carbonate minerals) of residual drilling fluid effects (Table 4-2). Cluster 2 contains significantly reducing conditions but relatively low concentrations of the carbonate minerals. This is consistent with Category C. All of the well screens assigned by HCA to Clusters 1 or 2 scored poorly in the 2005 well screen analysis described in section 4. Clusters 1 and 2 also correspond well to PCs 1 and 2 of the factor loadings matrices.

PC 4 in the factor loading matrix for nonfiltered samples highlights elevated sodium and sulfate and likely reflects the presence of residual bentonite. The differences between the remaining clusters identified in HCA are more subtle and are interpreted to show minimal to moderate impacts from drilling fluids. There is a good correspondence between spatial locations and statistical groups for Clusters 3, 4, and 5. For example, many of the filtered samples from springs and wells within the central portion of the Pajarito Plateau are assigned to Cluster 3 and those from the southern portion are assigned to Cluster 5 (Figure 5-6).

5.5 Interpretation of Uranium Correlations

A major result from PCA is that anomalous chemical concentrations can be identified. This is true for concentrations that are either unusually elevated or unusually low. Thus, if significant removal of uranium from solution is occurring in some R wells, the PCA would identify abnormally low uranium concentrations as a key component of variance in the data set.

A review of the factor loadings matrices (Appendix F) shows that uranium concentrations are correlated with other constituents sensitive to oxidation/reduction. Uranium correlates positively with vanadium and nitrate concentrations, and inversely to iron and manganese concentrations. Abnormally low concentrations of uranium, if present, are statistically associated with elevated iron and manganese concentrations. However, uranium is not significantly associated with any other factors in the PCA. Uranium is not expected to adsorb onto bentonite because it forms anionic or neutrally charged carbonate complexes and is rarely present as a cation. The PCA is consistent with this. If sorption were a dominant mechanism controlling the concentration of uranium, sorption would have been identified as a different component, separate from oxidation/reduction in the factor loadings matrix.

5.6 Key Findings from Statistical Analyses

The chemical signatures of most of the water-supply wells are consistent with those of the test wells and White Rock Canyon springs. This indicates that the water-supply wells reflect the regional aquifer water quality and show no discernible residual effects from drilling fluids. Taken together, results from the springs, test wells, and water-supply wells represent the regional aquifer “baseline” water quality (as distinguished from “background” because it includes normal effects from aging wells).

- In many cases, the single-screen wells are compositionally similar to the baseline stations. There is indication of slightly higher iron or manganese concentrations in some of the single-screen wells. Overall, the analysis indicates that there is minimal to slight residual impacts from drilling in the single-screen wells.
- The multiple-screen R- wells show considerable residual drilling impacts. Significant impacts are seen in the multiple-screen wells in all metals and major ion data sets analyzed. The well screens showing the most impacts include R-20 (screen 2), CdV-R-37-2 (screen 2), R-22 (screen 1), R-22 (screen 4), and R-31 (screen 2).
- The magnitude of drilling impacts was assessed by considering the similarity in chemical signatures to the “baseline” stations—the springs, test wells, and water-supply wells. Table 5-4 summarizes the preliminary interpretation of the results for the most recent data from each site.

5.7 Comparison of PCA Results with Data Qualification Test Outcomes

The two independent approaches largely produce consistent results but differ in a number of aspects. The differences include

- method objectives,
- the number of screens included in the analysis,
- the type of data used in the analysis,
- the period of coverage for samples from each screen,
- the collection dates of samples that represent the “most current” sample, and
- assumptions that underlie interpretation of the results.

Regarding method objectives, the PCA was designed primarily to test whether the screens had chemical characteristics that differed significantly from those shown by local springs and water-supply wells. The latter are assumed to represent relevant background conditions. In contrast, the well screen analysis approach described in section 4 was designed to test whether the screens produced water samples that were reliable and representative of predrilling concentrations for a number of specific categories of analytes of concern, many of which are not detected in background waters.

The two methods use a similar number of inorganic indicator species: about 21 for the well screen analysis method presented in section 4 and 18 for the PCA method. Notably absent from the PCA input data are organic species and field-based parameters other than alkalinity. Organic-based drilling fluids, if used during drilling of supply wells, have been removed during several decades of pumping. Neither method includes any radionuclides as indicators.

Table 5-5 provides a qualitative comparison of the outcomes of both methods. The methods overlapped in coverage for 51 screens. Screens that were included in the well screen analysis but excluded from the PCA method for the most part were either newly completed wells that only produced water-quality data in the past couple of months, after the PCA study had already been conducted (in June 2005), or older wells for which water-quality data had not yet been transferred into the WQDB from the Environmental Restoration Database (ERDB).

In Table 5-5, shaded cells indicate those 45 screens (88%) for which both methods produced qualitatively comparable results. The two methods differed for 6 screens. The differences are traceable, for the most part, to just a few reasons:

- absence of consideration of organic analytes by the PCA method
- absence of consideration of most field-based data by the PCA method
- differences in the date of the sample considered "most current"
- the specification of background ranges by the well screen analysis approach that may not reflect the full range of conditions that actually occur
- the treatment of partial data sets for which key analytes are not available (included by the screen analysis method, excluded from the PCA method which requires full data sets)

6.0 SUMMARY AND CONCLUSIONS

6.1 Summary

In addition to the sampling events examined in the initial version of this report, all newer characterization (i.e., post-screening), surveillance, and special-study water samples were evaluated. These newer samples were taken from 42 wells during a period from August 2005 through December 31, 2006. The full set of data included a total of 95 screens, of which 80 were functional: 22 screens in single-screen wells and 58 screens in multiple-screen wells. This is an addition of 9 wells and 14 screens to the list of those evaluated in Revision 0, for a total of about 390 individual sampling events, nearly doubling the original set of 200 samples.

The evaluation in Revision 1 used revised background values from an expanded set of 30 background locations, approved by NMED and reported in the "Groundwater Background Investigation Report, Revision 2" (LANL 2007, 094856). Use of revised background values along with their detailed statistical characterization allowed for fine-tuning of test threshold values for geochemical indicators. Overall, the use of these revised threshold values increased the number of tests passed for many indicator analytes as well as improving the internal consistency among test outcomes. Furthermore, reclassification of water supply well samples from filtered to nonfiltered in the "Groundwater Background Investigation Report, Revision 3" (LANL 2007, 095817) did not change the overall test outcomes in Revision 2 of this report.

A major shift in philosophy introduced in Revision 1 was the implementation of a single, comprehensive approach to examining geochemical data for the presence of impacts from any drilling fluids, rather than the separate, tailored evaluations of organic-based and bentonite drilling fluids used in the initial report. The rationale for the single approach is that bentonite drilling fluids still contain minor amounts of organic polymers, and bentonite and organic additives are used in well construction to fill in the annular space between the casing and the formation so as to isolate the screen interval. In other words, individual indicators cannot be linked to just one type of primary drilling fluid. This approach is justified by a vastly improved knowledge of the compositions and uses of drilling fluids and additives and more refined conceptual models about their effects on groundwater and mineral geochemistries. The single comprehensive approach also allows for more efficient automation of the evaluation protocol, which requires well-defined conditions and boundaries for determining which tests are applicable to a sample and whether an indicator passes or fails a test.

In Revision 1, boron was dropped as an indicator because it was found not to be a reliable indicator of leaching from bentonite mud (data in Table A-10). However, the following eight indicators were added to the 18 remaining indicators that were used in Revision 0: barium, chromium, magnesium, molybdenum, nickel, perchlorate, phosphate, and turbidity. The ratio of total to dissolved iron and the ratio of total to dissolved chromium were also added to provide indicators of stainless-steel corrosion. Some indicators were added based on the results of leaching tests of drilling products (section 4.4.2, Tables 4-7 and

A-10); others were added based on statistical correlations revealed by the statistical PCA (section 5 and Appendix F); and still others were recommended by the EPA (EPA 2005, 090545) (EPA 2006, 094894), NMED (NMED 2006, 094373), and other reviewers.

Revisions 1 and 2 deal more explicitly than Revision 0 with screens in which the presence of a contaminant plume interfered with the validity of the screen analysis. As an example, the presence of nitrate or sulfate in a contaminant plume can obscure drilling fluid-induced reducing conditions that are otherwise chiefly revealed by negligibly low concentrations of these two species. This potential for reducing conditions to be masked is one primary reason that field parameters—sulfide, DO, and ORP—are important to include in the evaluation, despite their known limitations. Conversely, elevated chloride in a water sample in which chloride is present in a contaminant plume can be misinterpreted as an indication of the persistent presence of water-soluble drilling-fluid constituents.

As shown in Figure 6-1a, thirty-one percent of the screens show no impacts from residual drilling fluids. The most common effects are reducing conditions (Category C) and instability of carbonate minerals (Category E). No single-screen wells are impacted by adsorption onto clay minerals (Category D). Figure 6-1b indicates that 100% of the screens provide reliable and representative data for tritium, 92% are reliable for strontium-90, and 85% are reliable for chloride. The break is noticeable between these constituents and the remaining constituents in this figure (only 55–58% of screens in both single-screen and multiple-screen wells are reliable for perchlorate, zinc, RDX, TNT, VOCs, cesium-137, plutonium, chromium, and nitrate); however, the inability to provide reliable data is only 2% for these constituents in single-screen wells.

6.2 Conclusions

Any comparison between the well-screen evaluation results in Revision 0 and those in Revisions 1 and 2 must take into account several factors:

- Both the test criteria as well as the evaluation protocols were substantially overhauled in Revision 1.
- Revision 0 limited its examination to the three most recent samples as of August 31, 2005. In contrast, Revisions 1 and 2 extended evaluation of these water-quality data to include the large number of characterization and surveillance samples collected since August 2005, up through December 31, 2006.
- Water quality in nine screens from three wells (R-12, R-16, and R-20) was affected by pilot rehabilitation activities that postdated Revision 0.

The first two factors lead to a greater degree of confidence in Revisions 1 and 2 results than in Revision 0. However, because all three aspects introduce multiple variables, an interpretation of the change in screen results is more complicated than if only one of these situations had been changed. The conclusions must be viewed with this caveat in mind.

Many of the findings of Revision 0 are still true in Revisions 1 and 2:

- The most common drilling artifact is the presence of reducing conditions.
- Single-screen wells show the least impact from residual drilling fluids.
- The majority of the screens in multiple-screen wells appear to be impacted by residual drilling fluids, although nearly all multiple-screen wells have at least one nonimpacted screen interval.

A preliminary conclusion in Revision 0 was that some screens appeared to be improving over time. This overall trend is not only confirmed by the outcomes of the evaluation protocol presented in Revisions 1 and 2 but also made more apparent because of the improved assessment methodology, inclusion of a greatly expanded database, the passage of time, and early effects of pilot rehabilitation activities. Nearly 25% of the showed improvements in the reliability and representativeness of their water-quality data by the end of their assessment periods (2005–2006) (Table 6-5), whereas previously, the number of sampling events available for many of these screens had been too few to establish definitive trends for them.

6.2.1 Observations

The results of the water-quality evaluations documented in this report underscore the importance of examining long-term trends when assessing the reliability and representativeness of water-quality data for a screen. It is not always sufficient to look at the current geochemical characteristics of a water sample; one must also often consider the geochemical path that it followed to arrive at that point. Whether an indicator's concentration is rising, falling, or stable is an important trend to establish because such a trend may be a distinguishing characteristic between a residual drilling effect and an effect arising from a local contaminant plume. Factoring in the effects of a local contaminant plume is one of the major challenges for the development and implementation of a data-qualification protocol for residual drilling effects.

Subject to the above caveats, Figure 6-1(a) and Table 6-1 summarize the frequency with which residual drilling effects appear to be present in the most recent sample from the 80 well screens evaluated in this report.

- No residual drilling effects are detected in 25 of the 80 screens. Twelve of these are single-screen wells, and thirteen are screens in multiple-screen wells.
- Among those screens in which residual drilling effects are indicated, the most frequently observed effect (44% of the screens) is the presence of reducing conditions that presumably arise from biodegradation of residual organic drilling products.
- Another 44% of the screens are affected by shifts in carbonate mineral stabilities, which have major implications for chemical transport because of the high degree with which trace metals complex with carbonate species in groundwater.
- The third most frequently detected effect (36% of the screens) are indicators of residual organic drilling materials.
- Less frequently detected (25% of the screens) are indicators of residual inorganic drilling fluids; this lower rate may reflect the effectiveness of development in removing these mobile constituents, and also the fact that these indicators are not evaluated if they are known to be present in a local contaminant plume.
- The conditions detected with the lowest frequencies are indicators for enhanced adsorption (9% of the screens) and indicators of stainless-steel corrosion (5% of the screens).

Several observations are made about each of the six categories of effects, and the indicators used to detect those effects:

- Category A—Among all indicators of residual inorganic species derived from drilling fluids, the most frequently observed are elevated concentrations of alkalinity (31% of screens) and chloride (25%), with fluoride a close third (24%) (Figure 4-8b). Characterization data for drilling products

(Tables 4-7 and A-10) indicate that a number of these are candidate sources for the elevated concentrations of these indicators.

- Category B—Among indicators of residual organic drilling fluids, ammonia (28% of the screens) and TOC (30% of the screens) are by far the most commonly detected above their threshold values (Figure 4-14b). Because natural background levels of these species are negligible, these organic indicators also show an obvious decrease as a screen improves over time.
- Category C—“Fully oxidizing” (i.e., aerobic) conditions exist at 55% of the screens (Figure 4-18). In the reducing category, 33% are in the range of more reducing (i.e., iron or sulfate reducing), whereas only 12% are more mildly reducing (reduction of manganese and nitrate). Time will tell whether the more reducing conditions in the screens will improve toward more oxidizing, but the distribution of conditions is clearly bimodal, whereas the preferred outcome would have been to observe a higher percent in the mildly reducing and oxidizing categories. The dearth of screens showing mildly reducing conditions may reflect the effectiveness with which redox conditions in the groundwater are buffered by reactive minerals in the formation, particularly iron-bearing minerals. Some mineralogy altered by drilling fluids is likely to remain unchanged for long periods of time. For example, severely altered iron mineralogy is inferred as being present in well CdV-R-37-2 screen 2, because dissolved iron remained highly elevated (>10,000 µg/L) for all six of the sampling events included in this report, which span a year and a half.
- One observation that changed between Revisions 1 and 2 is related to RDX. In Revision 1 it was thought that RDX behaved as a conservative species, just like tritium. However, RDX biodegradation pathways were recently reviewed by Crocker et al. (Crocker et al. 2006, 095581), and RDX biodegradation under anaerobic conditions was reported by Beller (2002, 095589) and Bradley and Dinicola (2005, 095588). On this basis, it is assumed that RDX can degrade under reducing conditions in the presence of the appropriate microbial population (LANL 2007, 095787).
- Category D—All screens in single-screen wells are able to detect indicators of adsorbing species, to the extent that reliable surrogates for these species could be identified. The results for single-screen wells are identical for wells drilled with and without bentonite mud (section 4.7.3). Multiple-screen wells showed some variation between outcomes for wells drilled with and without bentonite mud; but in either case, a vast majority of the screens were able to detect strontium, barium, and zinc. In contrast, only 82% of the screens were able to detect uranium. In this case, however, the nondetects are attributed to the presence of reducing conditions, and not to adsorption onto residual bentonite.
- One observation that has not changed between Revision 0 and Revision 1 of this report is that no good surrogate has been found to evaluate the ability of a screen to provide reliable data for highly sorbing radionuclides such as plutonium-239, which is routinely measured (but not detected) in Laboratory groundwater samples. Analyses of lanthanides have occasionally been conducted but these elements are also only rarely detected, just as one would expect, based on their highly adsorptive characteristics.
- Category E—Calcium, strontium and barium manifest very similar proportions of excursions outside the background range (37%, 35%, and 30%, respectively) as does alkalinity (31% of the 80 screens). In a process similar to the case of the alteration of iron minerals under extended reducing conditions, the long period of time (more than four years) over which carbonate alkalinity, barium, and strontium concentrations have remained very high in screens 1, 4 and 5 in well R-22 is likely to have led to significant changes in carbonate mineralogy in the vicinity of the screen.

- Category F—The presence of steel corrosion indicators (Table 6-1) identifies four screens in three wells which may not provide reliable or representative data for trace metals and adsorbing species.

Figure 6-1(b) and Table 6-4 summarize the implications of the inferred residual drilling effects for the ability of the screens to provide reliable and representative water-quality data. A few examples are given here:

- Tritium can be detected reliably in 100% of the screens because none of the residual drilling effects can alter its concentration or transport behavior.
- RDX can be detected in 58% of the screens.
- Sr-90 can be detected 92% of the time. The few exceptions are all screens in multiple-screen wells.
- Fifty-eight percent of the screens can produce reliable and representative data for zinc, and 56% can do so for chromium. The other 42 and 44% manifest one or more of the following conditions that affect both of these trace metals: iron or sulfate-reducing conditions, altered iron mineralogy in the screen interval, or stainless-steel corrosion.
- Fifty-eight percent of the screens can reliably detect perchlorate, which is only affected by the presence of reducing conditions.
- Like perchlorate, the detection of nitrate is unreliable in the presence of reducing conditions. However, because nitrate is also leached from some drilling products, the proportion of the screens that can provide reliable and representative nitrate data is slightly lower (55%) than that for perchlorate.
- Fifty-eight percent of the screens can reliably detect VOCs. For those screens which cannot, either reducing conditions are present that could enhance biodegradation rates, or else the presence of residual organic drilling fluids raises the possibility of a reservoir of immobile residual organic matter into which hydrophobic VOCs could partition.

Two aspects that received attention in Revisions 1 and 2 are the effects of well development and purging protocols on the reliability of water-quality data from a screen. The influence of well development protocols on present-day screen conditions was examined in section 4.2.1 by tabulating water-quality ratings and redox conditions for the most recent sample from each screen as a function of three measures for the effectiveness of development in removing residual drilling fluids from a screen. The indicators were the TOC attained by the end of development, the year in which development was completed, and the elapsed time between completion of drilling and the end of well development. The most striking trend was observed when current screen conditions were mapped against the year in which development was completed. Development that was completed in 2003 or later shows an improved track record of groundwater quality compared to screens that were developed prior to 2003. This apparent improvement is attributed to the cumulative effect of multiple factors: implementing additional development criteria, modifying drilling practices to minimize fluid use and loss into the formation, switching to rod-based screens, and—perhaps most important—switching to a much higher proportion of single-screen and dual-screen wells rather than multiple-screen wells.

The effects of purging on water-quality reliability were also examined by plotting trends for field parameters that are monitored prior to sample collection. No systematic difference was revealed by this exercise. It is concluded that no systematic difference is readily apparent when field data from different sampling systems are compared because site-specific factors dominate. For example, any differences in water-quality parameters that might arise due to differences in purging volumes or rates are presumably largely masked by natural variability induced by changes in water levels for water samples from perched intermediate aquifers.

6.2.2 Test Score Results

The overhaul of the data-evaluation protocol and near-doubling of the sampling events to which this protocol has been applied instills an increased level of confidence in the outcomes as compared to those in the original report. Revision 2 differs from previous revisions in that it has dropped the ranking system (Very Good, Good, Fair, Poor) that had been based on test scores. Because of the significant changes that have been made, the test outcomes in Revisions 1 and 2 are not strictly comparable to those in the original report. With this caveat in mind, outcomes from the two revisions of this report are compared below with the objective of sorting out similarities and differences that are meaningful from those which are merely artifacts of changing methodologies and datasets.

Table 6-2a compares the outcomes for the most recent samples that were assessed in Revision 0 (i.e., most recent as of August 2005) to the most recent samples assessed as of December 2006). On average, where the reports overlap in coverage, samples received higher test scores in Revisions 1 and 2 than in Revision 0. Tables 6-2b through 6-2e are used to evaluate the extent to which this shift to a higher percentage of tests passed is attributable to improvements in data quality as opposed to changes in the evaluation protocol.

To address the former possibility, Table 6-2b compares test outcomes for identical sets of samples (the most recent sample as of August 2005) when these are evaluated using the two different methodologies. The table shows that 35 screens (55% out of 64) maintained the same test outcome, 16 screens (25%) shifted to a higher percentage of tests passed, and 13 screens (20% of 64) shifted to a lower percentage of tests passed. Thus, there is general agreement in the qualitative outcomes assigned to the same sample by the two approaches, and no systematic bias toward either higher or lower outcomes.

To clarify the effects of changes in the evaluation protocol, Tables 6-2c through 6-2e compare outcomes for the presence or absence of specific residual drilling effects.

- Table 6-2c compares the outcomes for identifying the presence or absence of residual inorganic drilling fluids. The report revisions reach the same conclusions for seven samples, but differ on five others. This apparent difference arises primarily because Revisions 1 and 2 use more appropriate indicators for this condition, and because threshold values are established based on statistically-derived background values rather than extremes of the background distribution. Another point underscored by this table is the consequence of the decision to extend tests for residual inorganic drilling fluids to all water samples, regardless of the drilling method used in an interval. Of the 52 screens to which this test was not applied in Revision 0 (because they were drilled with organic drilling fluids and not bentonite mud), Revisions 1and 2 conclude that residual inorganic constituents of drilling fluid products are present in 22 (43%).
- Table 6-2d compares outcomes for identifying the presence or absence of residual organic drilling fluids. The report revisions reach the same conclusions for 52 (81%) of the 64 samples. Revisions 1 and 2 concluded residual organic drilling fluids were present in 12 (19%) of the 64 samples in which Revision 0 had concluded they were absent. The only difference between the two methodologies is the application of lower thresholds in Revisions 1 and 2 than were used in Revision 0.
- Table 6-2e compares the apparent redox condition for the most recent sample (again, as of August 2005) as concluded by the two methodologies. The outcomes are consistent for only

about half of the samples. The differences are mostly due to the use of improved threshold values adopted from the "Groundwater Background Investigation Report, Revision 2" (LANL 2005, 088789).

Figure 6-2 tabulates the frequency with which multiple residual drilling effects are observed in the most recent sample, based upon the summary of conditions tabulated for each screen in Table 6-1. For this tabulation, ten categories of residual drilling effects are considered:

- Elevated turbidity, elevated alkalinity, and/or pH less than or greater than its range in background groundwater,
- Residual inorganic drilling fluids,
- Residual organic drilling fluids,
- Nitrate-reducing condition,
- Manganese-reducing condition,
- Iron-reducing condition,
- Sulfate-reducing condition,
- Enhanced clay adsorption,
- Unstable carbonate mineralogy, and
- Stainless steel corrosion.

The presence of each reducing condition less than oxic is counted as a separate category, such that the presence of a sulfate-reducing condition is counted as four conditions because in that case the water is also reducing with respect to iron, manganese, and nitrate. The presence of an iron-reducing condition is counted as three conditions because the water is also reducing with respect to manganese and nitrate. A manganese-reducing condition is counted as two conditions, and a nitrate-reducing condition is counted as one condition, following the same logic.

As shown in Figure 6-2, 31% (25 screens out of 80) are characterized by oxidizing conditions and show no residual impacts from the use of drilling fluids. Another 26% (21 screens) show an impact for one or two categories. All but three of these 21 screens are also characterized by oxidizing conditions, and the most common residual drilling effect for the 18 oxidizing screen intervals is the presence of organic fluids. Of the other three screens showing low degree of impact, one is characterized by nitrate-reducing conditions, and two others by manganese-reducing conditions. Single-screen wells show the fewest number of impacts overall.

A higher frequency of residual drilling effects are present in the remaining 43% of the screens (34 out of 80), which are generally characterized by iron-reducing and sulfate-reducing conditions. Twenty screens (25%) exhibit symptoms of three to five residual drilling effects; 11 of these screens have developed iron-reducing or sulfate-reducing conditions. Eighteen percent (14 screens) are affected by six or more categories of residual drilling effects; and half of these screens have developed sulfate-reducing conditions.

6.3 Limitations or Uncertainties

The protocol described in this report provides a significant step forward in establishing a comprehensive technical framework and protocol for evaluating the residual drilling effects that could compromise the reliability and representativeness of water-quality data produced by a screen. The protocol inevitably still has limitations, of which the user must remain cognizant. None of the outcomes using these indicator species is infallible. The common shortcomings of field measurements such as dissolved oxygen are already well recognized in the user community. However, the limitations of other indicators are not as readily apparent or explained. For instance, detection of tritium is generally assumed to indicate the presence of a component of modern water, such that the absence of measurable tritium would appear to rule out the presence of a groundwater contaminant plume as being unlikely. However, as shown in Table 6-1, there are screens—such as in wells R-10a and R-23—in which modern contamination is obviously present but in which tritium is below detection.

Multiple interfering conditions created by different constituents in drilling fluids make it challenging to determine a single responsible indicator for a well screen condition. A change in iron mineralogy, for example, cannot be observed directly but can only be inferred from water-quality data. More than one cause could give rise to the identical symptom, but the different causes may have very different long-term prognoses. This ambiguity makes it difficult to predict when or if conditions might change such that the altered mineralogy in the vicinity of a screen will begin to transition back to predrilling conditions.

Three additional categories of residual drilling effects are addressed in Revisions 1 and 2: transformation of iron mineral phases, changes in carbonate mineral stabilities, and corrosion of stainless-steel components. The described protocol identifies those screens in which these effects appear to be present. However, further progress on interpreting the causes and effects of these geochemical shifts outside the range of background conditions requires better knowledge of the co-evolution of geochemical species and the ability to incorporate consideration of kinetic rates. For example, zinc may be more mobile than assumed in this evaluation as a result of site-specific chemical conditions such as elevated alkalinity, due to its tendency to form neutral or anionic carbonate complexes.

Although closely related, several aspects nonetheless lie outside the scope of this report:

- specifying actions to be taken for analytes judged as unreliable or not representative of predrilling conditions,
- predicting when an impacted screen may be able to provide chemical data that are reliable and representative of predrilling conditions,
- specifying corrective actions to be taken if a screen is judged as unlikely to produce reliable or representative water-quality samples in the foreseeable future, and
- discussing methods for rehabilitating impacted well screens, which is the subject of a separate evaluation.

6.4 Next Steps

Data adequacy determination relies on multiple lines of evidence. Implementation of a data-adequacy protocol will evolve as insights are gained from testing and modeling. The screen assessment establishes a technically defensible foundation for several follow-on tasks:

- Selection and prioritization of screens for rehabilitation or other corrective action;
- Revision of sample-collection protocols;
- Assignment of data qualifiers in WQDB for past, present, and future water-quality data; and
- Establishment of additional data-quality objectives for area-specific monitoring networks and an assessment approach for evaluating how screens within area wells meet those objectives.

The only "corrective action" that can be confidently stated as an initial requirement in response to data flagged as unreliable or not representative of predrilling groundwater chemistry is to reassess the screen's data quality objectives (DQOs). DQOs define the type and quality of data to be collected from each screen. These data needs may be affected to varying degrees by residual drilling fluids, requiring a screen-specific analysis of impacts. Some data needs, such as piezometric data, are totally unaffected by drilling fluids, while others could be significantly affected. Consequently, it is not a simple or straightforward matter to specify the next corrective-action step because this decision requires a level of detailed evaluation that is far beyond the scope of the evaluation of water-quality data. For example, the selection of an appropriate corrective action requires consideration of the following factors:

- the significance of the screen's location relative to contaminant pathways;
- whether the screen is needed for a monitoring program;
- whether the screen meets its DQOs as specified for the characterization program;
- whether other screens in the area satisfy any or all of the monitoring needs;
- the long-term prognosis for the screen's recovery to predrilling conditions;
- how many screens in the multiple-screen well are providing reliable water-quality data;
- whether the screen is capable of providing reliable water-quality data for the specific suite of COPCs that could credibly be present; and
- whether the screened interval is located in a formation that is too tight to be adequately developed or to allow adequate purging so as to attain a high degree of confidence for all water-quality parameters.

As area-specific assessments are conducted, these criteria will assist in determining the reliability of R-well screens for a monitoring network.

7.0 REFERENCES

7.1 Documents Cited in Main Body of Report

The following list includes all documents cited in this report, except for Appendixes A and B. Parenthetical information following each reference provides the author(s), publication date, and Environmental Restoration (ER ID) number. This information is also included in text citations. ER ID numbers are assigned by the Environmental Programs Directorate's Records Processing Facility (RPF) and are used to locate the document at the RPF and, where applicable, in the master reference set.

Copies of the master reference set are maintained at the NMED Hazardous Waste Bureau; the U.S. Department of Energy–Los Alamos Site Office; the U.S. Environmental Protection Agency, Region 6; and the Directorate. The set was developed to ensure that the administrative authority has all material needed to review this document, and it is updated with every document submitted to the administrative authority. Documents previously submitted to the administrative authority are not included.

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7.4 Procedures Governing the Collection, Analysis, and Review of Groundwater Data

- RRES-WQH-SOP-048, Groundwater Sampling Using Bladder Pumps
- RRES-WQH-SOP-049, Groundwater Sampling Using Submersible Pumps
- RRES-WQH-SOP-050, Groundwater Sampling Using Westbay System
- ENV-DO-203, Field Water Quality Analyses
- ENV-DO-206, Sample Containers and Preservation
- ENV-DO-207, Handling, Packaging, and Transporting Field Samples
- ENV-WQH-QP-029, Creating and Maintaining Chain of Custody
- ENV-ECR QP-4.4, Record Transmittal to the Records Processing Facility
- RRES-ECR QP-5.13, Rev 0, Analytical Data Verification/Validation Process
- ENV-ECR SOP-05.02, Well Development
- ENV-ECR SOP-06.01, Purging and Sampling Methods for Single Completion Wells
- ENV-ECR SOP-06.03, Sampling for Volatile Organic Compounds in Groundwater
- ENV-ECR SOP-06.32, Multi-Level Groundwater Sampling of Monitoring Wells—Westbay MP System
- ENV-ECR SOP-15.01, Routine Validation of Volatile Organic Data
- ENV-ECR SOP-15.02, Routine Validation of Semivolatile Organic Data
- ENV-ECR SOP-15.03, Routine Validation of Organochlorine Pesticides and Polychlorinated Biphenyls Data
- ENV-ECR SOP-15.04, Routine Validation of High Explosives Data
- ENV-ECR SOP-15.05, Routine Validation of Inorganic Data
- ENV-ECR SOP-15.06, Routine Validation of Gamma Spectroscopy Data
- ENV-ECR SOP-15.07, Routine Validation of Chemical Separation Alpha Spectrometry, Gas Proportional Counting, and Liquid Scintillation Data
- ENV-ECR SOP-15.09, Chain of Custody for Analytical Data Packages

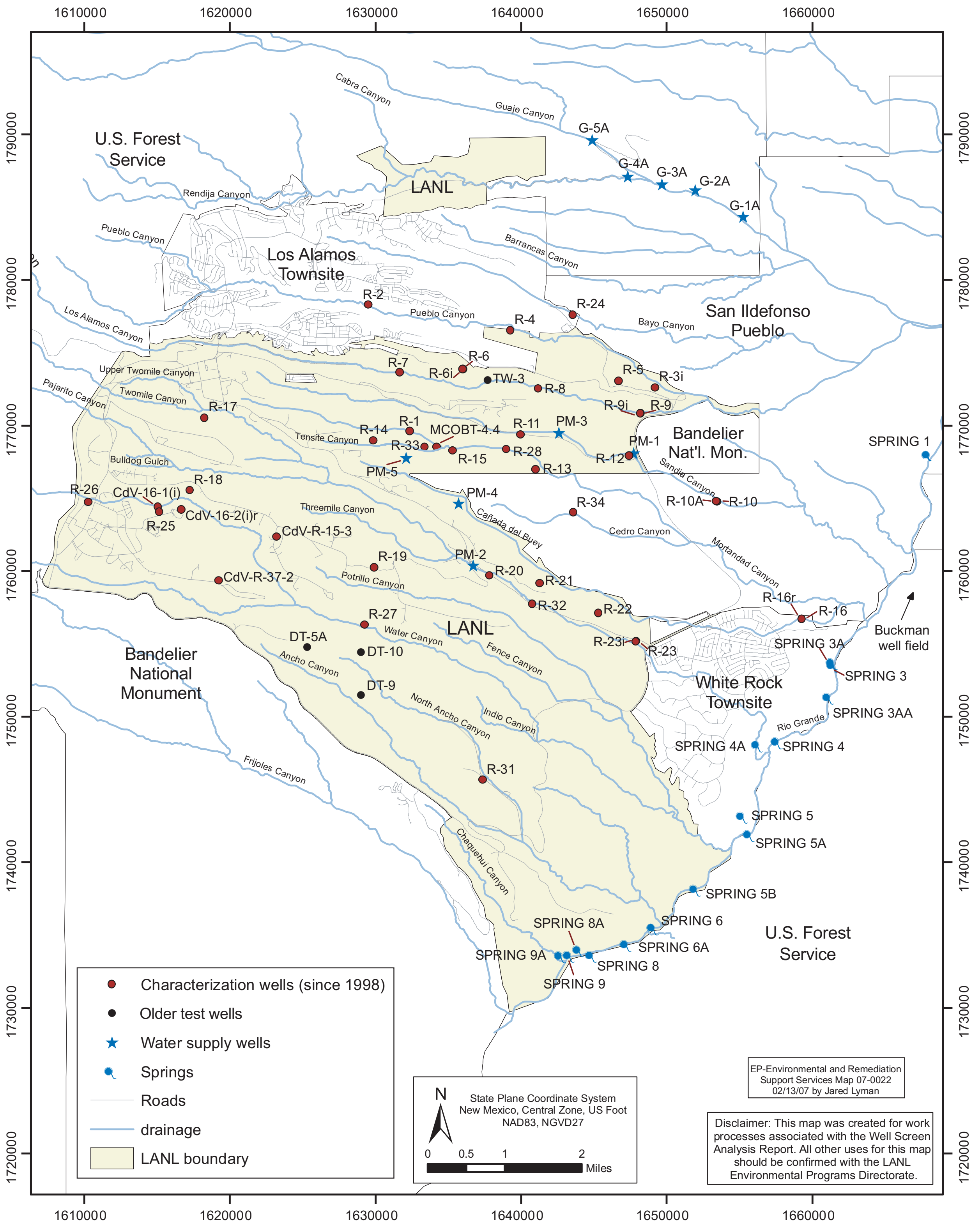
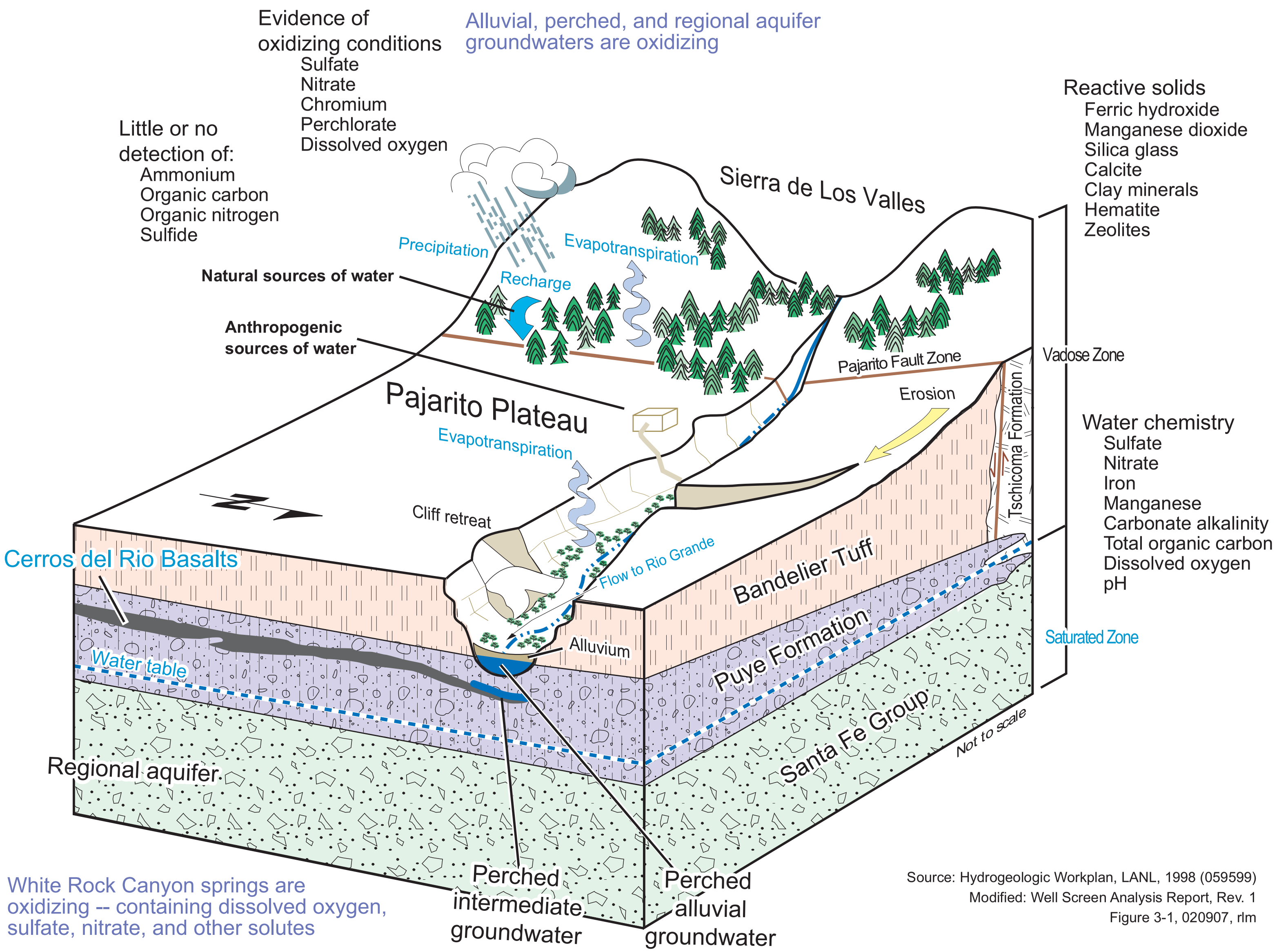
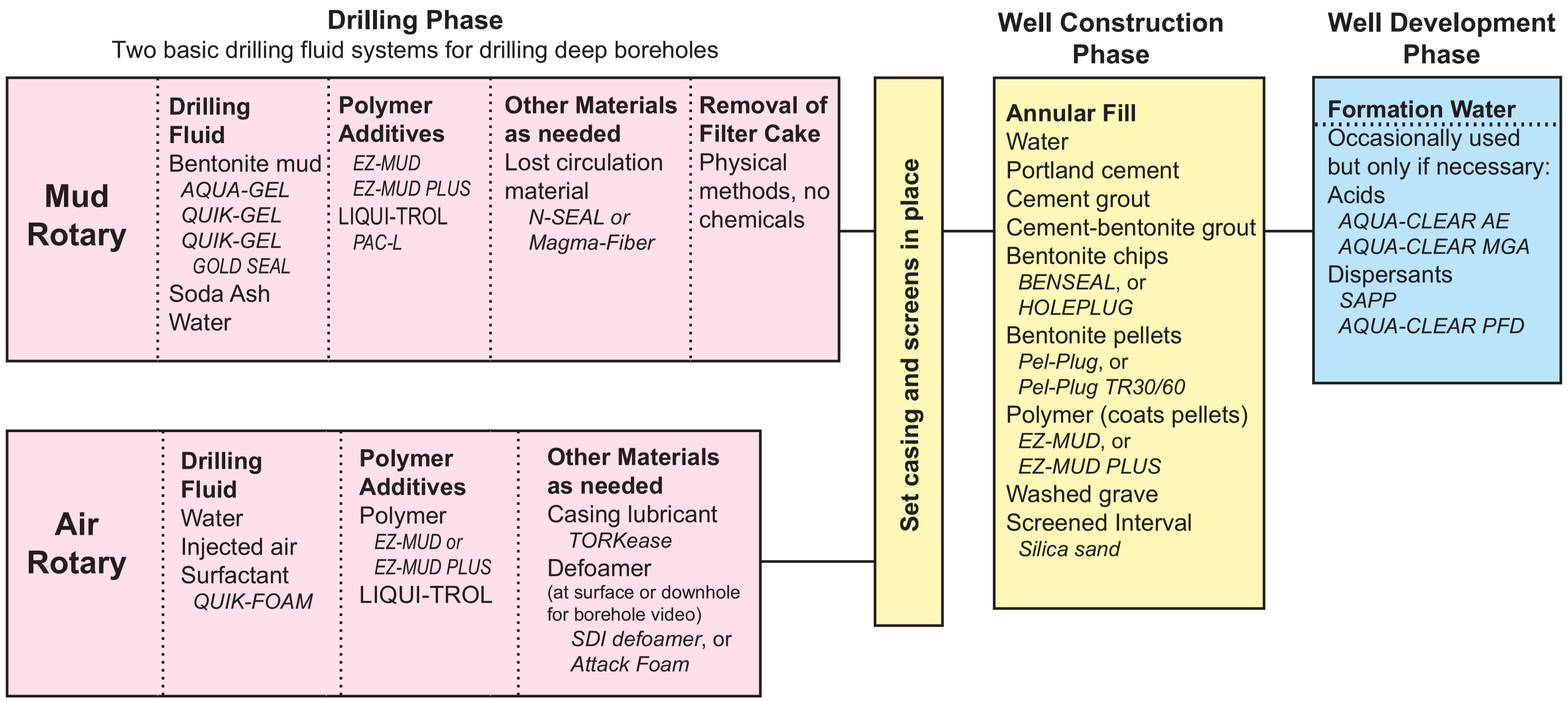


Figure 1-1 Map showing the location of wells and Rio Grande springs referenced in this report



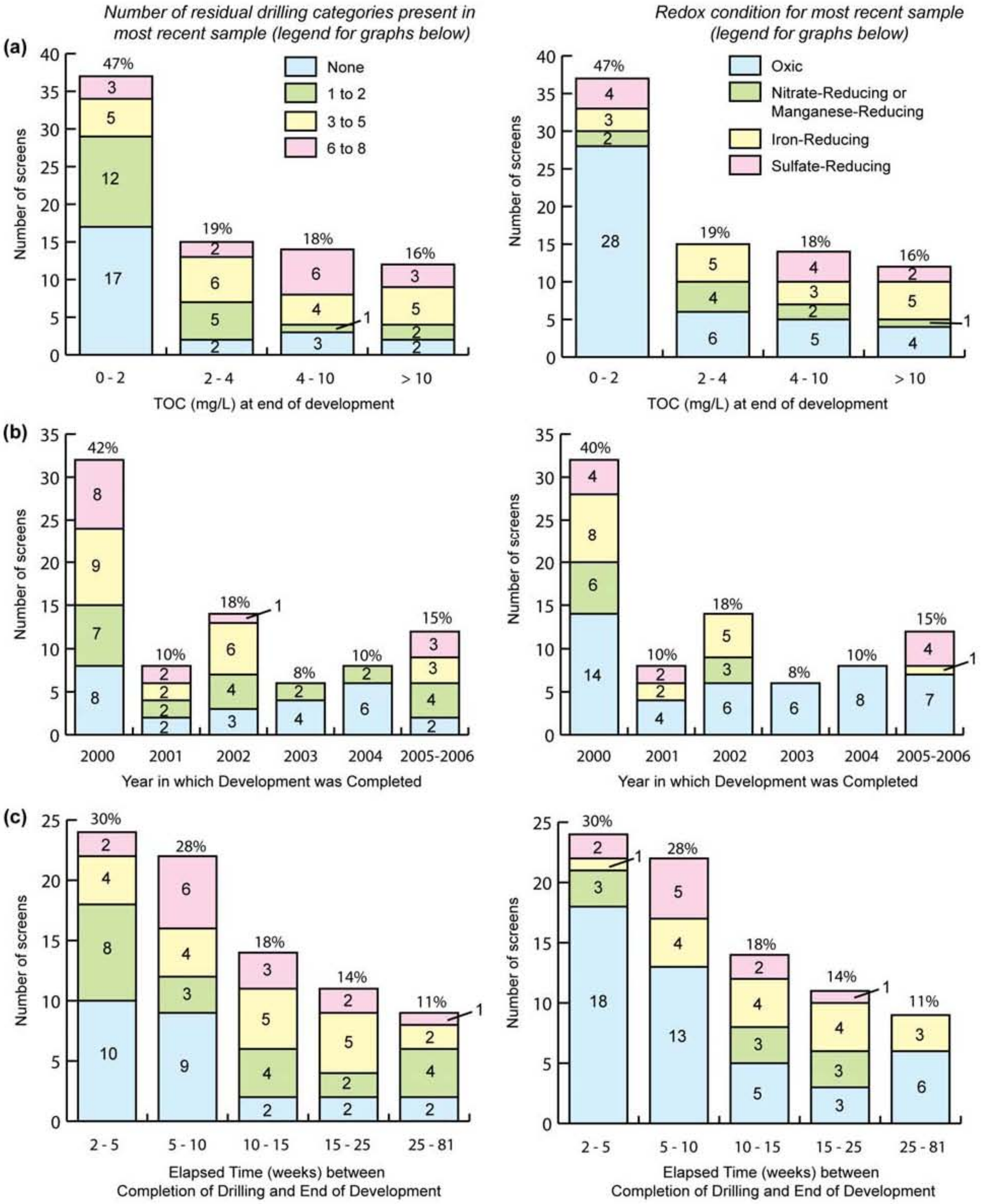
Source: Hydrogeologic Workplan, LANL, 1998 (059599)
Modified: Well Screen Analysis Report, Rev. 1
Figure 3-1, 020907, rlm

Figure 3-1. **Conceptual model of natural geochemistry of the Pajarito Plateau**



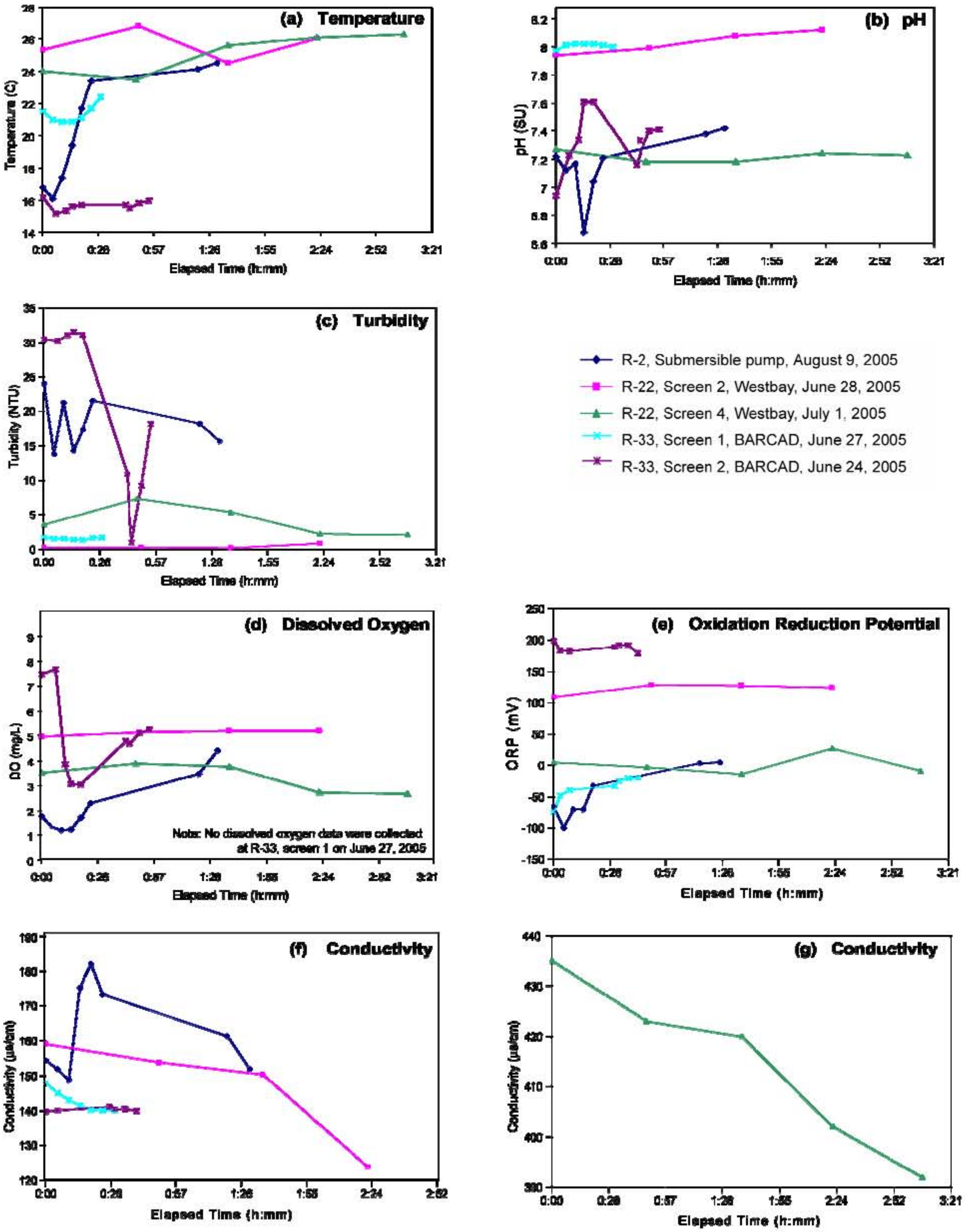
Note: This sketch clarifies, in a highly generalized way, the sequence in which chemicals are used to drill, complete, and develop a well, and the types of chemicals used in each of these phases. However, not all materials listed are used in all wells. Just as geologic formations vary widely in their 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



Sources: Well development dates and TOC data from Table 4-1; number of residual drilling categories present and redox condition for most recent sample from Table 6-1. Well completion dates from Table B-1.

Figure 4-2 **Present-day condition of well screen samples as a function of (a) total organic carbon concentration at end of well development, (b) the year in which the well was developed, and (c) time elapsed between completion of drilling and end of well development**



Note: No dissolved oxygen data were collected at R-33, screen 1 on June 27, 2005

Figure 4-3a **Monitoring of field parameters prior to sampling at wells with screens in the regional aquifer (R-2, R-22, and R-33): (a) temperature, (b) pH, (c) turbidity, (d) dissolved oxygen, (e) oxidation reduction potential, (f) conductivity, and (g) conductivity**

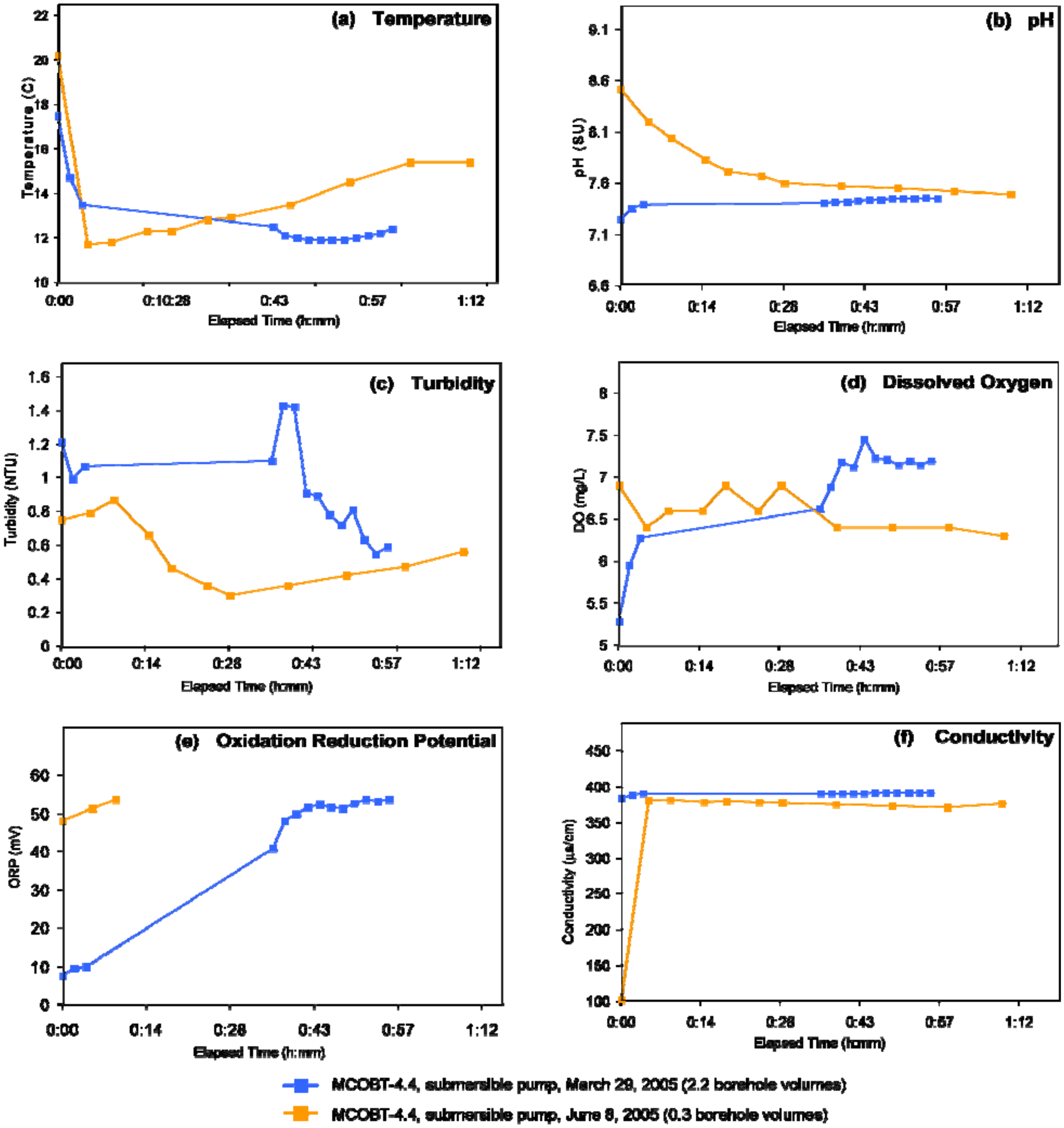


Figure 4-3b **Monitoring of field parameters prior to sampling at a well with a screen in the perched intermediate aquifer (MCOBT-4.4): (a) temperature, (b) pH, (c) turbidity, (d) dissolved oxygen, (e) oxidation reduction potential, and (f) conductivity**

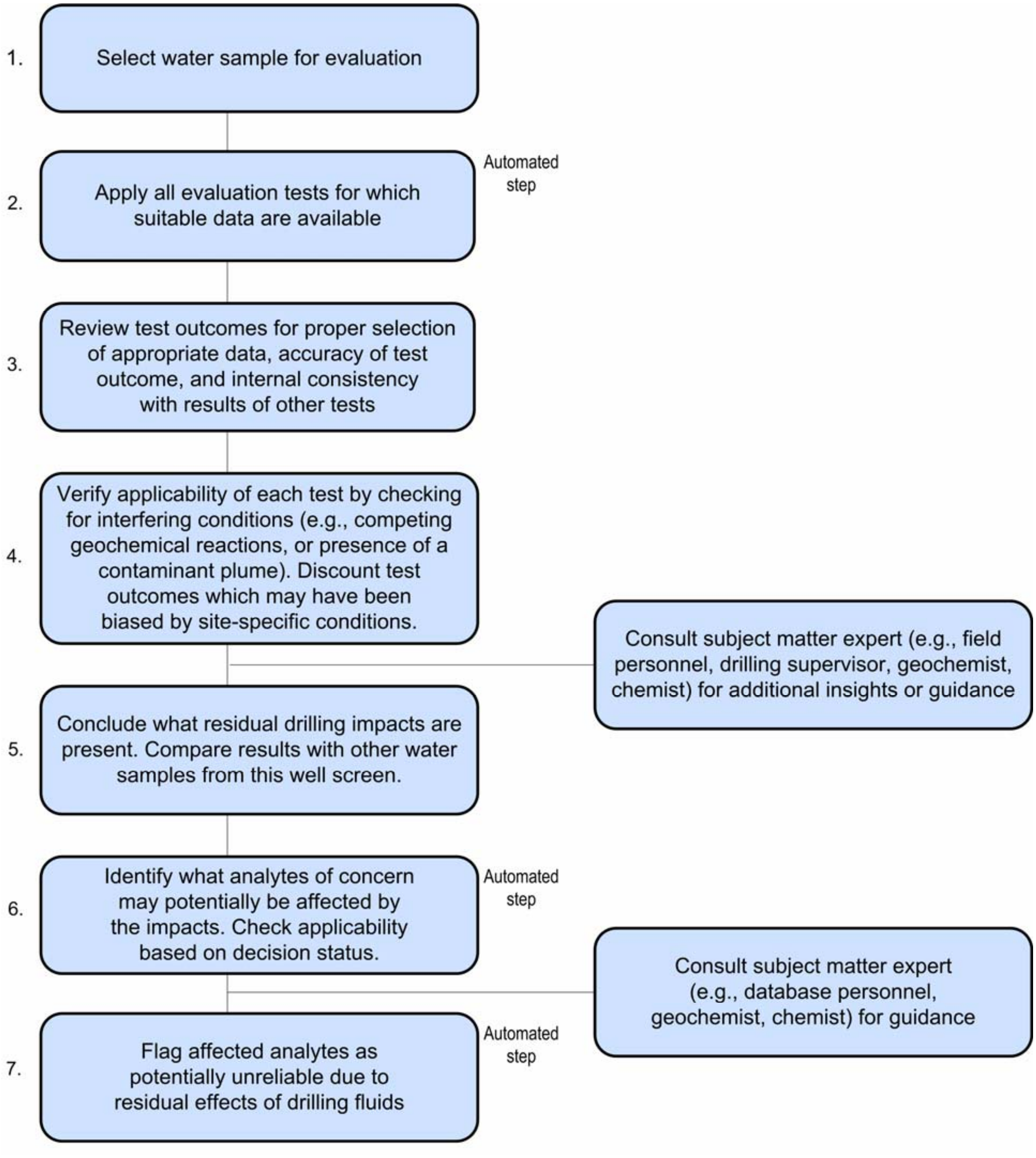


Figure 4-4 **Sequence of steps for evaluating water-quality samples for impacts of residual drilling fluids**

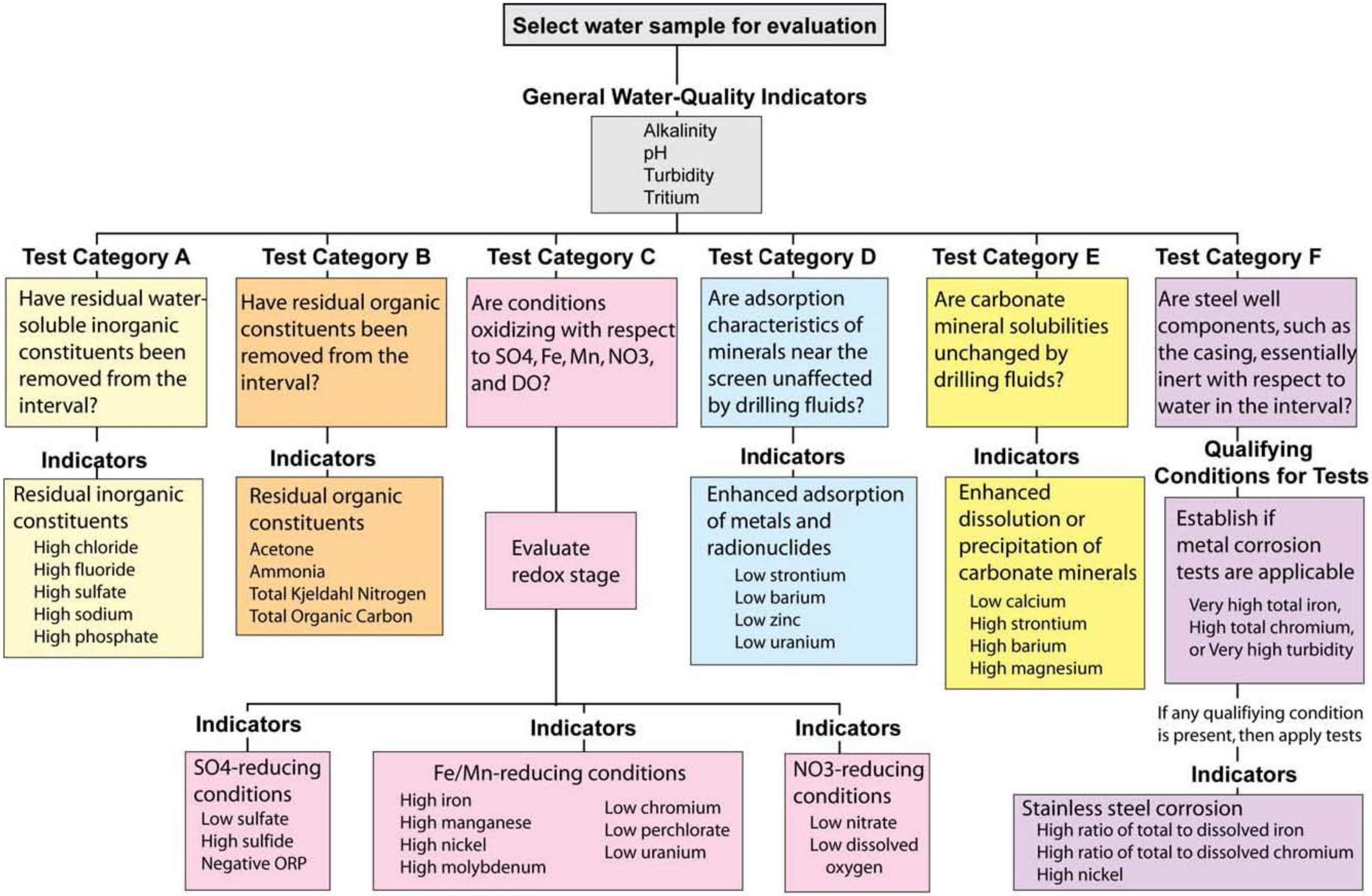
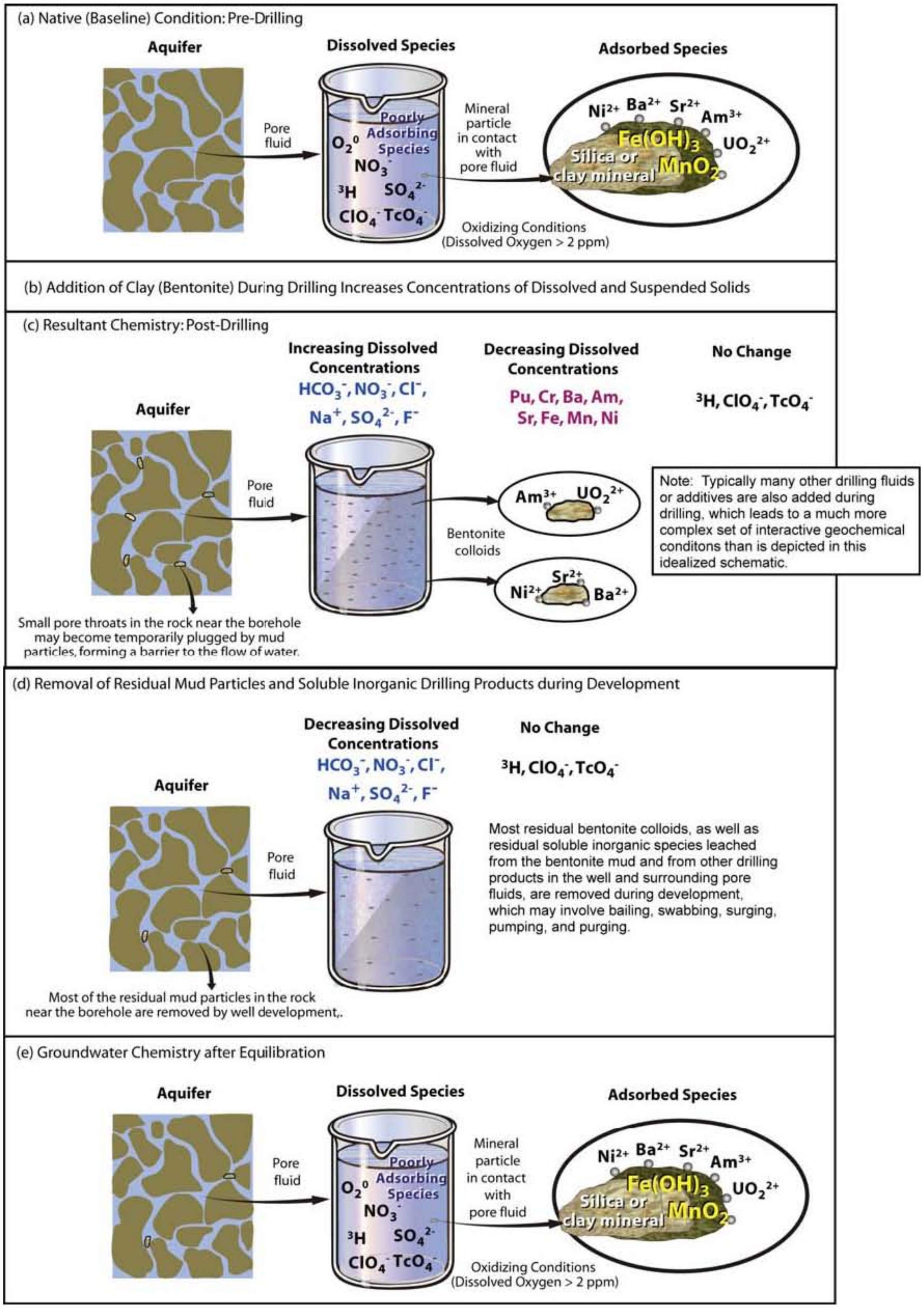


Figure 4-5 Appllication of tests for evaluating the presence of categories of effects from residual drilling fluids



Small pore throats in the rock near the borehole may become temporarily plugged by mud particles, forming a barrier to the flow of water.

Note: Typically many other drilling fluids or additives are also added during drilling, which leads to a much more complex set of interactive geochemical conditons than is depicted in this idealized schematic.

Most residual bentonite colloids, as well as residual soluble inorganic species leached from the bentonite mud and from other drilling products in the well and surrounding pore fluids, are removed during development, which may involve bailing, swabbing, surging, pumping, and purging.

Most of the residual mud particles in the rock near the borehole are removed by well development,.

Figure 4-6 Conceptual model of the effects of bentonite-based drilling fluids on water quality

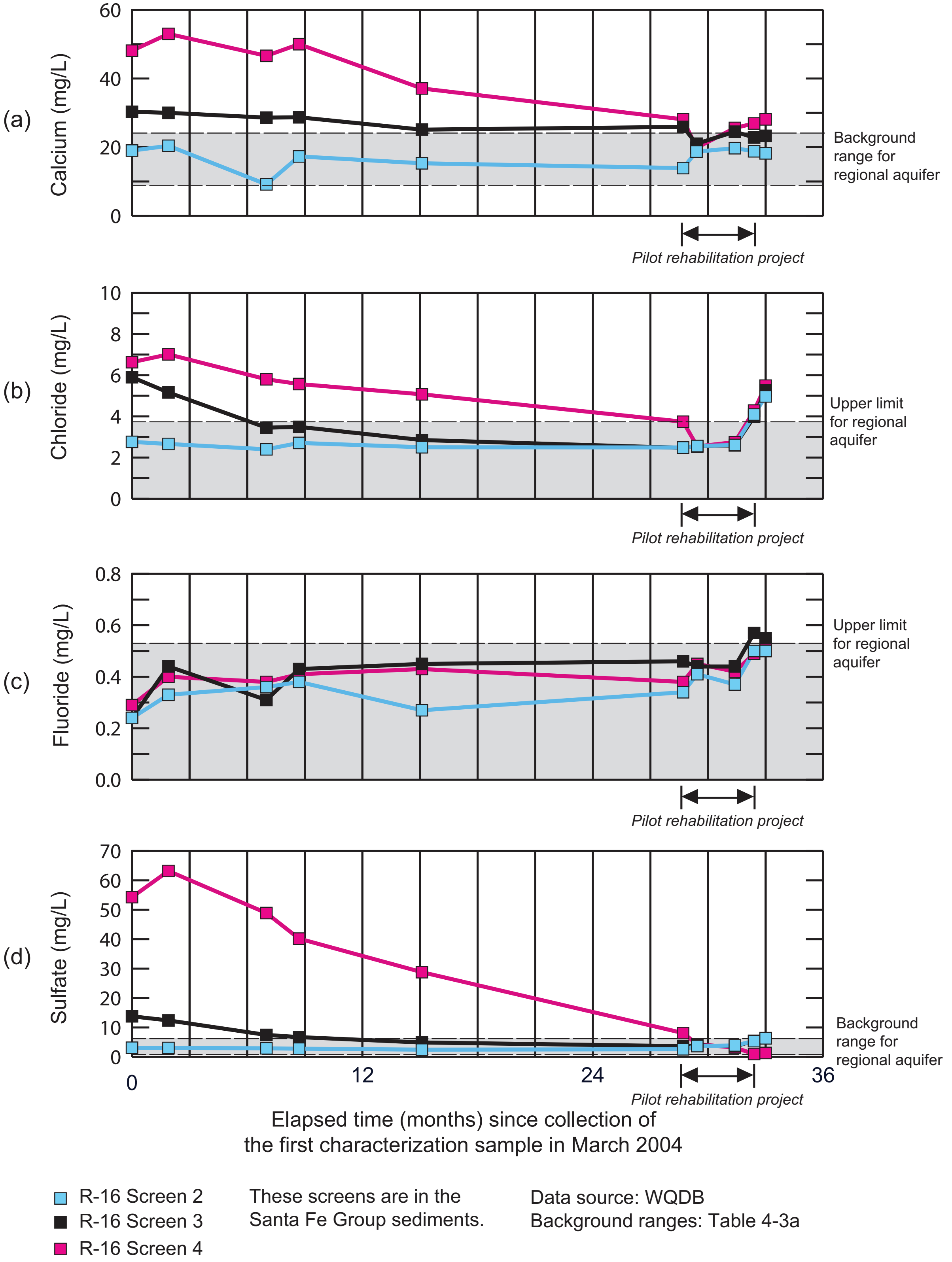
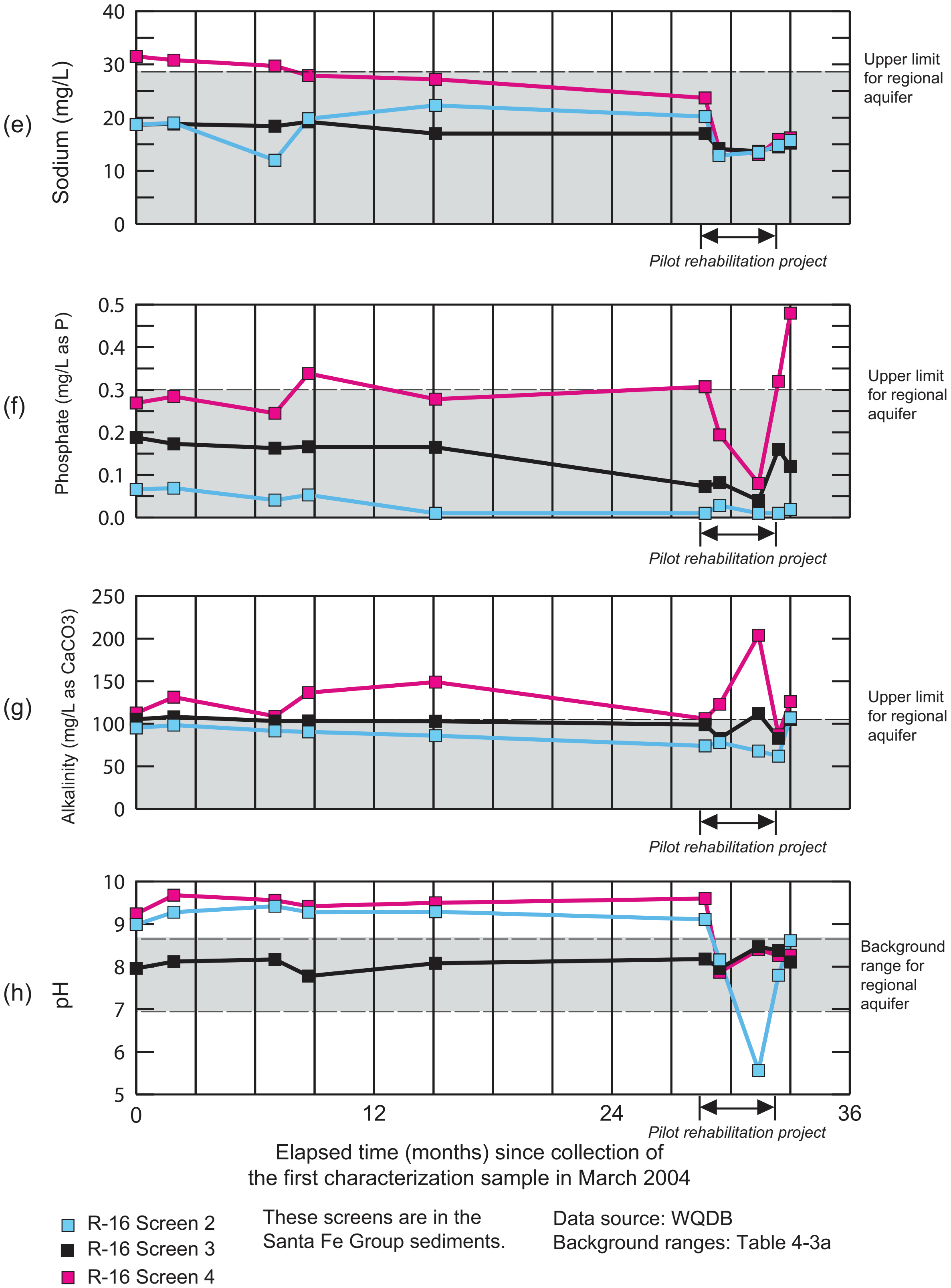


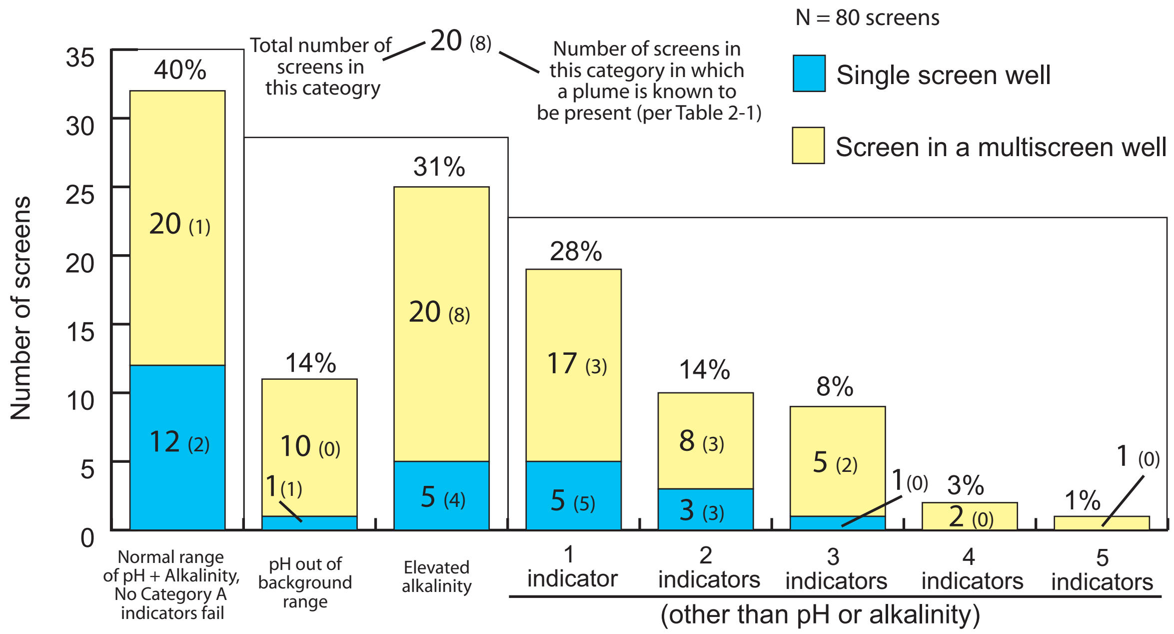
Figure 4-7 **Evolution of indicators for residual water-soluble inorganic drilling fluids in R-16: (a) calcium, (b) chloride, (c) fluoride, (d) sulfate, (e) sodium, (f) phosphate, (g) alkalinity, and (h) pH**



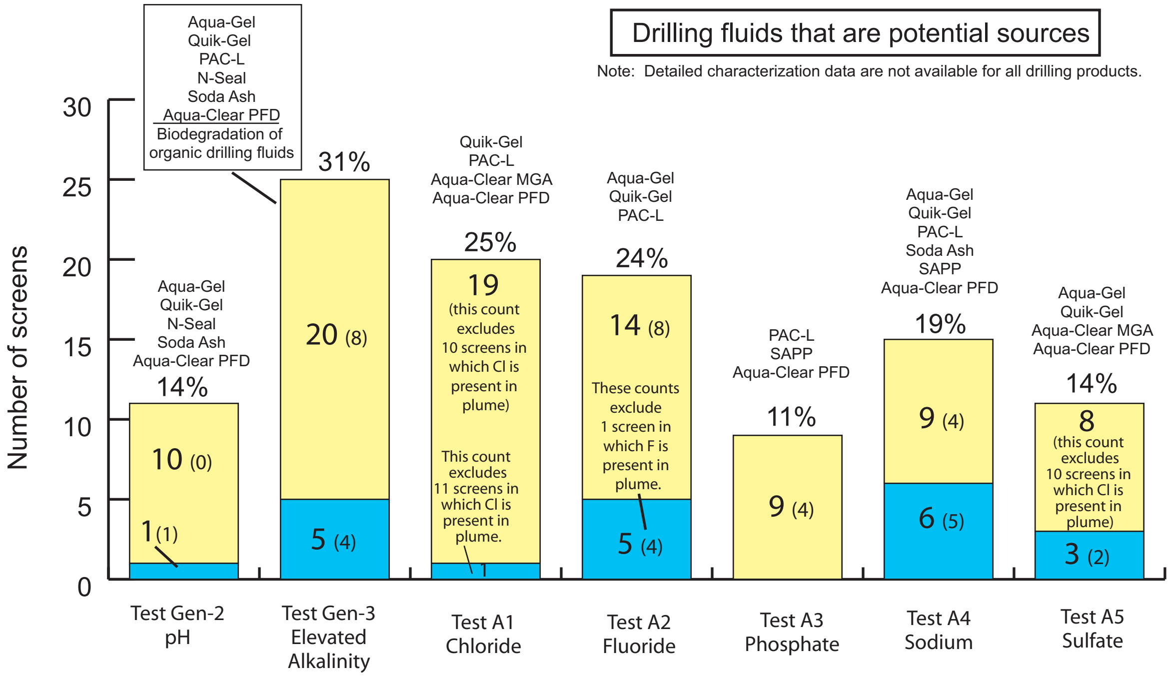
These screens are in the Santa Fe Group sediments.

Data source: WQDB
Background ranges: Table 4-3a

Figure 4-7 (continued) **Evolution of indicators for residual water-soluble inorganic drilling fluids in R-16: (a) calcium, (b) chloride, (c) fluoride, (d) sulfate, (e) sodium, (f) phosphate, (g) alkalinity, and (h) pH**



(a) Number of indicators of residual inorganic drilling fluids present in water sample



(b) Number of screens in which each indicator was present in water sample

Figure 4-8 **Presence of residual water-soluble inorganic constituents of drilling fluids in the most recent water sample from each screen**

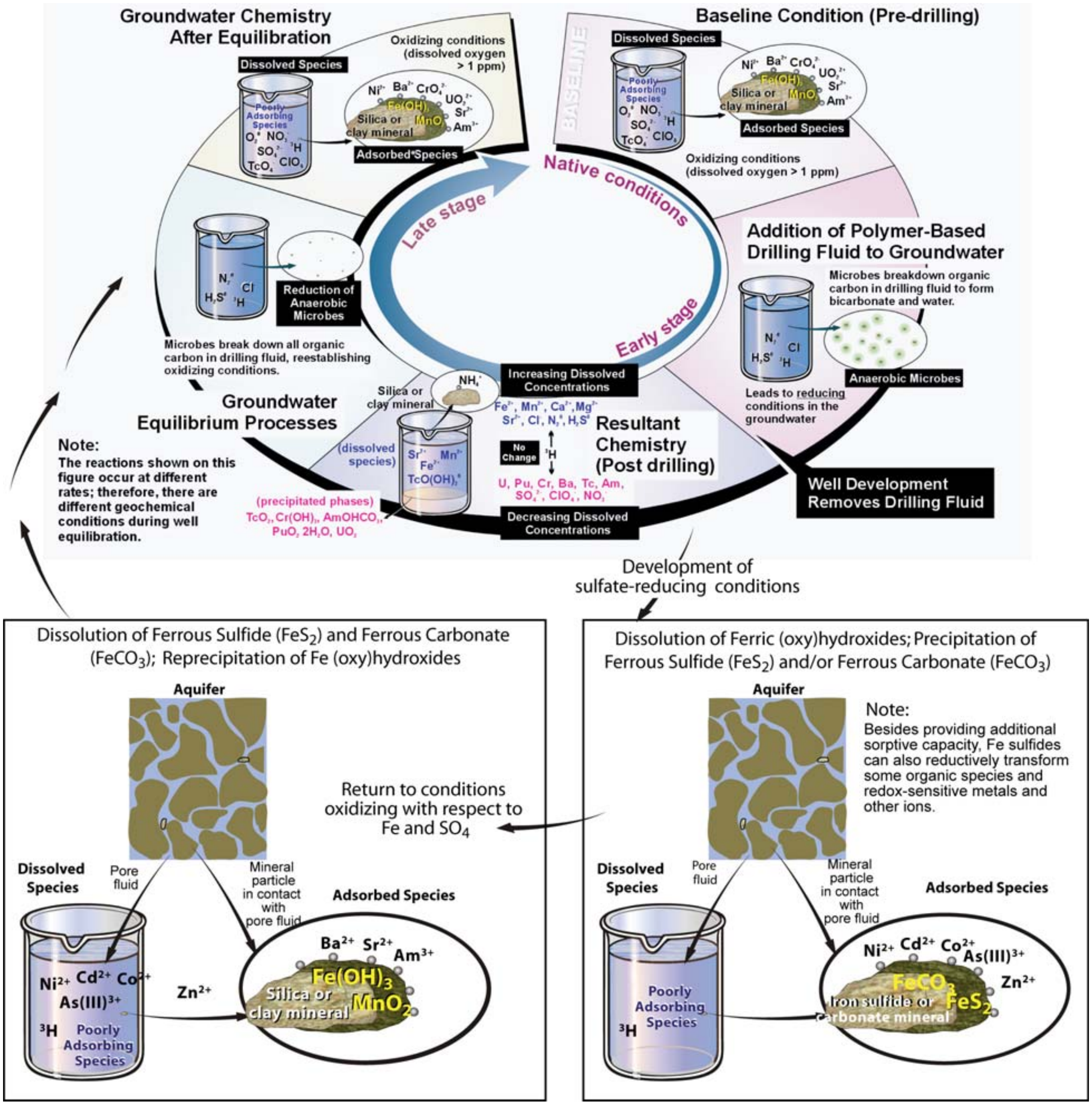
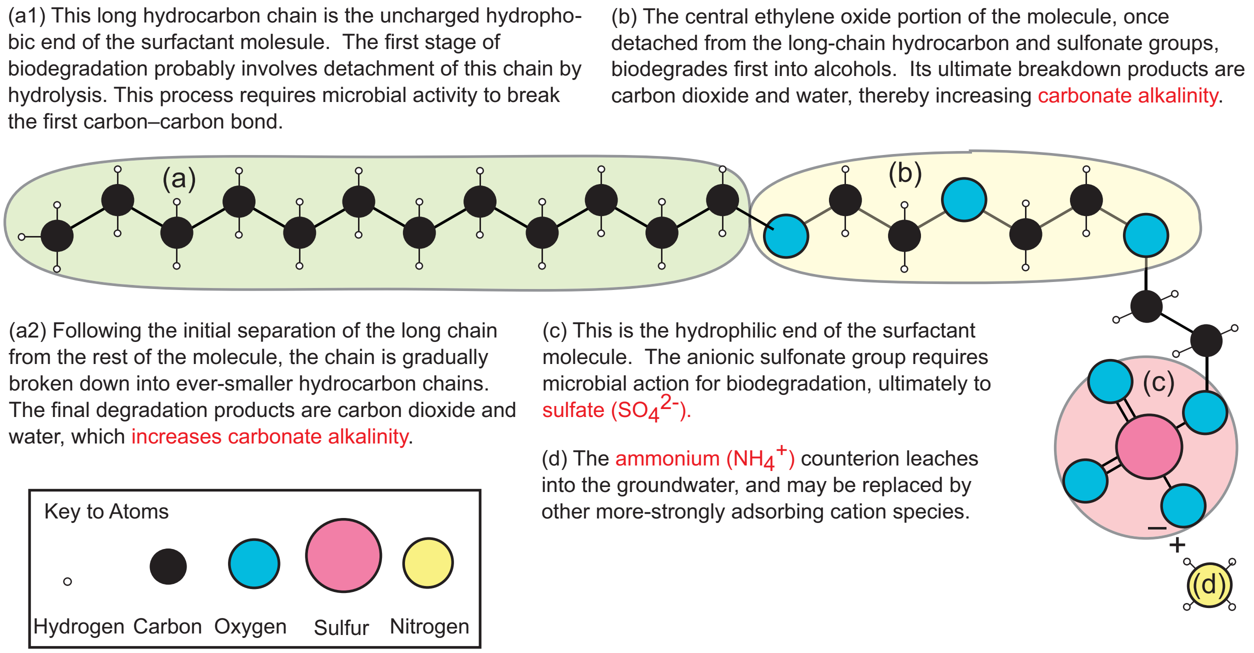


Figure 4-9 Conceptual model for the effects of polymer-based drilling fluids on water quality



(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.

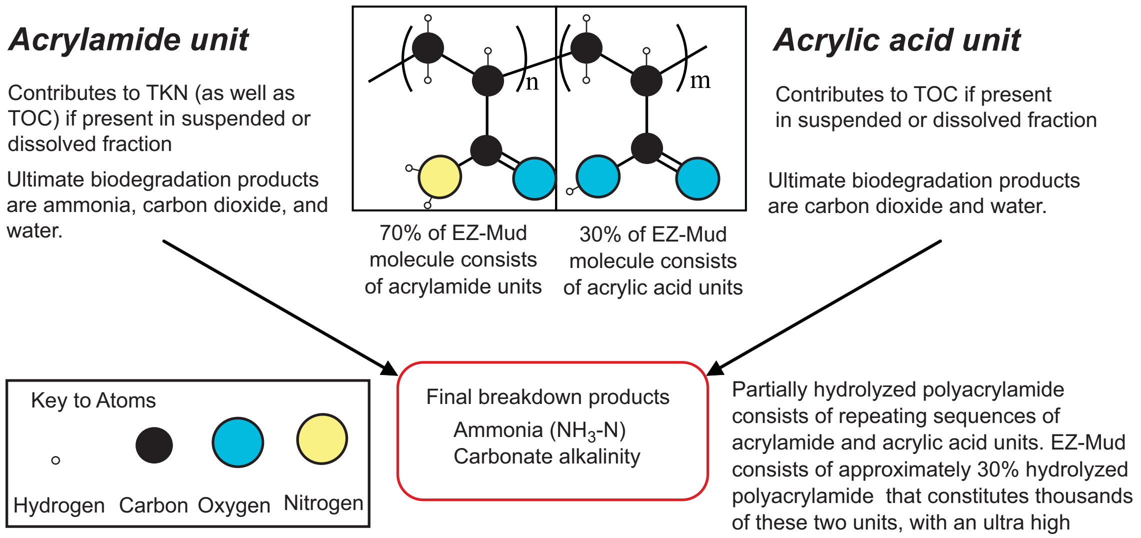
(a2) Following the initial separation of the long chain from the rest of the molecule, the chain is gradually broken down into ever-smaller hydrocarbon chains. The final degradation products are carbon dioxide and water, which increases carbonate alkalinity.

(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.

Figure 4-10 Biodegradation of an anionic surfactant (QUIK-FOAM constituent)



Acrylamide unit

Contributes to TKN (as well as TOC) if present in suspended or dissolved fraction

Ultimate biodegradation products are ammonia, carbon dioxide, and water.

70% of EZ-Mud molecule consists of acrylamide units

30% of EZ-Mud molecule consists of acrylic acid units

Acrylic acid unit

Contributes to TOC if present in suspended or dissolved fraction

Ultimate biodegradation products are carbon dioxide and water.

Final breakdown products
Ammonia (NH_3-N)
Carbonate alkalinity

Partially hydrolyzed polyacrylamide consists of repeating sequences of acrylamide and acrylic acid units. EZ-Mud consists of approximately 30% hydrolyzed polyacrylamide that constitutes thousands of these two units, with an ultra high molecular weight on the order of several million.

Figure 4-11 Biodegradation of polyacrylamide (EZ-MUD constituent)

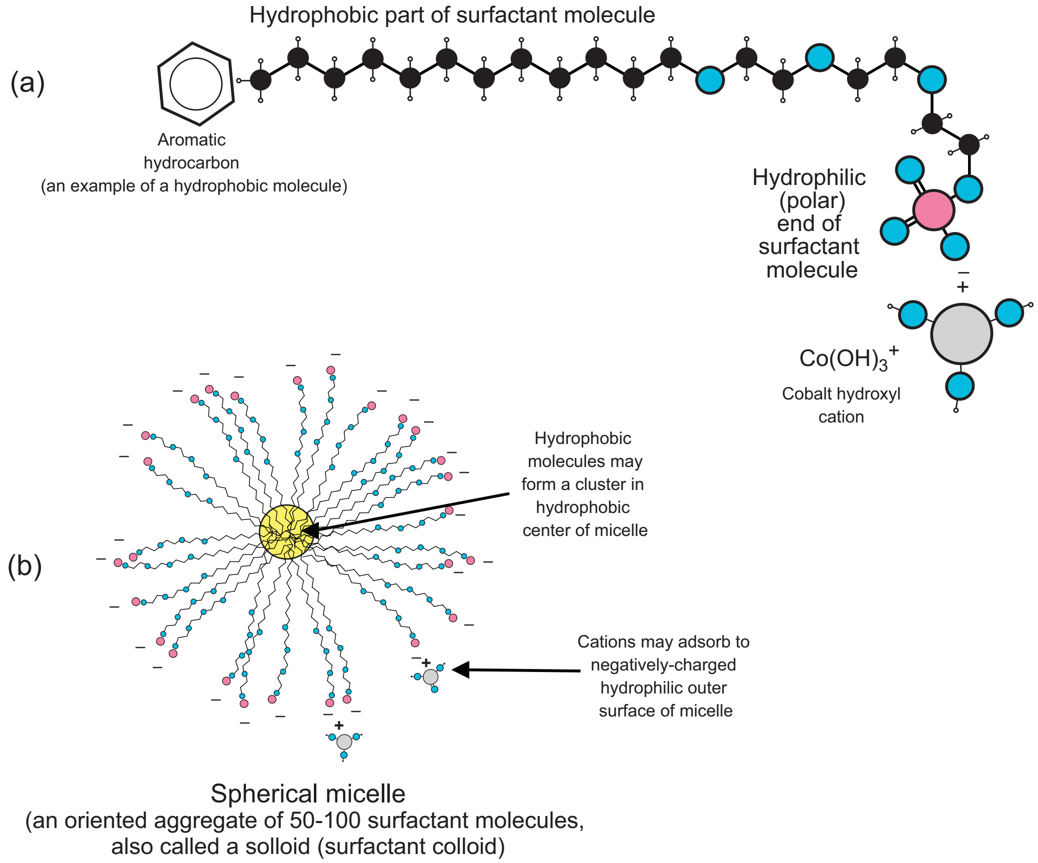


Figure 4-12 **Schematics of potential interactions between anionic surfactants and constituents in groundwater: (a) interactions with hydrophobic and hydrophilic ends of a surfactant molecule, and (b) interactions with a surfactant micelle**

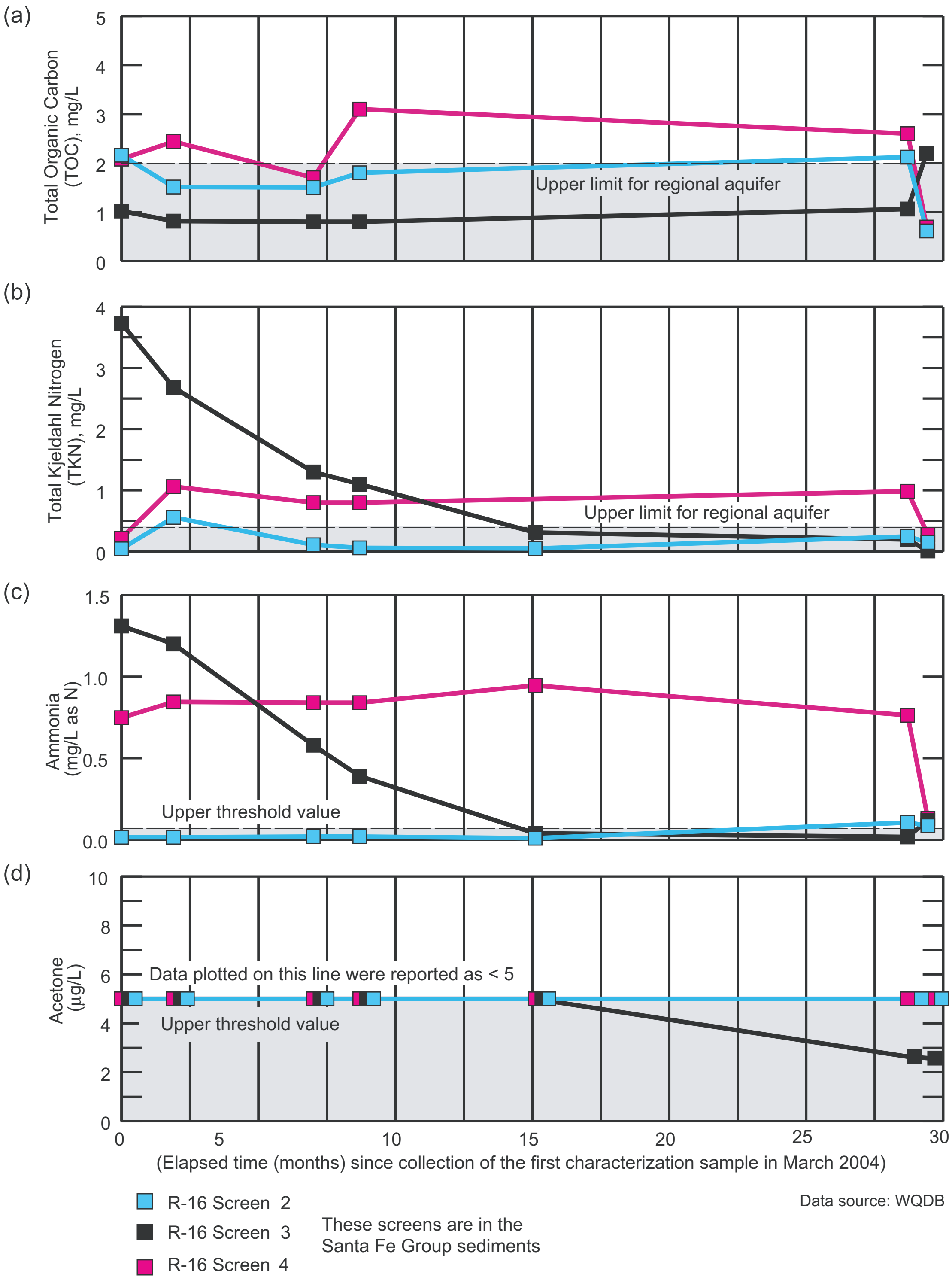
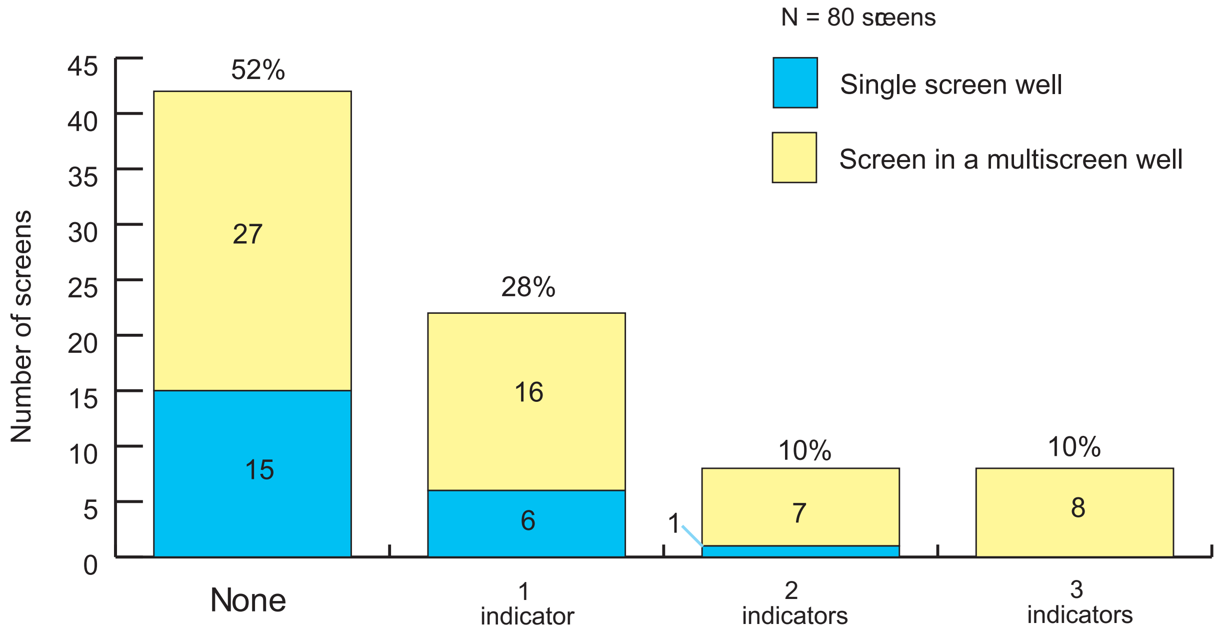
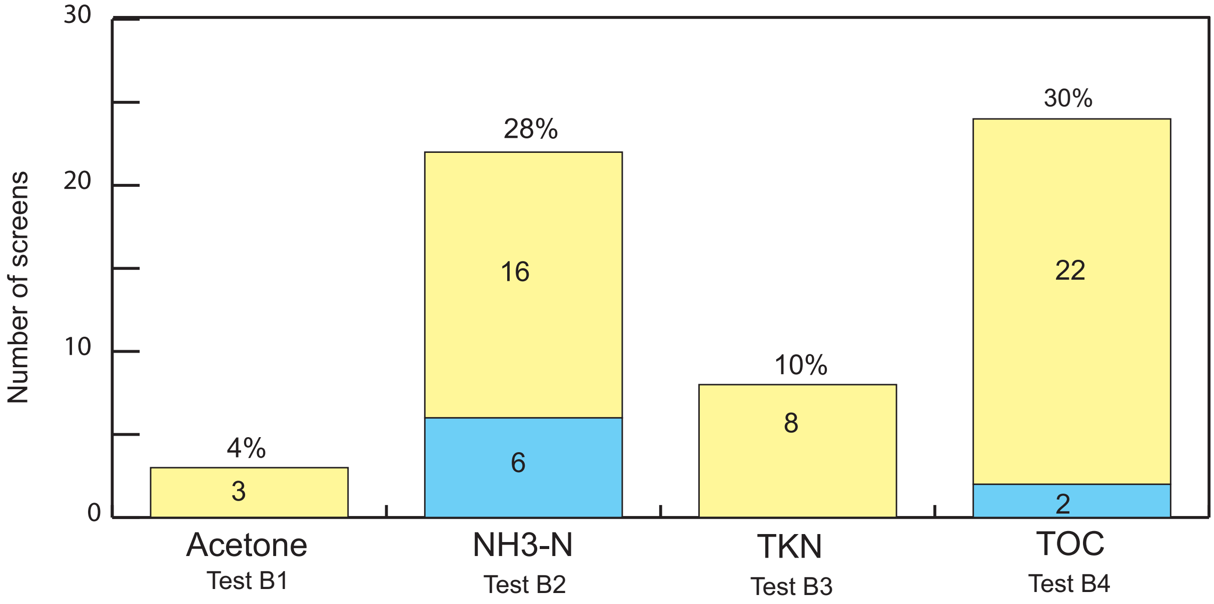


Figure 4-13 **Evolution of indicators for residual organic drilling fluids in R-16: (a) total organic carbon, (b) total Kjeldahl nitrogen, (c) ammonia, and (d) acetone**



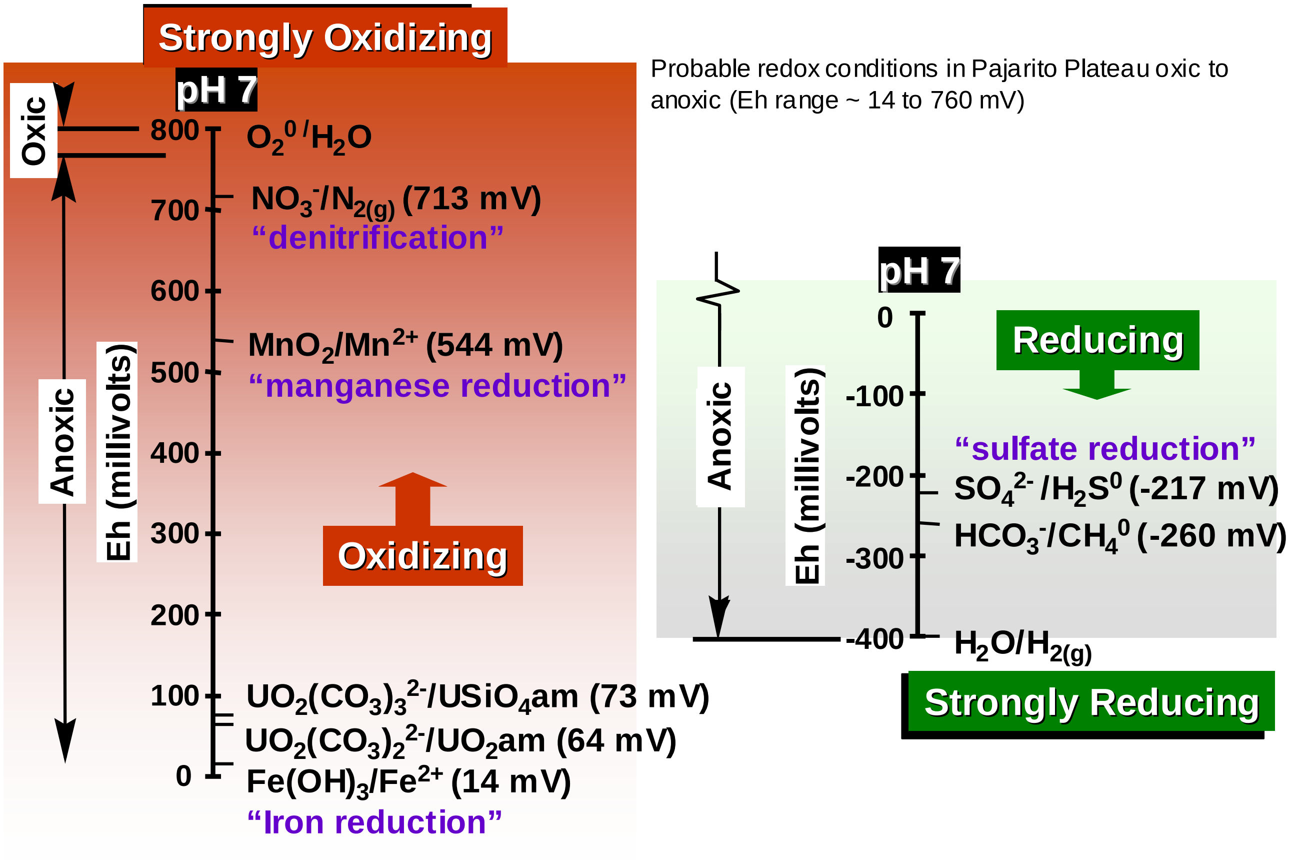
(a) Number of indicators of residual organic drilling fluids present in the most recent water sample from each screen



(b) Number of screens in which each indicator was present in water sample (for the last time in which this constituent was measured in this screen)

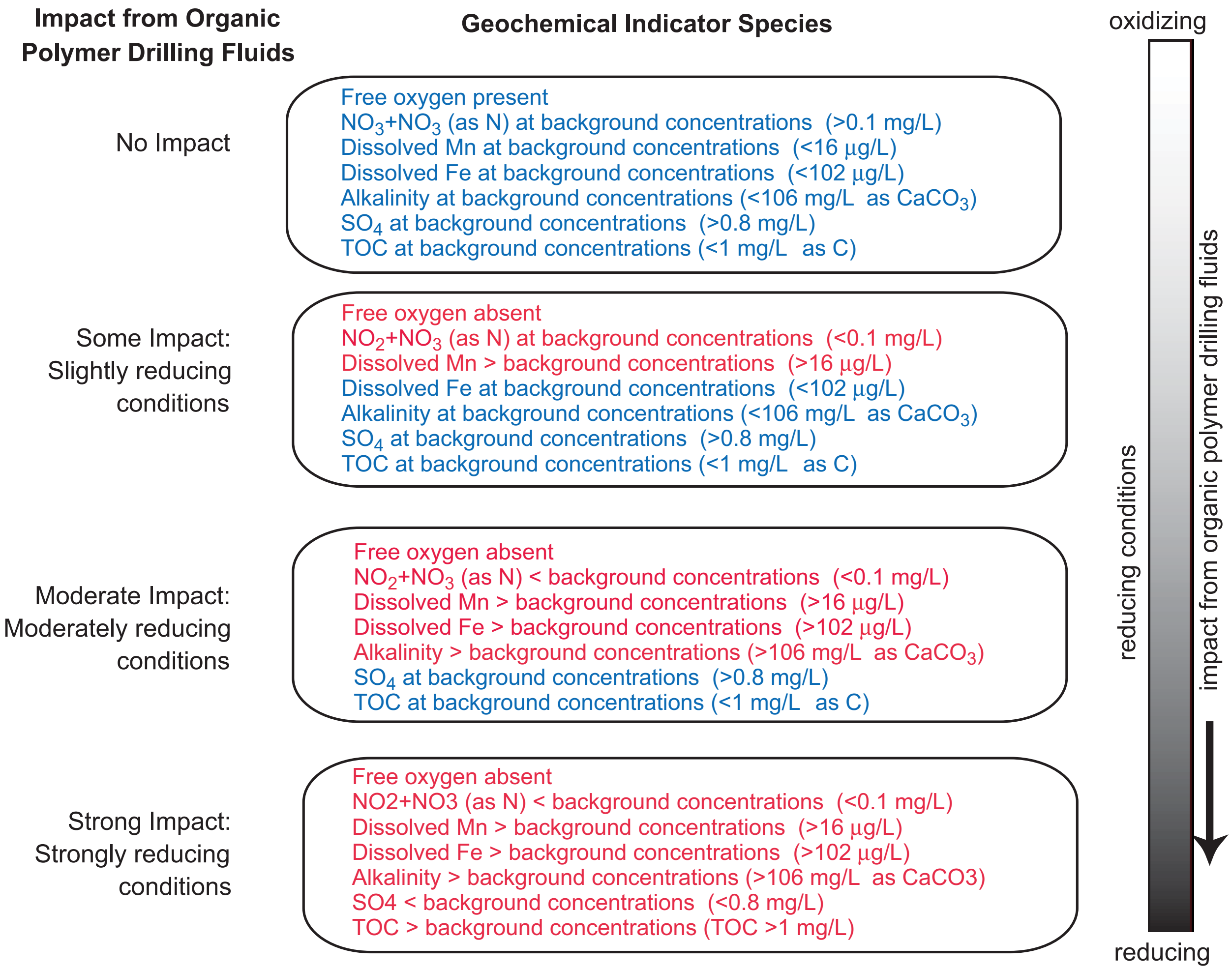
Data source: Table C-4

Figure 4-14 Indicators for the presence of residual organic drilling fluids in the most recent water sample from each screen



Probable redox conditions in Pajarito Plateau oxic to anoxic (Eh range ~ 14 to 760 mV)

Figure 4-15 Selected redox couples (at pH 7 and 25 ºC) for Pajarito Plateau and surrounding areas



Impact from Organic Polymer Drilling Fluids

Geochemical Indicator Species

No Impact

Free oxygen present
NO_3+NO_3 (as N) at background concentrations (>0.1 mg/L)
Dissolved Mn at background concentrations (<16 µg/L)
Dissolved Fe at background concentrations (<102 µg/L)
Alkalinity at background concentrations (<106 mg/L as $CaCO_3$)
SO_4 at background concentrations (>0.8 mg/L)
TOC at background concentrations (<1 mg/L as C)

Some Impact:
Slightly reducing
conditions

Free oxygen absent
NO_2+NO_3 (as N) at background concentrations (<0.1 mg/L)
Dissolved Mn > background concentrations (>16 µg/L)
Dissolved Fe at background concentrations (<102 µg/L)
Alkalinity at background concentrations (<106 mg/L as $CaCO_3$)
SO_4 at background concentrations (>0.8 mg/L)
TOC at background concentrations (<1 mg/L as C)

Moderate Impact:
Moderately reducing
conditions

Free oxygen absent
NO_2+NO_3 (as N) < background concentrations (<0.1 mg/L)
Dissolved Mn > background concentrations (>16 µg/L)
Dissolved Fe > background concentrations (>102 µg/L)
Alkalinity > background concentrations (>106 mg/L as $CaCO_3$)
SO_4 at background concentrations (>0.8 mg/L)
TOC at background concentrations (<1 mg/L as C)

Strong Impact:
Strongly reducing
conditions

Free oxygen absent
NO2+NO3 (as N) < background concentrations (<0.1 mg/L)
Dissolved Mn > background concentrations (>16 µg/L)
Dissolved Fe > background concentrations (>102 µg/L)
Alkalinity > background concentrations (>106 mg/L as CaCO3)
SO4 < background concentrations (<0.8 mg/L)
TOC > background concentrations (TOC >1 mg/L)

Figure 4-16 Redox criteria for assessing screens

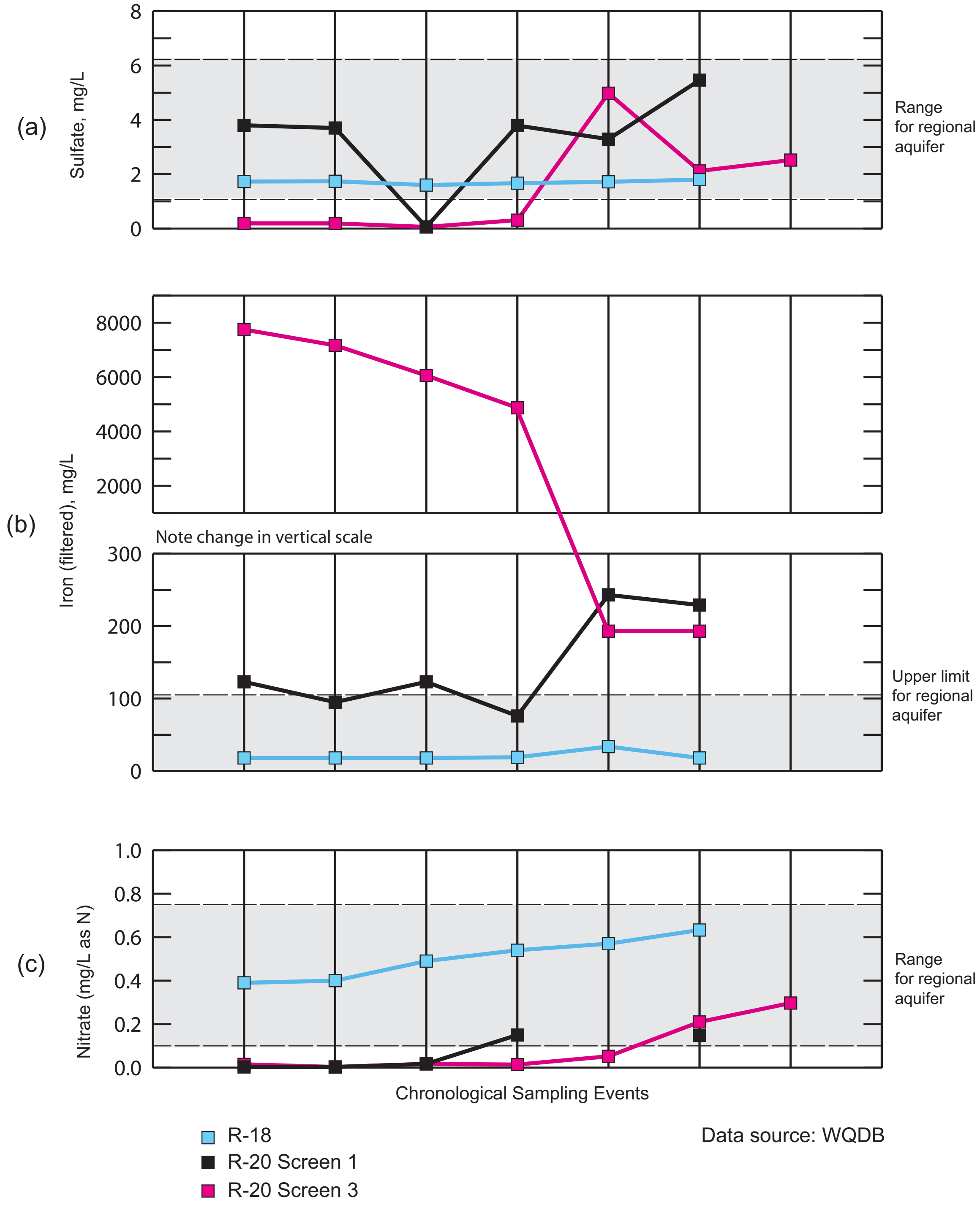
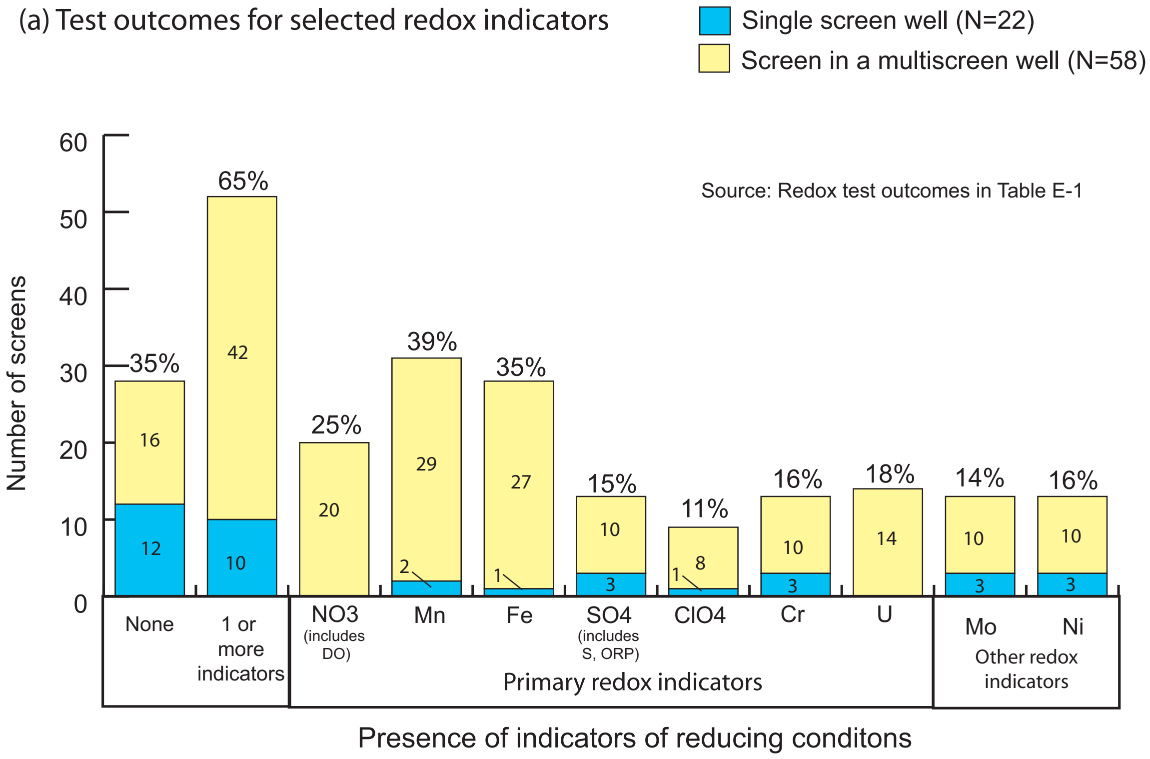


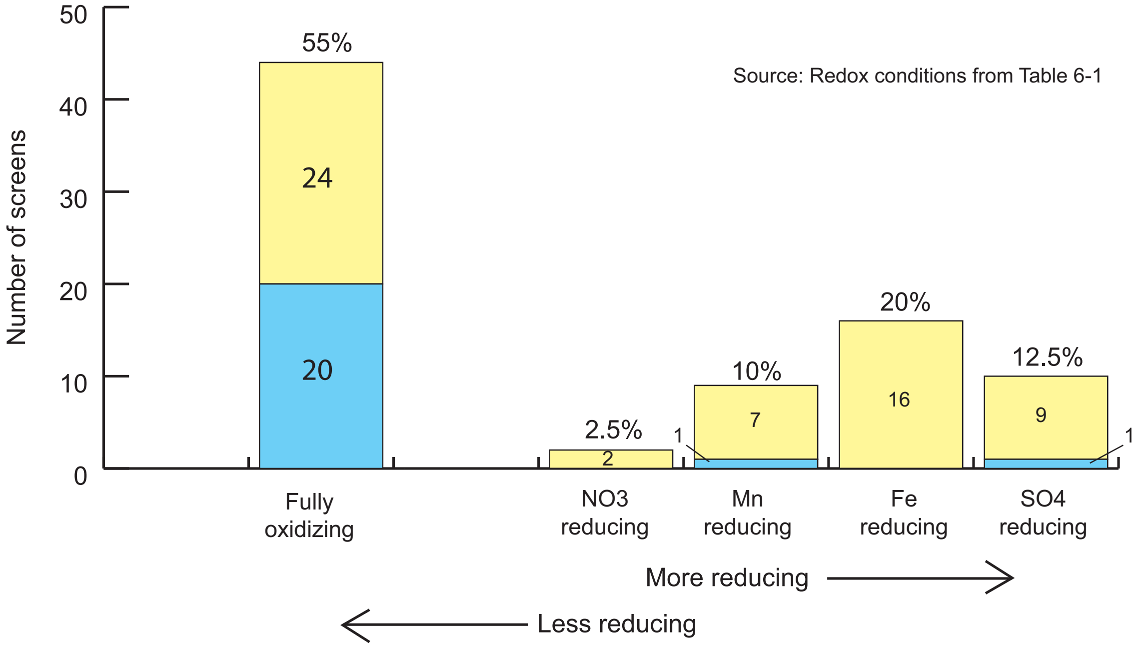
Figure 4-17 **Evolution of redox indicators in wells R-18 and R-20**

(a) Test outcomes for selected redox indicators



Source: Redox test outcomes in Table E-1

(b) Most probable redox state in screen interval



Source: Redox conditions from Table 6-1

Figure 4-18 **Effects of residual drilling fluids on redox conditions in groundwater**

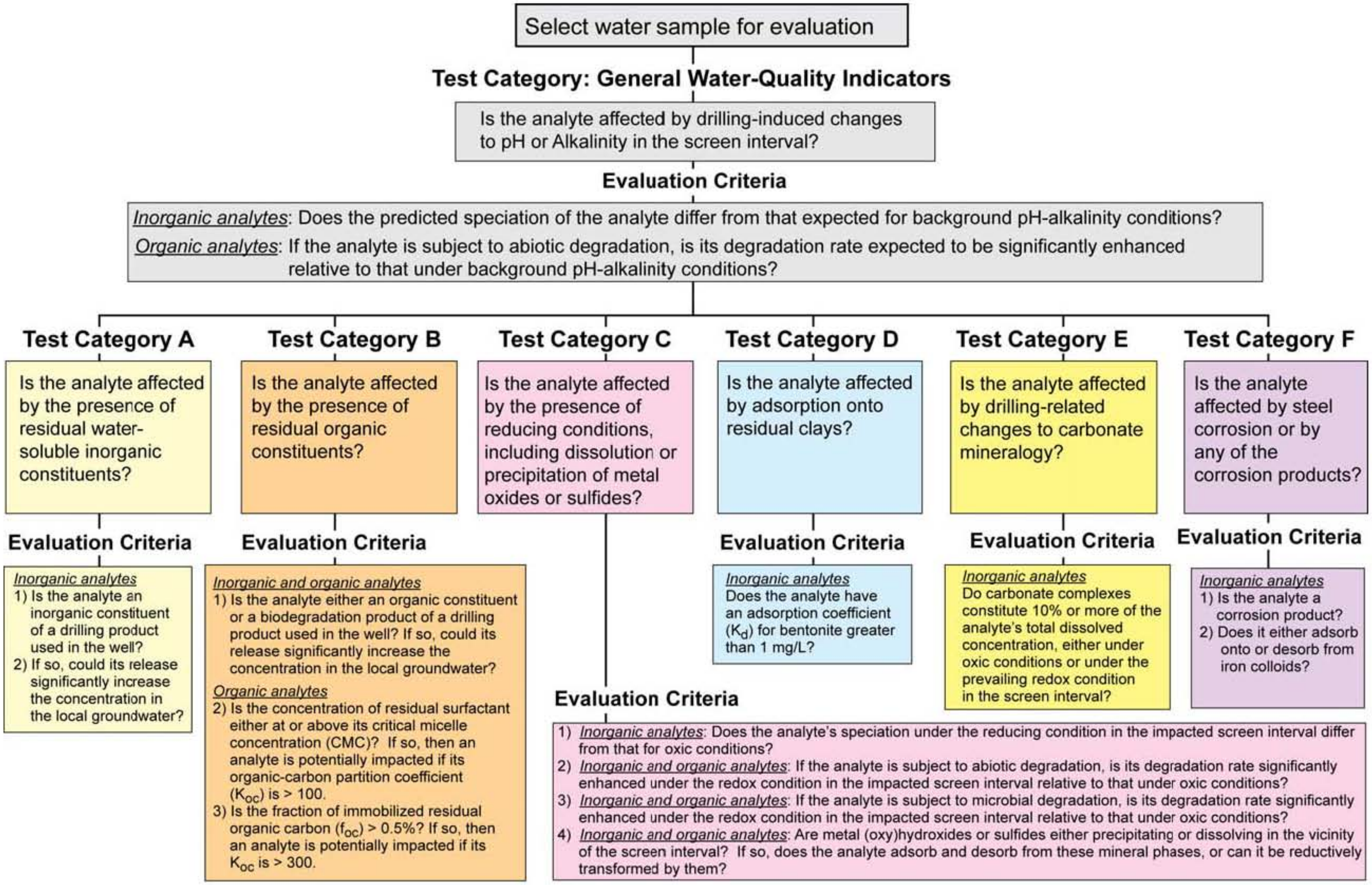


Figure 4-19 Application of tests for identifying analytes potentially impacted by the presence of residual drilling fluid effects

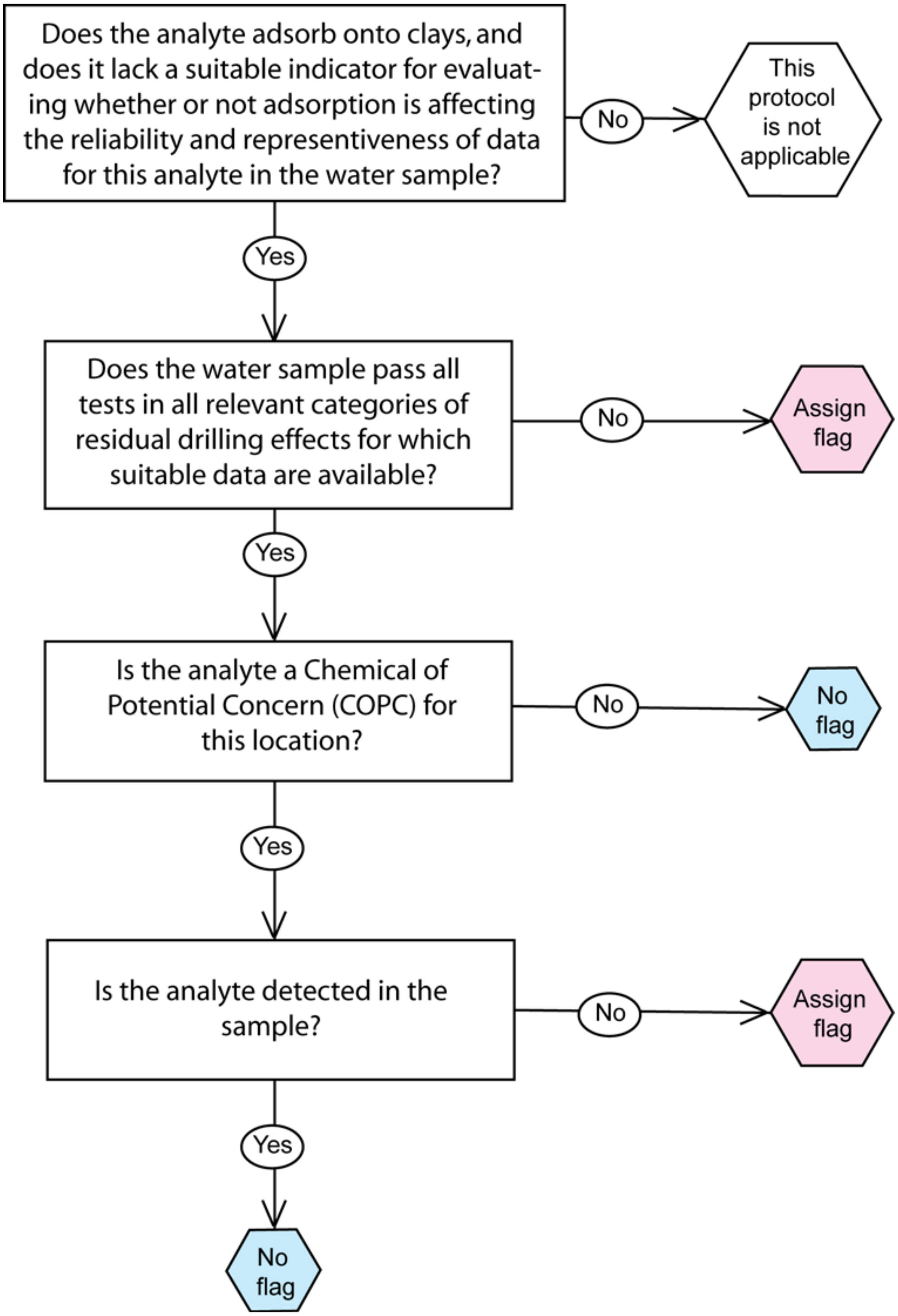
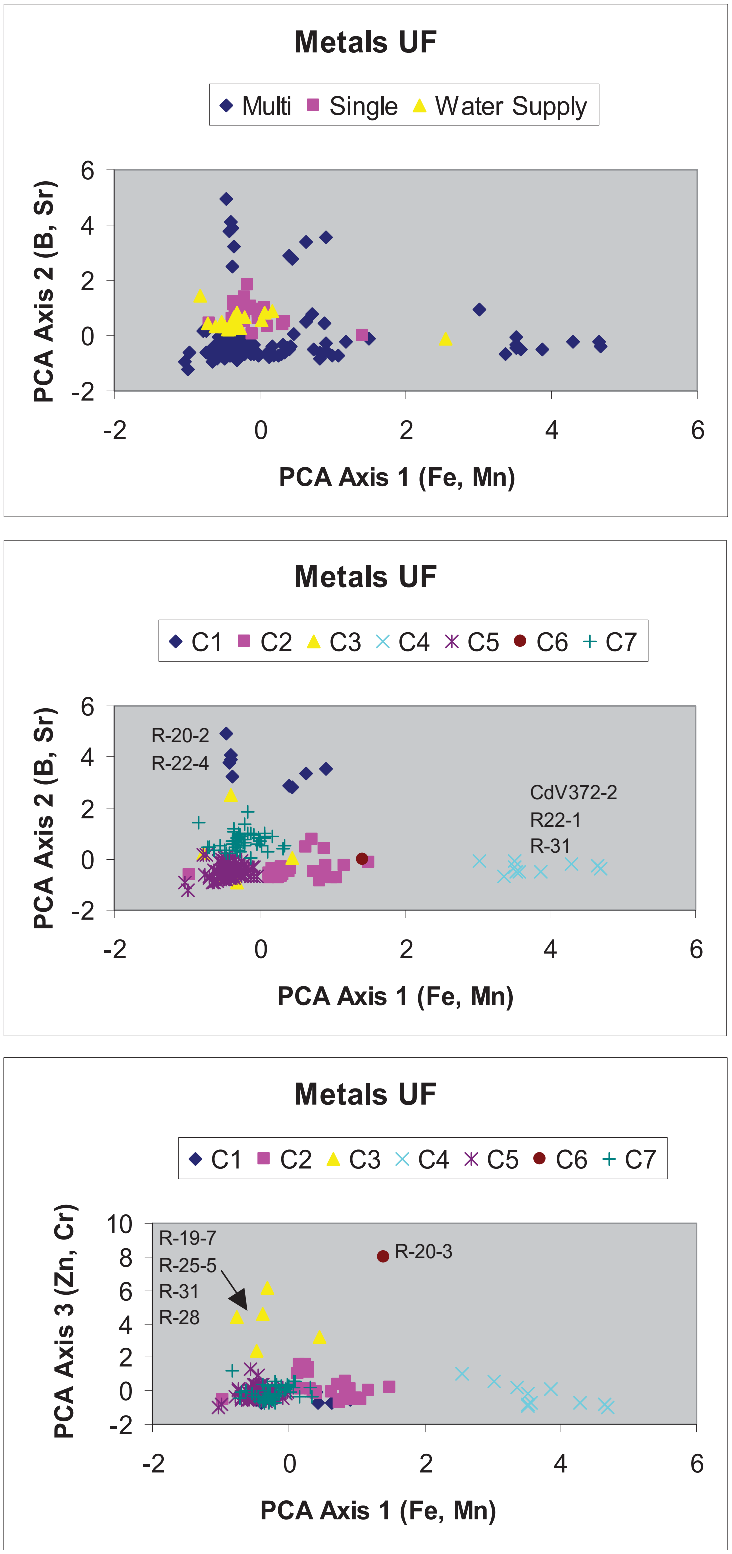


Figure 4-20 Protocol for assessing the reliability of data for strongly-absorbing analytes



Many samples from single screen-wells show compositions consistent with water supply wells. Multiscreen wells show significant differences from supply wells.

Interpretation:

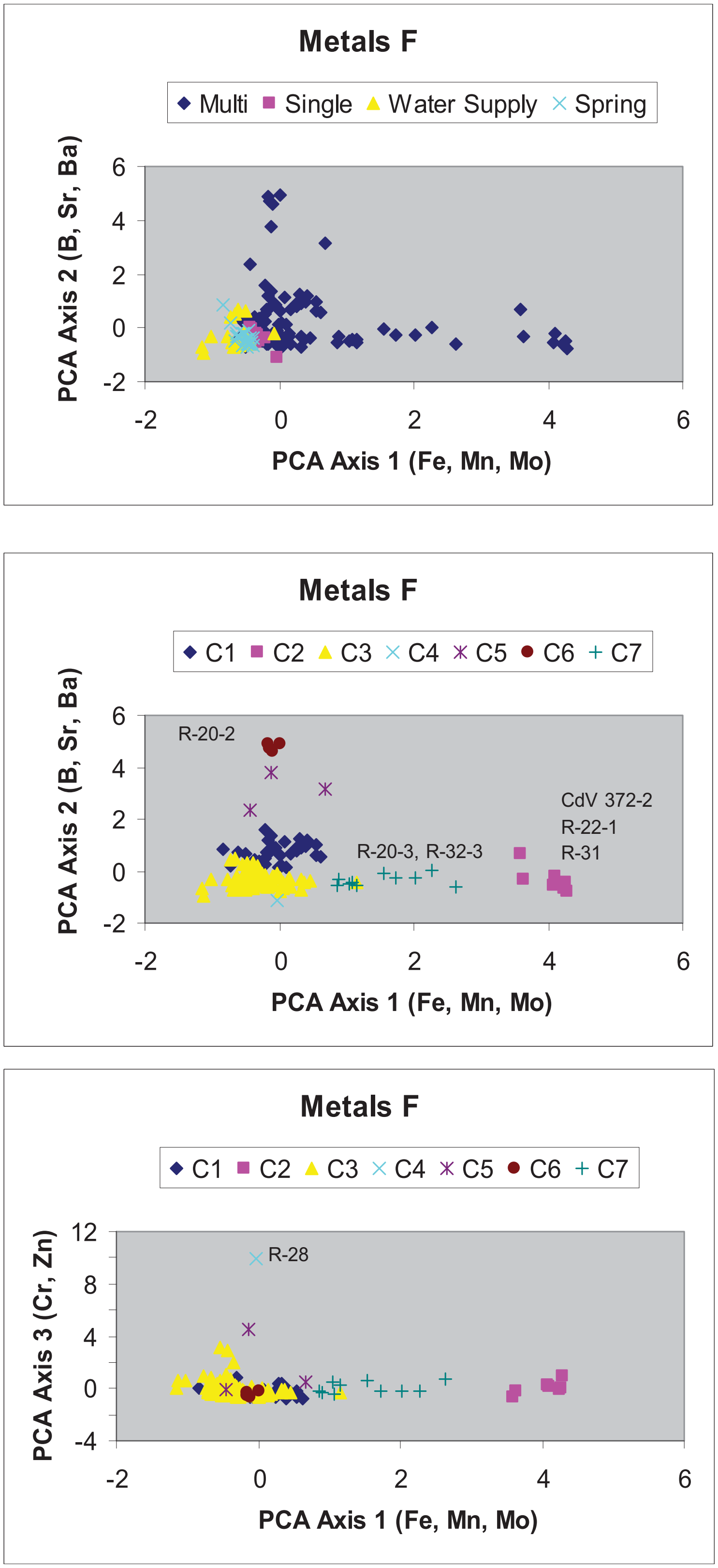
C5 = Consistent with White Rock Canyon springs or existing water-supply wells

C7 = Possible to slight impacts

C2, C3 = Moderate impacts

C1, C4, C6 = Significant impacts

Figure 5-1 Principal component analysis of metals based on non-filtered water samples



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

Interpretation:

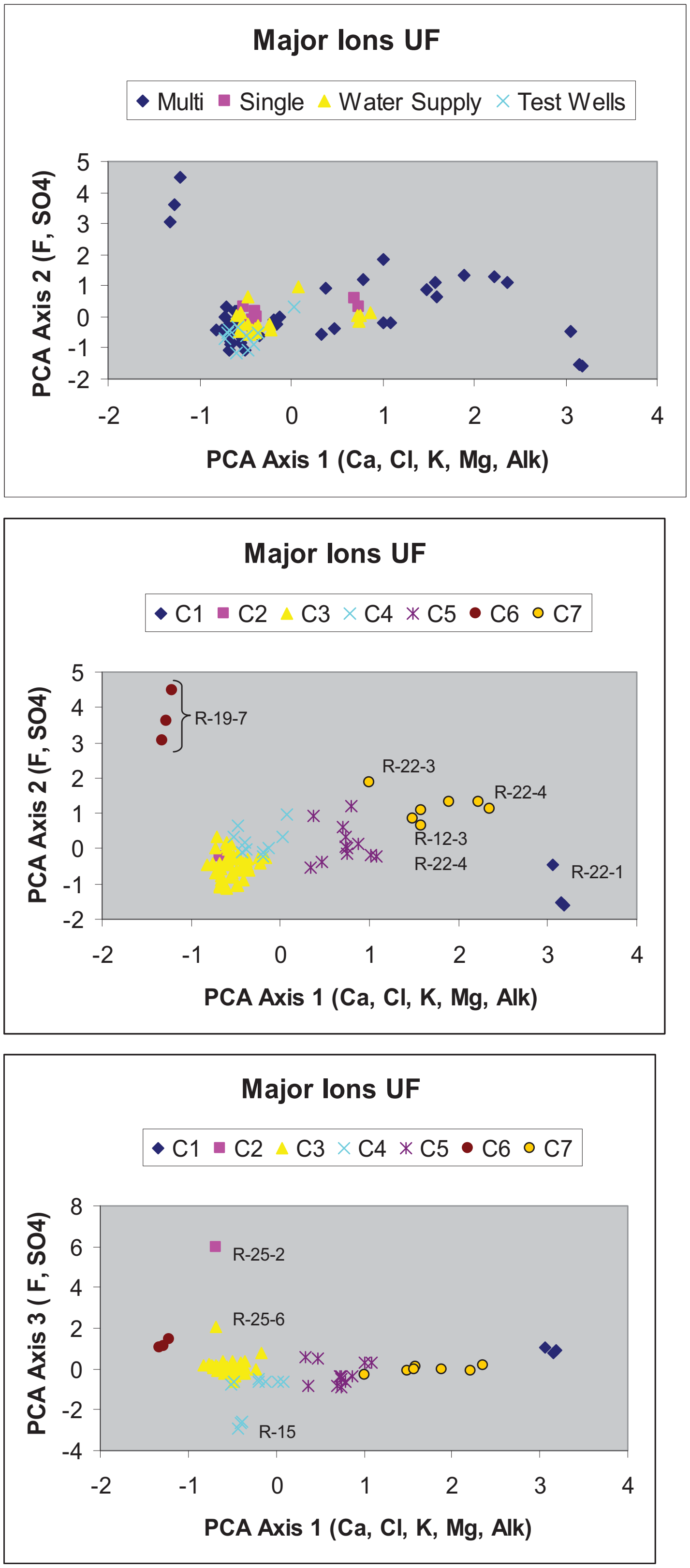
C3 = Consistent with White Rock Canyon springs or existing water-supply wells

C1 = Possible to slight impacts

C5, C7 = Moderate impacts

C2, C4, C6 = Significant impacts

Figure 5-2 **Principal component analysis of metals based on filtered water samples**



The chemistries of test wells are consistent with those of water supply wells. Most single-screen wells plot within chemistries represented by test and water supply wells.

Interpretation:

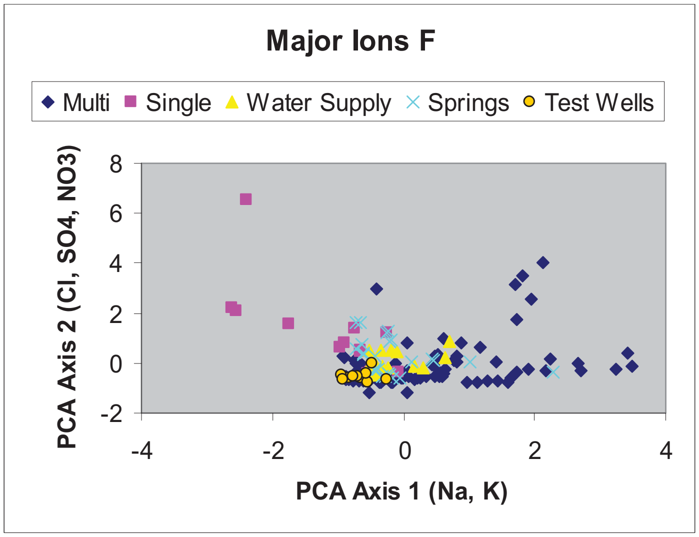
C3 = Consistent with White Rock Canyon springs or existing wells

C4 = Possible or slight impacts

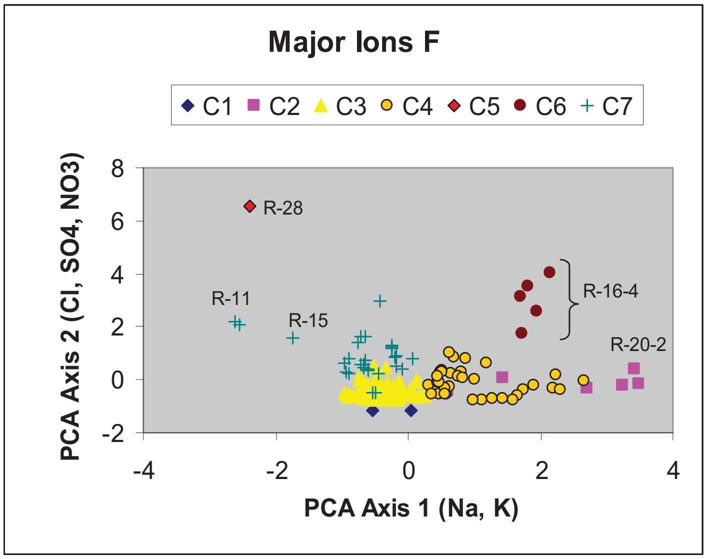
C5, C7 = Moderate impacts

C1, C2, C6 = Significant impacts

Figure 5-3 Principal component analysis of major ions based on non-filtered water samples



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.



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.

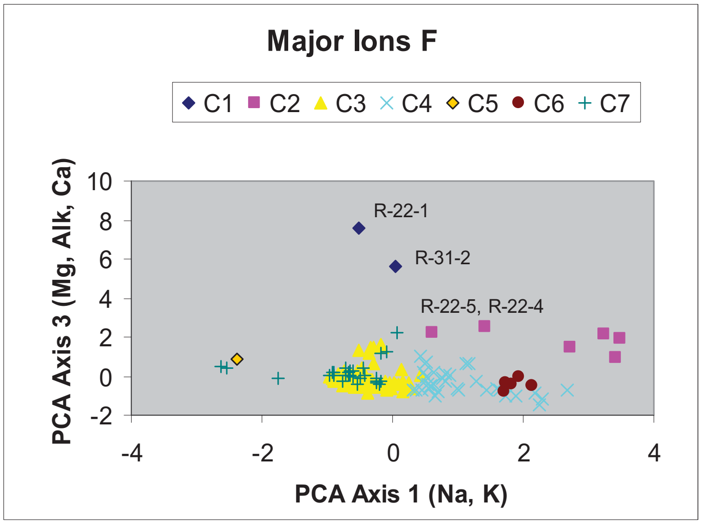


Figure 5-4 **Principal component analysis of major ions based on filtered water samples**

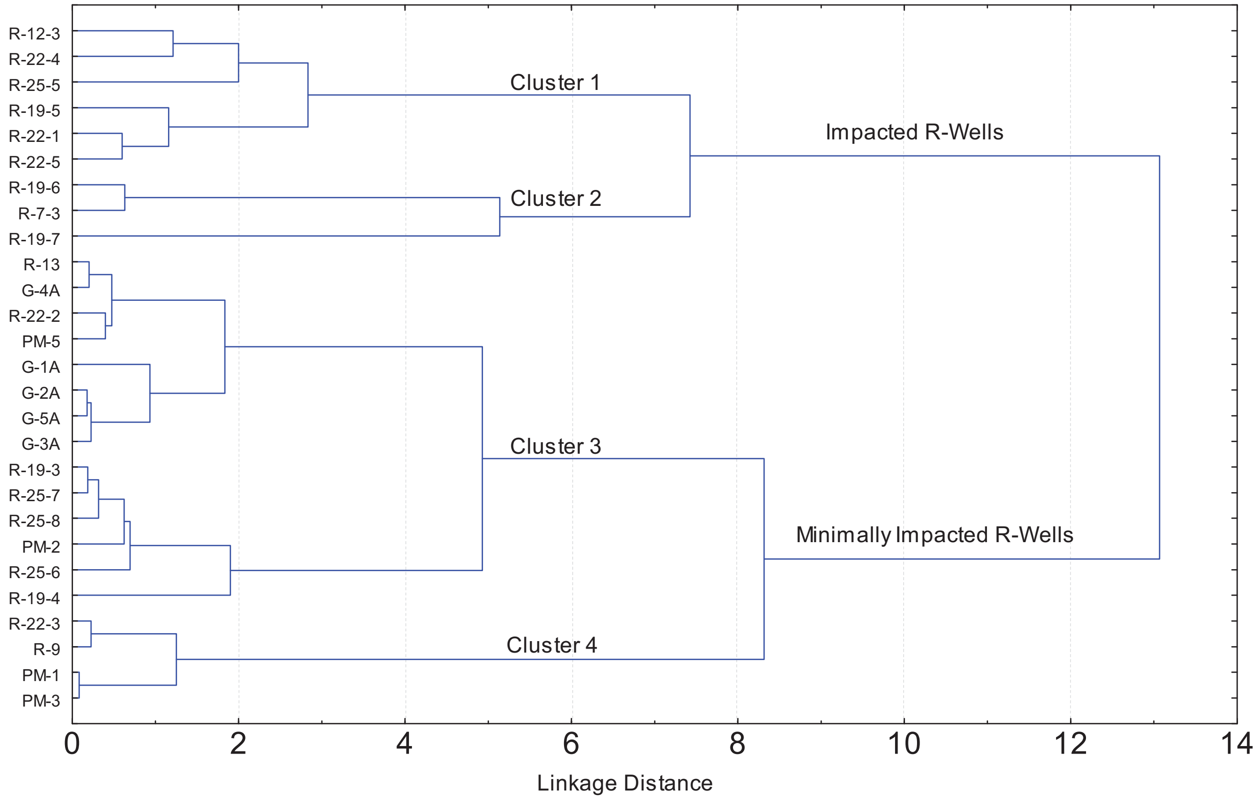


Figure 5-5 **Hierarchical cluster analysis tree diagram for non-filtered metals and major ions (merged)**

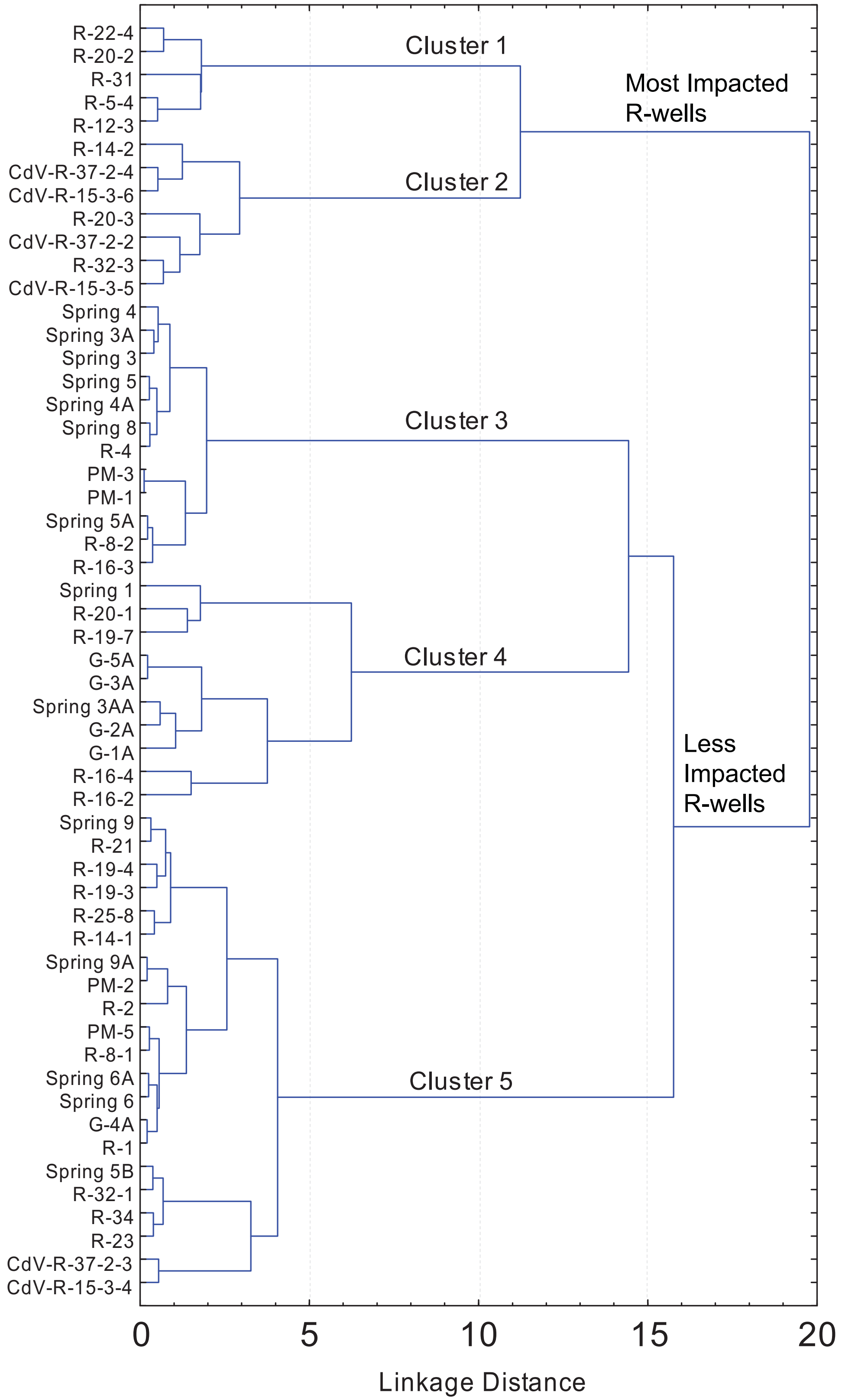
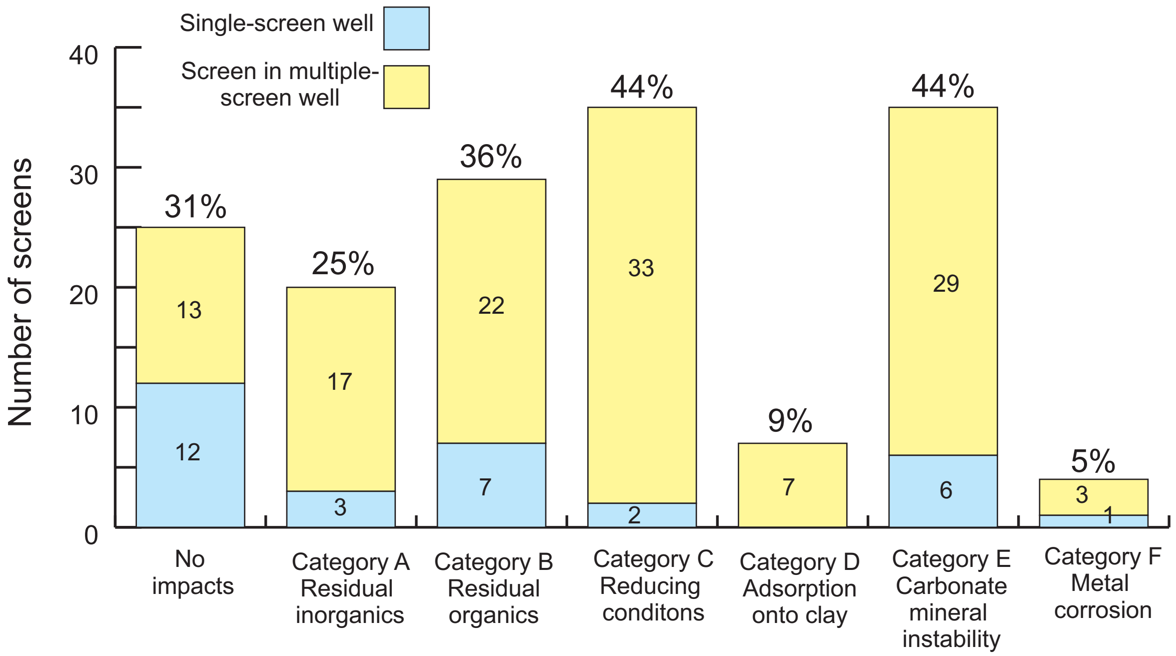
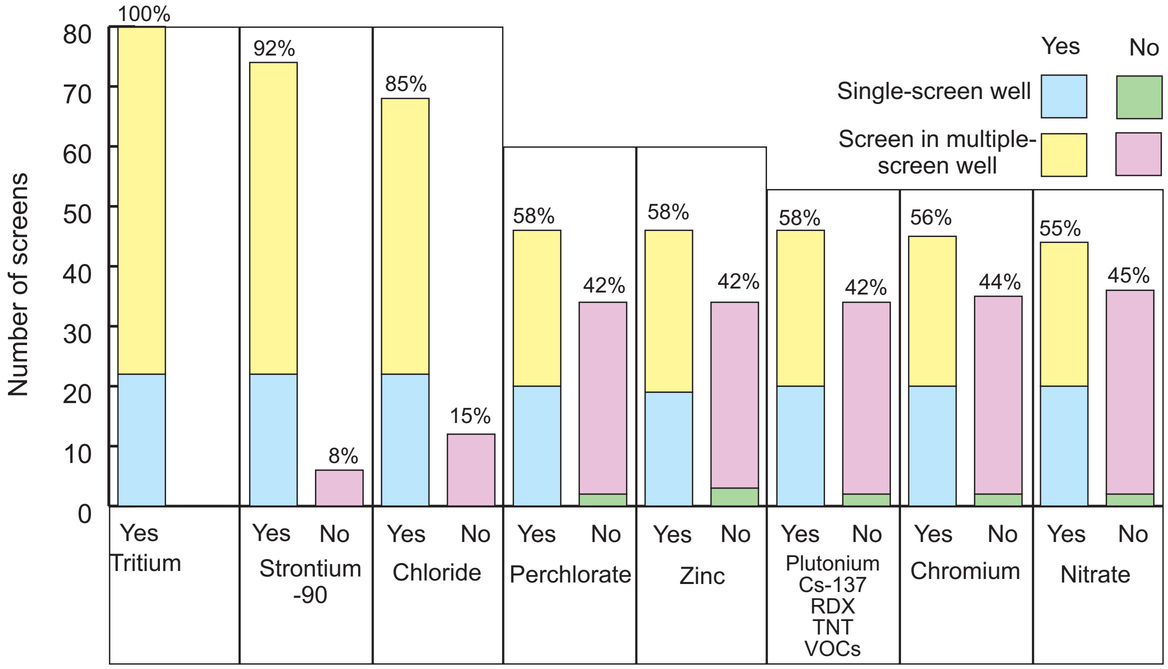


Figure 5-6 **Hierarchical cluster analysis tree diagram for filtered metals and major ions (merged)**

(a) Frequency of detections of drilling impacts by applying test criteria to water samples



(b) Assessment of data reliability based on outcomes of test criteria



Can water sample provide representative and reliable data for these chemicals?

Figure 6-1 Impacts of residual drilling products on water quality

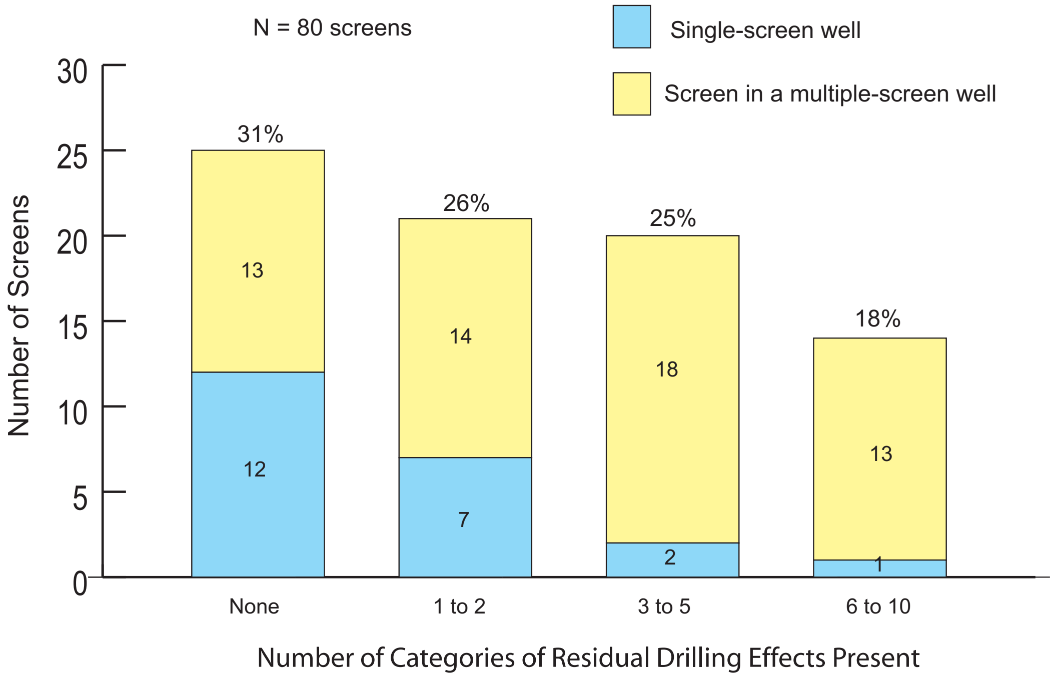


Figure 6-2 **Number of categories of residual drilling effects present in the most recent sample (as of December 31, 2006)**

Table 2-1
Indicators That May Not Be Applicable to a Water Sample Due to the Known Presence of a Contaminant Plume in the Screen Interval

Screen ID[a]	Well	Port Depth (ft)	Scr #	Watershed	^{3}H >1 pCi/L[a]	Local Plume	^{3}H >30 pCi/L[b]	Cl	ClO_4	Cr	NO_3	SO_4	U
1	CdV-16-1(i)	624	1	Caňon de Valle	Yes	Present	Yes	■[c]	■	—[d]	—	■	—
2	CdV-16-2(i)r	850	1	Caňon de Valle	Yes	Present	—	■	■	—	—	?[e]	—
3	CdV-R-15-3	1254	4	Caňon de Valle	—	None[f]	—	—	—	—	—	—	—
4	CdV-R-15-3	1350	5	Caňon de Valle	—	None	—	—	—	—	—	—	—
5	CdV-R-15-3	1640	6	Caňon de Valle	—	None	—	—	—	—	—	—	—
6	CdV-R-37-2	1200	2	Caňon de Valle	—	None	—	—	—	—	—	—	—
7	CdV-R-37-2	1359	3	Caňon de Valle	—	None	—	—	—	—	—	—	—
8	CdV-R-37-2	1551	4	Caňon de Valle	—	None	—	—	—	—	—	—	—
9	MCOBT-4.4	485	1	Mortandad	Yes	Present	Yes	■	■	■	—	■	—
10	R-1	1031	1	Mortandad	—	None	—	—	—	—	—	—	—
11	R-2	918	1	Pueblo	—	None	—	—	—	—	—	—	—
12	R-3i[g]	215	1	Pueblo	Yes	Present	—	■	—	—	■	■	■
13	R-4	793	1	Pueblo	Yes	Present	Yes	■	■	—	■	—	—
14	R-5	384	2	Pueblo	—	Present	—	■	■	■	■	■	■
15	R-5	719	3	Pueblo	—	Present	—	■	■	■	■	■	—
16	R-5	861	4	Pueblo	—	None	—	—	—	—	—	—	—
17	R-6	1205	1	Los Alamos	—	None	—	—	—	—	—	—	—
18	R-6i	602	1	Los Alamos	Yes	Present	Yes	■	■	—	■	■	—
19	R-7	915	3	Los Alamos	—	None	—	—	—	—	—	—	—
20	R-8	711	1	Los Alamos	—	None	—	—	—	—	—	—	—
21	R-8	825	2	Los Alamos	—	None	—	—	—	—	—	—	—
22	R-9	684	1	Los Alamos	Yes	Present	—	■	■	—	—	—	■
23	R-9i	199	1	Los Alamos	Yes	Present	Yes	■	—	—	—	■	—
24	R-9i	279	2	Los Alamos	Yes	Present	Yes	■	—	—	—	■	—
25	R-10	874	1	Sandia	—	None	—	—	—	—	—	—	—
26	R-10	1042	2	Sandia	—	None	—	—	—	—	—	—	—
27	R-10a	690	1	Sandia	—	Present	—	■	■	—	■	?	■
28	R-11	855	1	Sandia	Yes	Present	—	■	■	■	■	—	—
29	R-12	468	1	Sandia	Yes	Present	Yes	■	■	—	■	■	?
30	R-12	507	2	Sandia	Yes	Present	Yes	■	■	—	■	■	—
31	R-12	811	3	Sandia	Yes	Present	Yes	■	■	—	■	■	—
32	R-13	958	1	Mortandad	—	None	—	—	—	—	—	—	—
33	R-14	1204	1	Mortandad	—	None	—	—	—	—	—	—	—
34	R-14	1288	2	Mortandad	—	None	—	—	—	—	—	—	—

Table 2-1 (continued)

Screen ID[a]	Well	Port Depth (ft)	Scr #	Watershed	^{3}H >1 pCi/L[a]	Local Plume	^{3}H >30 pCi/L[b]	Cl	ClO$_4$	Cr	NO$_3$	SO$_4$	U
35	R-15	959	1	Mortandad	Yes	Present	Yes	■	■	■	■	■	—
36	R-16	866	2	Caňada del Buey	—	Indeter[e]	—	?	—	—	—	—	—
37	R-16	1018	3	Caňada del Buey	—	Indeter	—	?	—	—	—	—	—
38	R-16	1238	4	Caňada del Buey	—	Indeter	—	?	—	—	—	—	—
39	R-16r	600	1	Caňada del Buey	—	None	—	—	—	—	—	—	—
40	R-17	1057	1	Pajarito	—	None	—	—	—	—	—	—	—
41	R-17	1124	2	Pajarito	—	None	—	—	—	—	—	—	—
42	R-18	1358	1	Pajarito	—	None	—	—	—	—	—	—	—
43	R-19	909	2	Pajarito	—	None	—	—	—	—	—	—	—
44	R-19	1191	3	Pajarito	—	None	—	—	—	—	—	—	—
45	R-19	1413	4	Pajarito	—	None	—	—	—	—	—	—	—
46	R-19	1586	5	Pajarito	—	None	—	—	—	—	—	—	—
47	R-19	1730	6	Pajarito	—	None	—	—	—	—	—	—	—
48	R-19	1835	7	Pajarito	—	None	—	—	—	—	—	—	—
49	R-20	907	1	Pajarito	—	None	—	—	—	—	—	—	—
50	R-20	1150	2	Pajarito	—	None	—	—	—	—	—	—	—
51	R-20	1330	3	Pajarito	—	None	—	—	—	—	—	—	—
52	R-21	889	1	Caňada del Buey	—	None	—	—	—	—	—	—	—
53	R-22	907	1	Pajarito	Yes	None	—	—	—	—	—	—	—
54	R-22	963	2	Pajarito	—	None	—	—	—	—	—	—	—
55	R-22	1273	3	Pajarito	—	None	—	—	—	—	—	—	—
56	R-22	1378	4	Pajarito	—	None	—	—	—	—	—	—	—
57	R-22	1448	5	Pajarito	Yes	None	—	—	—	—	—	—	—
58	R-23	816	1	Pajarito	—	Present	—	—	—	—	■	—	—
59	R-23i[h]	470	2	Pajarito	Yes	Present	—	?	—	—	—	—	?
60	R-23i	524	3	Pajarito	Yes	Present	Yes	?	—	—	—	—	?
61	R-24	825	1	Bayo	—	Indeter	—	?	—	—	—	—	?
62	R-25	755	1	Caňon de Valle	Yes	Present	Yes	■	■	—	■	■	—
63	R-25	892	2	Caňon de Valle	Yes	Present	Yes	■	—	—	?	?	—
64	R-25	1192	4	Caňon de Valle	Yes	Present	Yes	■	—	—	?	?	—
65	R-25	1303	5	Caňon de Valle	Yes	Present	—	—	—	—	—	—	—
66	R-25	1406	6	Caňon de Valle	Yes	None	—	—	—	—	—	—	—
67	R-25	1606	7	Caňon de Valle	—	None	—	—	—	—	—	—	—
68	R-25	1796	8	Caňon de Valle	—	None	—	—	—	—	—	—	—
69	R-26	659	1	Caňon de Valle	—	None	—	—	—	—	—	—	—
70	R-27	852	1	Water	—	None	—	—	—	—	—	—	—
71	R-28	934	1	Mortandad	Yes	Present	Yes	■	■	■	■	■	—

Table 2-1 (continued)

Screen ID[a]	Well	Port Depth (ft)	Scr #	Watershed	^{3}H >1 pCi/L[a]	Local Plume	^{3}H >30 pCi/L[b]	Cl	ClO$_4$	Cr	NO$_3$	SO$_4$	U
72	R-31	532	2	Ancho	—	None	—	—	—	—	—	—	—
73	R-31	670	3	Ancho	—	None	—	—	—	—	—	—	—
74	R-31	831	4	Ancho	—	None	—	—	—	—	—	—	—
75	R-31	1011	5	Ancho	—	None	—	—	—	—	—	—	—
76	R-32	871	1	Pajarito	—	None	—	—	—	—	—	—	—
77	R-32	976	3	Pajarito	—	None	—	—	—	—	—	—	—
78	R-33	995	1	Mortandad	—	None	—	—	—	—	—	—	—
79	R-33	1112	2	Mortandad	—	None	—	—	—	—	—	—	—
80	R-34	895	1	Mortandad	—	None	—	—	—	—	—	—	—

[a] A “Yes” in this column indicates that tritium (^{3}H) is detected at this location, indicating the presence of a component of water less than 60 years old.

[b] A “Yes” in this column indicates that tritium (^{3}H) is present at this location as a constituent in a local contaminant plume. The threshold value of 30 pCi/L is based on the discussion of tritium in section 4.2.1 of the “Groundwater Background Investigation Report, Revision 2,” (LANL 2007, 094856). The highest activity found was 30 pCi/L in an alluvial perched groundwater from Well LAO-B in 2006, which is interpreted as representing the upper limit for uncontaminated local groundwater.

[c] ■ = The constituent is known to be present in a local contaminant plume that has reached the screened interval.

[d] — = The constituent is either absent from any local plume, or else its presence is indeterminate with the information available at this time.

[e] ? = The constituent is detected at this location and is likely to be a plume constituent, but incontrovertible evidence for this origin is lacking at the present time.

[f] None = No local contaminant plume is known with certainty to be present at this location.

[g] Entries for R-3i are preliminary. Although a contaminant plume is present at this location, it has not yet been completely characterized. Constituents identified on this table are based in part on the similarities between groundwater from R-3i to that from nearby well APCO-1, which is mainly impacted by discharges of treated sewage effluent from the Bayo Sewage Treatment Plant.

[h] Entries for the two screens in R-23i are preliminary. Although a contaminant plume is present at this location, it has not yet been completely characterized.

Table 2-2
Primary Chemicals of Potential Concern for Individual Wells

Well	Watershed	TA	Potential Contaminants in Watershed[a]
CdV-16-1(i)	Upper Water Canyon and Cañon de Valle	TA-16	High explosive (HE) compounds[b], nitrate, perchlorate, uranium, barium, lead, copper, zinc
CdV-16-2(i)r	Upper Water Canyon and Cañon de Valle	TA-16	HE compounds[b], nitrate, perchlorate, uranium, barium, lead, copper, zinc
CdV-R-15-3	Upper Water Canyon and Cañon de Valle	TA-15	HE compounds[b], nitrate, perchlorate, uranium, barium, lead, copper, zinc
CdV-R-37-2	Upper Water Canyon and Cañon de Valle	TA-37	HE compounds[b], nitrate, perchlorate, uranium, barium, lead, copper, zinc
MCOBT-4.4	Mortandad/Ten Site Canyons	TA-5	Tritium, nitrate, perchlorate, uranium, plutonium, cesium-137, strontium-90, americium-241
R-1	Mortandad	TA-54	Tritium, nitrate, perchlorate, uranium, plutonium, cesium-137, strontium-90, americium-241, technetium-99
R-2	Pueblo	TA-74	Nitrate, plutonium-239/240, metals (e.g., mercury), tritium, perchlorate, uranium
R-3i	Pueblo	TA-74	Nitrate, plutonium-239/240, metals (e.g., mercury), tritium, perchlorate, uranium
R-4	Pueblo	Los Alamos	Nitrate, plutonium-239/240, metals (e.g., mercury), tritium, perchlorate, uranium
R-5	Pueblo	TA-74	Nitrate, plutonium-239/240, metals (e.g., mercury), tritium, perchlorate, uranium
R-6	Los Alamos/DP Canyon	TA-53	Tritium, cesium-137, strontium-90, nitrate, uranium, perchlorate, molybdenum
R-6i	Los Alamos/DP Canyon	TA-53	Tritium, cesium-137, strontium-90, nitrate, uranium, perchlorate, molybdenum
R-7	Los Alamos	TA-53	Tritium, cesium-137, strontium-90, nitrate, uranium, perchlorate
R-8	Los Alamos	TA-72	Tritium, cesium-137, strontium-90, nitrate, uranium, perchlorate, molybdenum
R-9	Los Alamos	TA-72	Tritium, cesium-137, strontium-90, nitrate, uranium, perchlorate
R-9i	Los Alamos	TA-72	Tritium, cesium-137, strontium-90, nitrate, uranium, perchlorate
R-10	Sandia Canyon	San Ildefonso Pueblo	Tritium, nitrate, perchlorate, uranium, plutonium
R-10a	Sandia Canyon	San Ildefonso Pueblo	Tritium, nitrate, perchlorate, uranium, plutonium
R-11	Sandia Canyon	TA-5	Tritium, nitrate, perchlorate, uranium, plutonium
R-12	Sandia Canyon	TA-72	Tritium, nitrate, perchlorate, uranium, plutonium
R-13	Mortandad	TA-5	Tritium, nitrate, perchlorate, uranium, plutonium, cesium-137, strontium-90, americium-241

Table 2-2 (continued)

Well	Watershed	TA	Potential Contaminants in Watershed[a]
R-14	Mortandad/Ten Site	TA-5	Tritium, nitrate, perchlorate, uranium, plutonium, cesium-137, strontium-90, americium-241, barium, lanthanides
R-15	Mortandad	TA-5	Tritium, nitrate, perchlorate, uranium, plutonium, cesium-137, strontium-90, americium-241, lanthanides
R-16	Cañada del Buey	White Rock Overlook	Tritium, County Sewage Treatment Plant effluent (nitrate, sulfate, metals)
R-16r	Cañada del Buey	White Rock Overlook	Tritium, County Sewage Treatment Plant effluent (nitrate, sulfate, metals)
R-17	Pajarito	TA-15	Metals, radionuclides, HE, VOCs, nitrate, perchlorate
R-18	Pajarito	TA-14	Metals, radionuclides, HE, VOCs, nitrate, perchlorate
R-19	Pajarito/Threemile	TA-36	HE, VOCs
R-20	Pajarito	TA-36	Metals, radionuclides, HE, VOCs, nitrate, perchlorate
R-21	Cañada del Buey	TA-54	Tritium, VOCs
R-22	Pajarito (mesa above canyon)	TA-54	Tritium, metals, radionuclides, VOCs, nitrate, perchlorate
R-23	Pajarito	TA-36	Metals, radionuclides, HE, VOCs, nitrate, perchlorate
R-23i	Pajarito	TA-36	Metals, radionuclides, HE, VOCs, nitrate, perchlorate
R-24	Bayo	TA-74	Tritium, nitrate, perchlorate, uranium, plutonium, cesium-137, strontium-90, americium-241, lanthanides
R-25	Cañon de Valle (mesa above canyon)	TA-16	HE compounds, barium, solvents, perchlorate
R-26	Cañon de Valle	TA-16	HE, barium, solvents, perchlorate
R-27	Water Canyon	TA-36	Metals, radionuclides, HE, VOCs, nitrate, perchlorate
R-28	Mortandad	TA-5	Tritium, nitrate, perchlorate, uranium, plutonium, cesium-137, strontium-90, americium-241, lanthanides, molybdenum-99
R-31	Ancho	TA-39	HE, radionuclides, metals, tritium
R-32	Pajarito	TA-36	Metals, radionuclides, VOCs, nitrate, perchlorate
R-33	Mortandad/Ten Site	TA-5	Tritium, nitrate, perchlorate, uranium, plutonium, cesium-137, strontium-90, americium-241. lanthanides
R-34	Mortandad (Cedro)	San Ildefonso	Tritium, nitrate, perchlorate, uranium, plutonium, cesium-137, strontium-90, americium-241, lanthanides

[a] Reference: Hydrogeologic Workplan (LANL 1998, 059599).

[b] HE compounds relevant to these wells are RDX, HMX, TNT, and PETN.

Table 4-1
Turbidity and Total Organic Carbon Concentrations at the End of Development of the Well or Screen and for the Most Recent Sample

Well	Screen #	Screen Depth (ft)	End of Development[a]			Most Recent Sample[b]		
			Date	Turbidity (NTU[c])	TOC (mg/L)	Date	Turbidity (NTU)	TOC (mg/L)
CdV-16-1(i)	1	624	17-Dec-03	4.2	1.6	9-Mar-06	1.4	0.8
CdV-16-2(i)r	1	850	22-Aug-05	10.5	1.8	17-May-06	3.3	0.5
CdV-R-15-3	4	1254	2-Aug-00	1.4	1.5	27-Mar-06	0.3	<0.3
CdV-R-15-3	5	1350	1-Sep-00	1.5	4.5	28-Mar-06	0.4	1.6
CdV-R-15-3	6	1640	1-Sep-00	2.2	0.8	29-Mar-06	0.7	0.4
CdV-R-37-2	2	1200	21-Sep-01	4.9[d]	4.9[d]	21-Mar-06	3.4	4.2
CdV-R-37-2	3	1359	21-Sep-01	3.9	0.7	7-Jul-05	3.1	0.3
CdV-R-37-2	4	1551	21-Sep-01	4.7	3.9	22-Mar-06	1.1	0.7
MCOBT-4.4	1	485	13-Feb-02	0.8	0.8	8-Jun-05	0.6	1
R-1	1	1031	25-Nov-03	4.7	2.2	26-Oct-06	0.7	<0.3
R-2	1	918	11-Dec-03	11.2	2.2	24-Jul-06	7.6	0.6
R-3i	1	215	12-Sep-05	0.9	< 1	10-Aug-06	0.6	1.0
R-4	1	804	10-Oct-03	3.1	1.3	25-Jul-06	0.1	<0.3
R-5	2	384	21-Jun-01	nm[e]	nm	25-Jul-06	0.2	<0.3
R-5	3	719	21-Jun-01	15.5	0.5	26-Jul-06	0.2	4
R-5	4	861	21-Jun-01	8.8	3.7	5-May-05	0.5	0.8
R-6	1	1205	5-Jan-05	3.2	2.9	26-Jul-06	0.8	<0.3
R-6i	1	602	14-Feb-05	1.2	5.5	26-Jul-06	1.0	1.3
R-7	3	915	8-Feb-01	20.8	13.0	31-Jul-06	1.0	1.3[f]
R-8	1	711	14-Feb-02	nm	nm	1-Aug-06	0.2	<0.3
R-8	2	825	14-Feb-02	1.4	1.0	2-Aug-06	0.2	0.6[f]
R-9	1	684	13-Feb-00	< 1	26.0	31-Jul-06	3.6[f]	0.6
R-9i	1	199	7-Apr-00	2.7	3.0	10-Aug-06	0.2	3.4[f]
R-9i	2	279	7-Apr-00	2.6	4.2	10-Aug-06	0.5	1.4[f]
R-10	1	874	6-Oct-05	4.8	<0.5	12-Oct-06	0.9	1.2
R-10	2	1042	6-Oct-05	2.2	<0.5	12-Oct-06	1.2	1.3
R-10a	1	690	7-Sep-05	1.6	0.9	12-Oct-06	4.2	0.8
R-11	1	855	21-Oct-04	1.6	1.8	10-Oct-06	0.3	<0.3
R-12	1	468	6-Feb-00	3.3[d]	7.7[d]	10-Jul-06[g]	0.5[f]	0.5
R-12	2	507	6-Feb-00	2.8[d]	16[d]	11-Jul-06[g]	1.1	3.5
R-12	3	811	6-Feb-00	6.8[d]	45[d]	12-Jul-06[g]	0.9	1
R-13	1	958	30-Oct-01	2.7	0.3	25-Oct-06	4.2	0.3
R-14	1	1205	18-Nov-02	< 1	2.4	23-Oct-06	0.6	0.5
R-14	2	1289	18-Nov-02	< 1	2.0	23-Oct-06	1.0	2.1[f]
R-15	1	959	20-Feb-00	1.2	13.0	24-Oct-06	2.7	0.5

Table 4-1 (continued)

Well	Screen #	Screen Depth (ft)	End of Development[a]			Most Recent Sample[b]		
			Date	Turbidity (NTU[c])	TOC (mg/L)	Date	Turbidity (NTU)	TOC (mg/L)
R-16	2	866	4-Dec-02	1.3	2.1	20-Jul-06[g]	0.5	2.1
R-16	3	1018	4-Dec-02	0.9	1.9	20-Jul-06[g]	0.2	1.1
R-16	4	1238	4-Dec-02	1.9	2.2	20-Jul-06[g]	0.5	2.6
R-16r	1	600	17-Oct-05	4.3	1.0	1-Nov-06	0.6	0.3
R-17	1	1057	24-Feb-06	3.4	0.7	19-Oct-06	19.5	1
R-17	2	1124	24-Feb-06	3.8	<0.1	17-Oct-06	10	0.4
R-18	1	1358	24-Jan-05	2.3	1.7	18-Dec-06	1.4	0.4
R-19	2	909	24-Jun-00	25[d]	3.3	11-Dec-06	0.1	0.3[f]
R-19	3	1191	24-Jun-00	12.9	< 1	11-Dec-06	0.2	0.2[f]
R-19	4	1413	24-Jun-00	4.6	< 1	12-Dec-06	0.4	0.5
R-19	5	1586	24-Jun-00	4.6	8.9	11-Dec-06	2.4	6.4[f]
R-19	6	1730	24-Jun-00	5.1	2.7	11-Dec-06	0.2	0.6[f]
R-19	7	1835	24-Jun-00	4.9	6.3	18-Aug-06	15	2.3[f]
R-20	1	907	22-Dec-02	227	32.4[d]	6-Jun-06[g]	0.7	8.2
R-20	2	1150	22-Dec-02	2.8	2.1	7-Jun-06[g]	1.4	49
R-20	3	1330	22-Dec-02	4.2	2.8	8-Jun-06[g]	5.0	2.3
R-21	1	889	5-Dec-02	2.3	5.9	6-Nov-06	0.4	0.5
R-22	1	907	19-Nov-00	26[d]	11.0	26-Aug-06	7.8	6.4[f]
R-22	2	963	19-Nov-00	0.3[d]	< 1	7-Dec-06	0.3	<0.3
R-22	3	1274	19-Nov-00	4.2	4.9	8-Dec-06	0.5	1.2
R-22	4	1378	19-Nov-00	3.0	23.0	8-Dec-06	2.1	16.7[f]
R-22	5	1448	19-Nov-00	2.7	13.0	21-Aug-06	1.0	2.6[f]
R-23	1	816	20-Feb-03	1.4	< 1	18-Dec-06	1.8	<0.3
R-23i	2	470	20-Dec-05	1.7	<0.1	3-Oct-06	9.2	0.9
R-23i	3	524	20-Dec-05	2	1.8	11-Oct-06	785	1.1
R-24	1	825	20-Sep-05	2.4	1.0	27-Jul-06	0.7	0.5
R-25	1	755	13-Sep-00	1.6	< 1	2-Aug-05	9.1	0.9[f]
R-25	2	892	13-Sep-00	41.7	6.6	3-Aug-05	12	2.4[f]
R-25	4	1192	13-Sep-00	5.3	2.2	4-Aug-05	7.6	1.0[f]
R-25	5	1303	13-Sep-00	6.2	7.0	9-Aug-05	3.6	10.3[f]
R-25	6	1406	13-Sep-00	1.8	0.9	9-Dec-03	0.4	0.3
R-25	7	1606	13-Sep-00	10.2	1.7	8-Dec-03	1.4	0.2
R-25	8	1796	13-Sep-00	14.3	15.0	10-Aug-05	5.1	<0.5[f]
R-26	1	659	16-Nov-03	4.9	2.0	22-Feb-06	0.2	0.1[f]
R-27	1	852	14-Nov-05	3.1	1.2	1-Jul-06	0.8	<0.3
R-28	1	946	13-Jan-04	1.8	0.4	26-Oct-06	0.4	0.6
R-31	2	532	27-Mar-00	0.9	5.4[d]	28-Nov-06	1.9	5

Table 4-1 (continued)

Well	Screen #	Screen Depth (ft)	End of Development[a]			Most Recent Sample[b]		
			Date	Turbidity (NTU[c])	TOC (mg/L)	Date	Turbidity (NTU)	TOC (mg/L)
R-31	3	670	27-Mar-00	1.1	21.9[d]	30-Nov-06	1.0	3.4
R-31	4	831	27-Mar-00	1.9	6.7[h]	6-Dec-06	0.3	0.5
R-31	5	1011	27-Mar-00	2.7	2.4[h]	6-Dec-06	0.2	0.3
R-32	1	871	31-Oct-02	3.7	8.0	12-Dec-06	0.2	0.5
R-32	3	976	31-Oct-02	1.9	14.0	13-Dec-06	1.6	0.6
R-33	1	996	3-Dec-04	2.2	1.8	31-Oct-06	1.6	1.2[f]
R-33	2	1112	22-Nov-04	3.0	1.8	1-Nov-06	2.1	0.7[f]
R-34	1	895	2-Sep-04	3.7	2.0	30-Oct-06	22	<0.3

[a] Development date and data from well completion reports listed in Section 7.2, except where indicated otherwise.

[b] Sampling date, turbidity, and TOC concentrations for the most recent sample from Tables C-3 and C-4.

[c] NTU = Nephelometric turbidity unit.

[d] This parameter was not reported in the well completion report. The value used in this table is the first one reported in the WQDB for a sampling event that postdates the development date.

[e] nm = Not measured.

[f] This parameter was not reported in the WQDB. The value used in this table was reported for an earlier event.

[g] To ensure comparability with other screens in evaluating the long-term effectiveness of well development, the “most recent samples” used in this table for R-12, R-16, and R-20 are the ones collected immediately prior to the start of rehabilitation activities at these locations.

[h] TOC data were not reported for this sample; the value shown is Dissolved Organic Carbon (DOC) concentration.

Table 4-2

Categories of Residual Drilling Fluid Effects

Category		Examples of Sources	Examples of Effects	Overall Screening Question
A	Residual water-leachable inorganic constituents of drilling fluids Note: This category also includes the physical effects of residual solids	• Inorganic constituents leached from bentonite drilling mud or bentonite annular fill • Sulfide (as sulfamic acid) in AQUA-CLEAR MGA • Salts, acids, phosphate solutions, and soda ash added to drilling mixes or used during development • Residual clay particles from bentonite drilling mud	• Competition for adsorption sites • Mineral dissolution or precipitation • False indication of contaminant plume • Ligands (F, PO_4, CO_3 species, OH) may modify solubility and speciation of trace metals and radionuclides • Residual clays and other solids, even if inert, may plug pore openings and thereby reduce hydraulic conductivity and create microenvironments	Have residual inorganic constituents of drilling fluids been removed from the screen interval?
B	Residual organic carbon and nitrogen constituents of drilling fluids	DOC and TOC from: • Alcohols in QUIK-FOAM • Hydrocarbons in EZ-MUD • Anionic surfactants in QUIK-FOAM • Polyacrylamide in EZ-MUD Organic nitrogen and NH_4 from: • NH_4^+ counterion in anionic surfactant product (QUIK-FOAM) • Polyacrylamide in EZ-MUD • Sulfamic acid in AQUA-CLEAR MGA	• Increased number and diversity of microbial populations • False indication of contaminant plume • Organic ligands may modify solubility and speciation of metal analytes, including radionuclides • Organic colloids or micelles may modify transport characteristics of other organic species or inorganic ions • Generation of intermediate organic species as degradation products (e.g., alcohols, aldehydes, acetate, formate) • Increased HCO_3, NH_4, and SO_4 concentrations as final inorganic degradation products	Have residual organic carbon and nitrogen constituents of drilling fluids been removed from the screen interval?

Table 4-2 (continued)

Category		Examples of Sources	Examples of Effects	Overall Screening Question
C	Reducing conditions	• Develops primarily as a result of residual organic carbon that fuels microbial populations	• May obscure presence of NO_3 and Cr in contaminant plumes • Precipitation, dissolution, or transformation of Fe- and Mn-bearing minerals • Release of adsorbed metal species from dissolved Fe-Mn minerals • Changes in mineral solubilities • Changes in speciation and thus transport characteristics of dissolved species	Are conditions oxidizing with respect to: • Dissolved oxygen? • Nitrate? • Manganese(IV)? • Iron(III)? • Sulfate?
D	Changes in adsorption capacities of surface-active minerals	• Residual clay from bentonite drilling mud • Changes in mineral surface properties initiated by changes in redox conditions	• Adsorption onto residual bentonite clay • Adsorption of metal species onto newly formed surfaces	Are adsorption capacities and characteristics of minerals near the screen unimpacted by residual drilling fluids?
E	Precipitation or dissolution of carbonate minerals	• Addition of surfactants, sodium carbonate, phosphate, and acids in drilling, well construction, and well development products	• Precipitation of Ca by surfactant • Changes in concentrations of Ba, Sr, Ca, Mg • Carbonate ligands may modify solubility and speciation of trace metals and radionuclides	Are carbonate mineral stabilities unchanged by residual drilling fluids?
F	Corrosion of steel components of well casing or screen	Formation of microcracks or pits at stressed steel	• Highly elevated concentrations of steel components: Fe, Cr, Ni • Adsorption of metals and radionuclides by colloidal Fe oxides	Are steel components of the well essentially inert with respect to water in the screen interval?

Table 4-3a
Background Values for Key Indicator Species in the Regional Aquifer

Analyte	Symbol	Units	% Non-detects	Median	Lower Limit[a]		Upper Limit[b]	
Alkalinity (total carbonate)	$CaCO_3$	mg/L	0	66	50.7	5th percentile	105.1	UTL[c]
Ammonium	NH_4-N	mg/L	93	ND[d] (<0.01)	ND (<0.01)	5th percentile	0.05	Max detected[e]
Barium (filtered)	Ba	µg/L	5	21	4.68	5th percentile	69.2	UTL
Calcium	Ca	mg/L	0	12	8.62	Min detected[f]	24.12	UTL
Chloride	Cl	mg/L	0	2.2	1.65	5th percentile	3.75	UTL
Chromium (filtered)	Cr	µg/L	20	3.47	1.1	Min detected[g]	6.62	UTL
Chromium (total)	Cr	µg/L	29	3.00	1.2	Min detected[g]	9.80	Max detected
Fluoride	F	mg/L	9	0.32	0.11	5th percentile	0.53	UTL
Iron (filtered)	Fe	µg/L	71	ND (<13)	ND (<13)	5th percentile	102	90th percentile[h]
Iron (total)	Fe	µg/L	38	21	ND (<13)	5th percentile	102	90th percentile
Magnesium	Mg	mg/L	0	3.0	0.53	5th percentile	4.81	UTL
Manganese (filtered)	Mn	µg/L	67	ND (<2)	ND (<1)	5th percentile	16	Max detected[e]
Molybdenum (filtered)	Mo	µg/L	49	1.1	ND (<1)	5th percentile	3.82	UTL
Nickel (filtered)	Ni	µg/L	78	ND (<1)	ND (<1)	5th percentile	1.7	Max detected
Nitrate (as N)	NO_3-N	mg/L	9	0.33	0.15	10th percentile[i]	0.75	UTL
Perchlorate	ClO_4	µg/L	1	0.31	0.17	5th percentile	0.45	UTL
pH	pH	SU	0	7.82	6.94	5th percentile	8.65	UTL
Phosphate (as P)	PO_4-P	mg/L	69	ND (<0.035)	ND (<0.01)	5th percentile	0.34	Max detected
Sodium	Na	mg/L	0	12.5	8.45	5th percentile	28.55	UTL
Strontium (filtered)	Sr	µg/L	0	55.5	44.88	5th percentile	179.8	UTL
Sulfate	SO_4	mg/L	3	2.9	0.80	Min detected	6.22	UTL
Total Kjeldahl Nitrogen	TKN	mg/L	57	ND (<0.044)	ND (<0.01)	5th percentile	0.28	Approx 90th percentile
Total organic carbon	TOC	mg/L	52	ND (<0.5)	ND (<0.2)	5th percentile	1.0	Max detected[e]

Table 4-3a (continued)

Analyte	Symbol	Units	% Non-detects	Median	Lower Limit[a]		Upper Limit[b]	
Uranium (filtered)	U	µg/L	3	0.45	0.16	5th percentile	1.52	UTL
Zinc (filtered)	Zn	µg/L	61	1.9	ND (<2)	5th percentile	41.1	Max detected[e]

Source of values: Table 4.2-3 in Groundwater Background Investigation Report, Rev. 2 (LANL 2007, 094856)

[a] Except as noted otherwise, the lower limit is set at the 5th percentile for filtered or nonfiltered samples, whichever value is lowest.

[b] Except as noted otherwise, the upper limit is set at the UTL if available, the 90th percentile for filtered samples (if available), or the maximum detected values for the background data set.

[c] UTL = Upper threshold limit.

[d] ND = Not detected.

[e] The upper limits for ammonia, manganese, total organic carbon, and zinc are set at the maximum concentrations detected in background samples collected only from wells because the range in concentrations in background samples collected from springs that discharge from the regional aquifer extend significantly outside the range of values observed in the well samples.

[f] The lower limit for calcium is set at the minimum detected value for water samples from wells, excluding the single anomalously low concentration (0.61 mg/L) reported for PM-2 (05/24/06 sample); note that values for the other five samples from this well ranged from 8.6 to 10.7 mg/L.

[g] The lower limits for filtered and total chromium concentrations are set at the minimum detected value for background samples because a detected value is considered more representative of the prevailing oxidizing conditions in well samples.

[h] The upper limit for dissolved iron is set at the 90th percentile for total (nonfiltered) iron. Percentiles were not calculated for dissolved iron due to the high proportion of nondetects in this dataset.

[i] The lower limit for nitrate is set at the 10th percentile for filtered samples because the higher value is considered more representative of the prevailing oxidizing conditions in the regional aquifer.

[j] pH = -log[H+].

[k] SU = Standard units.

Table 4-3b
Background Values for Key Indicator Species in the Perched Intermediate Aquifer

Analyte	Symbol	Units	% Non-detects	Median	Lower Limit [a]		Upper Limit[b]	
Alkalinity (total carbonate)	$CaCO_3$	mg/L	0	38	33.8	5th percentile	52.00	UTL[c]
Ammonium	NH_4-N	mg/L	—[d]	—	[e]	—	[e]	—
Barium (filtered)	Ba	µg/L	0	16	1.4	5th percentile	71.83	UTL
Calcium	Ca	mg/L	0	7.6	4.39	Min detected[c]	17.31	UTL
Chloride	Cl	mg/L	0	1.4	0.99	5th percentile	1.75	95th percentile
Chromium (filtered)	Cr	µg/L	77	ND[f] (<1)	[e]	—	2.4	Max detected
Chromium (total)	Cr	µg/L	74	ND (<1)	[e]	—	2.4	Max detected
Fluoride	F	mg/L	0	0.12	0.04	5th percentile	0.23	UTL
Iron (filtered)	Fe	µg/L	45	20	ND (<10)	5th percentile	[e]	—
Iron (total)	Fe	µg/L	—	—	[e]	—	[e]	—
Magnesium	Mg	mg/L	0	1.7	0.78	5th percentile	6.12	UTL
Manganese (filtered)	Mn	µg/L	77	ND (<1)	ND (<1)	5th percentile	[e]	—
Molybdenum (filtered)	Mo	µg/L	55	ND (<1)	ND (<1)	5th percentile	4.3	Max detected
Nickel (filtered)	Ni	µg/L	86	ND (<1)	ND (<1)	5th percentile	[e]	—
Nitrate (as N)	NO_3-N	mg/L	0	0.34	0.18	Min detected	1.78	Max detected
Perchlorate	ClO_4	µg/L	—	—	[e]	—	[e]	—
pH[g]	pH	SU[h]	0	7.4	6.73	Min detected	8.80	UTL
Phosphate (as P)	PO_4-P	mg/L	14	0.02	ND (<0.01)	5th percentile	0.08	UTL
Sodium	Na	mg/L	0	7.2	5.17	5th percentile	12.19	UTL
Strontium (filtered)	Sr	µg/L	0	55	19.1	5th percentile	154.8	UTL
Sulfate	SO_4	mg/L	0	4.1	1.07	Min detected	4.48	95th percentile
Total Kjeldahl Nitrogen	TKN	mg/L	—	—	[e]	—	[e]	—
Total Organic Carbon	TOC	mg/L	—	—	[e]	—	[e]	—

Table 4-3b (continued)

Analyte	Symbol	Units	% Non-detects	Median	Lower Limit [a]		Upper Limit[b]	
Uranium (filtered)	U	µg/L	43	0.30	ND (<0.2)	5th percentile	0.72	UTL
Zinc (filtered)	Zn	µg/L	59	ND (<2)	ND (<1)	5th percentile	19	Max detected

Source of values: Table 4.2-2 in Groundwater Background Investigation Report, Rev. 2 (LANL 2007, 094856).

[a] Unless noted otherwise, the lower limit is set at the 5th percentile for filtered or nonfiltered samples, whichever value is lowest.

[b] The lower limit for filtered and total chromium is set at the minimum detected value for background samples, because a detected value is considered more representative of the prevailing oxidizing conditions in well samples.

[c] UTL = Upper threshold limit.

[d] — =Not calculated.

[e] Insufficient data to calculate statistical distribution parameters; use same limits as for regional aquifer (Table 4-3a).

[f] ND = Not detected.

[g] pH = -log[H+].

[h] SU = Standard units.

Table 4-4
Proposed Drilling Flag Codes and Drilling Reason Codes Assigned by the Data Qualification Protocol

Drilling Flag Code	Drilling Reason Code	Description	Examples of Analytes That Might Be Assigned This Code[a]
J+	Res_Inorg1	Analyte Concentration may be biased high relative to that in pre-drilling groundwater due to leaching of inorganic constituents from drilling muds and fluids	Na, Cl, SO_4, Mo, B
J-	Bentonite2	Analyte Concentration may be biased low relative to that in pre-drilling groundwater due to adsorption onto residual bentonite drilling mud.	Detections of Pb, TNT, Cs-137, Pu isotopes
UJ	Bentonite3	Analyte Reporting Limit may be biased low relative to that in pre-drilling groundwater due to adsorption onto residual bentonite drilling mud.	Nondetects of Pb, TNT, Cs-137, Pu isotopes
J+	Organic_Drill1	Analyte Concentration may be biased high relative to that in pre-drilling groundwater due to residual organic drilling fluid.	Detections of NH_3, TOC, acetone
J	Sul_Red1	Analyte concentration should be regarded as more uncertain than usual relative to that in pre-drilling groundwater due to sulfate-reducing conditions.	Detections of Fe, Mn, Mo (if detected below the test criteria’s upper limits as listed in Tables 4-3a and 4-3b)
J-	Sul_Red4	Analyte concentration should be regarded as more uncertain than usual and biased low relative to that in pre-drilling groundwater due to sulfate-reducing conditions.	Detections of SO_4, Sb, As, Hg
J+	Sul_Red3	Analyte concentration should be regarded as more uncertain than usual and biased high relative to that in pre-drilling groundwater due to sulfate-reducing conditions.	Detections of Fe, Mn, Mo (if detected above the test criteria’s upper limits as listed in Tables 4-3a and 4-3b)
UJ	Sul_Red2	Analyte reporting limit should be regarded as more uncertain than usual relative to that in pre-drilling groundwater due to sulfate-reducing conditions.	Nondetects of SO_4, Sb, As, Hg, Tc-99, dioxins, HEXPs, pesticides, SVOCs, VOCs
J	Fe_Red1	Analyte concentration should be regarded as more uncertain than usual relative to that in pre-drilling groundwater due to iron-reducing conditions.	Detections of Ba, Se, U, dioxins, HEXPs, pesticides, SVOCs, VOCs
J-	Fe_Red4	Analyte concentration should be regarded as more uncertain than usual and biased low relative to that in pre-drilling groundwater due to iron-reducing conditions.	Am-241, Co-60, Pu-239/240
J+	Fe_Red3	Analyte concentration should be regarded as more uncertain than usual and biased high relative to that in pre-drilling groundwater due to iron-reducing conditions.	Detections of Mo
UJ	Fe_Red2	Analyte reporting limit should be regarded as more uncertain than usual relative to that in pre-drilling groundwater due to iron-reducing conditions.	Nondetects of Se, U, dioxins, HEXPs, pesticides, SVOCs, VOCs
J	Mn_Red1	Analyte concentration should be regarded as more uncertain than usual relative to that in predrilling groundwater due to manganese-reducing conditions.	Detections of Be, Cd, Cr, Mn,

Table 4-4 (continued)

Drilling Flag Code	Drilling Reason Code	Description	Examples of Analytes That Might Be Assigned This Code
J-	Mn_Red4	Analyte concentration should be regarded as more uncertain than usual and biased low relative to that in predrilling groundwater due to manganese-reducing conditions.	Am-241, Co-60, Pu-239/240
J+	Mn_Red3	Analyte concentration should be regarded as more uncertain than usual and biased high relative to that in predrilling groundwater due to manganese-reducing conditions.	Detections of Mn
UJ	Mn_Red2	Analyte reporting limit should be regarded as more uncertain than usual relative to that in predrilling groundwater due to manganese-reducing conditions.	Nondetects of Be, Cd, Cr,
J	Nitrate_Red1	Analyte concentration should be regarded as more uncertain than usual relative to that in pre-drilling groundwater due to nitrate-reducing conditions.	Detections of dioxins, HEXPs, pesticides, SVOCs, VOCs
J-	Nitrate_Red4	Analyte concentration should be regarded as more uncertain than usual and biased low relative to that in pre-drilling groundwater due to nitrate-reducing conditions.	ClO_4, Am-241, Co-60, Pu-239/240
J+	Nitrate_Red3	Analyte concentration should be regarded as more uncertain than usual and biased high relative to that in pre-drilling groundwater due to nitrate-reducing conditions.	Possibly none
UJ	Nitrate_Red2	Analyte reporting limit should be regarded as more uncertain than usual relative to that in pre-drilling groundwater due to nitrate-reducing conditions.	Nondetects of dioxins, HEXPs, pesticides, SVOCs, VOCs
J+	Carbonate_1	Analyte concentration should be regarded as more uncertain than usual and biased high relative to that in pre-drilling groundwater due to enhanced dissolution of carbonate minerals due to residual drilling fluids	Detections of Ba, Sr, U, Mn, Zn (if detected above the test criteria's upper limits as listed in Tables 4-3a and 4-3b)
J-	Carbonate_2	Analyte concentration should be regarded as more uncertain than usual and biased low relative to that in pre-drilling groundwater due to enhanced precipitation of carbonate minerals due to residual drilling fluids	Detections of Ba, Sr, U, Mn, Zn (if detected below the 5th percentile as listed in Tables 4-3a and 4-3b)
J	Carbonate_3	Analyte concentration should be regarded as more uncertain than usual relative to that in pre-drilling groundwater due to enhanced dissolution and/or precipitation of carbonate minerals due to residual drilling fluids	Detections of Ba, Sr, U, Mn, Zn (if detected below the test criteria's upper limits as listed in Tables 4-3a and 4-3b)
J+	Corrosion_1	Analyte concentration should be regarded as more uncertain than usual and biased high relative to that in pre-drilling groundwater due to corrosion of the stainless steel casing	Detections of Fe, Cr, Ni, Mn
J	Corrosion_2	Analyte concentration should be regarded as more uncertain than usual relative to that in pre-drilling groundwater due to potential adsorption onto iron-(oxy)hydroxyl colloids generated from corrosion of the stainless steel casing	Detections of Pb, Hg, Cs-137, Ra isotopes

Drilling Flag Code	Drilling Reason Code	Description	Examples of Analytes That Might Be Assigned This Code
UJ	Corrosion_3	Analyte reporting limit should be regarded as more uncertain than usual relative to that in pre-drilling groundwater due to potential adsorption onto iron-(oxy)hydroxyl colloids generated from corrosion of the stainless steel casing	Nondetects of Pb, Hg, Cs-137, Ra isotopes

[a] **Analytes potentially affected by a particular category of residual drilling effects are indicated as such in Tables A-1 through A-8.**

Table 4-5
Examples of Organic and Inorganic Drilling Fluids Used in Borehole Screen Intervals Drilled Primarily with Bentonite Mud

Well Screen	Screen Depth (ft)	Water (gal.)	Bentonite (lb)	PAC-L (lb)	N-SEAL (lb)	Soda Ash (lb)	MAGMA FIBER (lb)	QUIK-FOAM (gal.)	EZ-MUD (gal.)	LIQUI-TROL (gal.)
R-14 Screen 1	1205	14157	3836	95	247	0	292	23	0	3.2
R-14 Screen 2	1289	8485	2300	57	148	0	175	14	0	1.9
R-16 Screen 2	866	3120	2530	4	65	8	65	0	21	0.4
R-16 Screen 3	1018	2873	2330	4	60	8	60	0	19	0.4
R-16 Screen 4	1238	6550	5312	9	136	17	136	0	44	0.9
R-20 Screen 1	907	3253	614	17	9	0	54	0	0	7.7
R-20 Screen 2	1150	3361	634	18	9	0	56	0	0	8.0
R-20 Screen 3	1330	2784	525	15	8	0	46	0	0	6.5
R-32 Screen 1	871	7592	4234	8	135	0	135	0	4	0.7
R-32 Screen 3	976	7592	4234	8	135	0	135	0	4	0.7

Notes: This list is limited to screens in multiple-screen wells. It does not include the three single-screen wells drilled with bentonite mud (R-2, R-4, and R-6). This list does not include additional chemical treatments conducted after well installation. Information compiled by J. Pavletich from Well Completion Reports (LANL 2003, 076062; LANL 2003, 076061; LANL 2003, 079600; LANL 2003, 079602) and drillers' field logbooks. Quantities used in the interval are estimated from the total use by apportioning it according to the length of screen interval, including 10 ft above and below it. For example, if the total use over a 100-ft section is recorded as 90 gal. of Product X, and the screen interval is 10 ft, then the quantity used in that interval is estimated as 30-ft/100-ft = 0.33 x 90 gal. = 30 gal.

Table 4-6
Water-Soluble Inorganic Constituents Leached from Drilling Products

Constituent	AQUA-GEL GOLD SEAL (bentonite)	Bentonite (product not specified)	QUIK-GEL (bentonite)	PAC-L	N-SEAL	Soda Ash	Sodium Acid Pyro-phosphate (SAPP)[a]	AQUA-CLEAR PFD	AQUA-CLEAR MGA[a]	Silicone Defoamer (SDI)	QUIK FOAM
pH	9.65	—[b]	9.1	8.0	9.5	11.4	—	8.8	0.9	7.5	—
Na, mg/kg	4021	1347	5390	93553	64	340000[a]	207207	94665	1210	638	—
Ca, mg/kg	65	10	138	116	593	—	—	35	—	28	—
K, mg/kg	75	6	15	33	80	—	—	12	—	4	—
Alkalinity (mg/kg as $CaCO_3$)	4130	—	17596	85557	75254	1052213	—	147058	—	929	—
SO_4, mg/kg	7897	1008	9484	<4	96	—	—	5067	7800	99	—
Cl, mg/kg	18	116	65	20769	4	—	—	13453	790	22	—
F, mg/kg	9	7	11	1630	16	—	—	27	—	2	—
NO_3, mg/kg	109	197	237	<4	<0.2	—	—	<0.2	1200	<0.2	—
NH_4, mg/kg	—	—	—	—	—	—	—	—	—	—	13650[a]
PO_4, mg/kg	<0.5	6.5	<0.5	10587	<0.5	—	576577	220	—	<0.5	—

Notes: Concentrations in mg/kg of product as packaged. Concentrations determined on deionized-water leaches of products by Dale Counce and Pat Longmire (GGRL, EES-6), except where noted. Measured raw data are reported in Table A-10.

[a] Water-soluble concentrations were calculated assuming the following stoichiometric compositions:
SAPP: $H_2P_2O_7{}^{-} \bullet 2Na^+$
AQUA-CLEAR MGA: 80% sulfamic acid (H_3NO_3S) + 20% NaCl (per MSDS). The concentration reported above assumes that the sulfide has converted to SO_4.
Soda Ash: Na_2CO_3
QUIK-FOAM: Assumes NH_4^+ is the counterion for the anionic ethyleneoxide sulfate (AES) surfactant (Wisconsin Department of Natural Resources 2006, 094917), which comprises 47% of QUIK-FOAM (Table 4-9) and has an average molecular weight of 633 (Table A-13) (Robison 2006, 094883). Thus the estimated proportion of NH_4^+ (molecular weight=18) in QUIK-FOAM is $0.48 \times 18/633 \times 10^6 = 13650$ ppm.

[b] — = Not measured. Concentration is expected to be negligible.

Table 4-7
Evaluation of Chemical Indicators for Residual Water-Soluble Inorganic Constituents Leached from Drilling Products

Constituent	Regional Aquifer[a]		Extent of increased concentration (mg/L) in drilling slurry when the indicated product quantity is added to 100 gallons water									
	Median	Upper Limit	AQUA-GEL GOLD SEAL (bentonite)	Bentonite (product not specified)	QUIK-GEL (bentonite)	PAC-L	N-SEAL	Soda Ash	Sodium Acid Pyrophosphate (SAPP)	AQUA-CLEAR MGA	AQUA-CLEAR PFD	QUIK-FOAM
			25 lb[b]	**25 lb**[b]	**25 lb**[b]	**1 lb**[b]	**5 lb**[b]	**0.25 lb**[b]	**33 lb**[c]	**5 lb**[b]	**1 gal.**[b]	**1 gal.**[b]
Na	12	29	120	40	161	112	0.4	2040	8200	7	148	—[d]
Ca	12	24	2.0	0.3	4.1	0.14	3.6	—	—	—	0.05	—
K	1.9	3.1	2.2	0.2	0.5	0.04	0.5	—	—	—	0.02	—
Alkalinity (as $CaCO_3$)	66	105	126	—	982	208	900	6300	—	—	~500	—
SO_4	2.9	6.2	237	30	284	0	0.6	—	—	45[e]	7.9	—
Cl	2.2	3.75	0.6	3.5	2.0	25	< 0.1	—	—	4.6	21	—
F	0.3	0.5	0.3	0.2	0.3	2.0	0.1	—	—	—	0.04	—
NO_3 (as N)	0.33	0.75	0.7	1.3	1.6	0	0	—	—	—	0	—
NH_4 (as N)	< 0.01	0.05	—	—	—	—	—	—	—	7.0	—	13.5
PO_4, (as P)	< 0.05	0.34	< 0.01	0.06	< 0.01	4.1	0	—	7400	—	0.11	—
Best candidates for indicators[f]			Na, Alkalinity, SO_4, Cl			Na, Alkalinity, Cl, F, PO_4	Alkalinity	Na, Alkalinity	Na, PO_4	SO_4 or S, Cl, NH_4	Na, Alkalinity, SO_4, Cl	NH_4
Others listed in this table that are potentially impacted[g]			NO_3, PO_4			None	None	No data	No data	No data	PO_4	No data

Notes: Concentration calculated assuming typical quantity used per 100 gallons drilling slurry. The concentrations shown above were calculated using the initial concentrations in the undiluted product summarized in Table 4-6.

[a] Values from Table 4-3a except K, which is from Table 4.2-3 in Groundwater Background Investigation Report, Rev. 2 (LANL 2007, 094856).

[b] Assumed quantity added per 100 gallons is based on industry guidance summarized in Table B-3.

[c] Estimated proportions used per 100 gal. in R-25.

[d] — = Not calculated because no data are available.

[e] Sulfur in AQUA-CLEAR MGA is initially in the form of sulfide. The concentration of SO_4 listed above corresponds to 15 mg/L as S^{2-}.

[f] These species appear to possess most of the desirable qualities listed for an indicator species in Section 4.3. Although it was measured at high concentrations in the deionized-water leachates of bentonite drilling muds, elevated NO_3 is not considered a reliable indicator species for this category of effects because it is commonly present in contaminant plumes and is very sensitive even to slightly reducing conditions.

[g] Section 4.10 describes the assessment protocol for identifying analytes with the potential to be impacted by this residual drilling effect. In this table, for the sake of simplicity, an analyte is listed simply if the increased concentration attributable to the product in the drilling fluid is greater than the median concentration for the regional aquifer.

Table 4-8

Category A: Questions and Test Criteria for Residual Water-Soluble Inorganic Constituents of Drilling Fluids

Issue: Have residual inorganic constituents been sufficiently removed such that they do not modify transport characteristics of contaminants in the screen interval?

Screening Question	Assessment Criteria[a]	Consequence of "NO" response[b]
Are concentrations of the following species all below the upper threshold value representative of maximum background concentrations in groundwater?	• A1—Is Chloride less than 3.8 mg/L (1.75 mg/L)? • A2—Is Fluoride less than 0.53 mg/L (0.23 mg/L)? • A3—Is Phosphate (as P) less than 0.3 mg/L (0.08 mg/L)? • A4—Is Sodium less than 29 mg/L (12 mg/L)? • A5—Is Sulfate less than 6.2 mg/L (4.5 mg/L)? • Gen1[c]—Is pH within the range representative of background groundwater? • Gen2[c]—Is Alkalinity (HCO_3+CO_3) less than 106 mg/L as $CaCO_3$ (52 mg/L)?	If NO for any analyte, then flag any detections of the following analytes as possibly elevated above predrilling concentrations (J+) due to residual water-soluble inorganic constituents of drilling products. General inorganic analytical suite: Cl, F, Na, NH_4, NO_3, PO_4, SO_4 Metal analytical suite: Sb, As, B, Cr, Cu, Fe, Pb, Mn, Hg, Mo, Ni, Se, Sr, U

[a] The assessment criteria lists the threshold value for the regional aquifer first, followed by a value for the perched intermediate aquifer shown in parentheses, if different. Threshold values are taken from Tables 4-3a and 4-3b.

[b] Section 4.10.2 describes the assessment protocol for identifying analytes with the potential to be impacted by this residual effect of drilling products. The list shown here is based on Tables 4-7, 4-19, A-1 and A-2.

[c] This test is neither required nor sufficient to establish the presence or absence of residual inorganic drilling fluids. However, it can determine the level of confidence that one should have in the outcome of the other test criteria.

Table 4-9
Compositions of QUIK-FOAM and EZ-MUD

Drilling Product Constituents	Concentration in Raw Product (wt %)[a]	%C for this Constituent (wt %)[b]	Constituent's Contribution of TOC to Raw Product (ppm)
QUIK-FOAM			
Water	40.0	0	0
Acetone	0.2	62	992
Isopropyl alcohol (IPA)	4.5	60	26775
Ethanol	7.5	52	39175
Anionic AES #1: Decyl nona(ethyleneoxide) sulfate (probably with NH_4^+ counterion[c])	43.2	53	229015
Anionic AES #2: Dodecyl hexa(ethyleneoxide) sulfate (probably with NH_4^+ counterion[c])	4.0	54	21748
Total	100.0		317705
EZ-MUD			
Alkanes with hydrocarbon chain lengths of C11-14: tridecane, dodecane, undecane, tetradecane	69.5	83	577242
Partially hydrolyzed (30.5%) polyacrylamide	30.5	51	154648
Total	100.0		731890

[a] Characterization data reported by Larson (2006, 094892) and Robison (2006, 094883; 2006, 094891).

[b] Calculated based on stoichiometric formulas.

[c] Based on information listed for QUIK-FOAM in Wisconsin Department of Natural Resources (2006, 094917).

Table 4-10
Water-Soluble Organic Constituents Leached from Drilling Products

Constituent	AQUA-GEL GOLD SEAL	QUIK-GEL	PAC-L	QUIK-FOAM[a]	EZ-MUD[a]	N-SEAL	AQUA-CLEAR PFD	Silicone Defoamer (SDI)
Oxalate	<0.2	<0.2	<4	—[b]	—	<0.2	11057	<0.2
TKN [c] (calculated)	—	—	—	10,600[d]	41000	—	—	—
TOC	—	—	—	318000	732000	—	—	—
DOC	124	94	196664	67000[e]	—	30	2950[f]	2654
Estimated DOC in drilling slurry[g]	18	14	1140	—	—	0.9	—	15

Notes: Concentrations in mg/kg of product as packaged. Concentrations determined on deionized-water leaches of products by Dale Counce and Pat Longmire (GGRL, EES-6), except where noted in footnote a.

[a] Based on characterization data reported by Larson (2006, 094892) and Robison (2006, 094883).

[b] — = Not calculated because no data are available.

[c] TKN = Total dissolved concentration of reduced nitrogen, which is the combination of organically-bound nitrogen and ammonia.

[d] Assumes NH_4^+ is the counterion of the AES molecule, which comprises 47% of QUIK-FOAM (Table 4-9) and has an average molecular weight of 633 (Robison 2006, 094883). Thus, the estimated proportion of N (atomic weight = 14) is $0.48 \times 14/633 \times 10^6$ = 10,616 ppm (rounded to 10,600 ppm). This value is assumed to apply to TKN as well.

[e] Sum of measured concentrations of acetone (0.16%), isopropyl alcohol (4.5%), and ethanol (7.5%) in QUIK-FOAM (Larson 2006, 094892).

[f] DOC in AQUA-CLEAR PFD is 27% of the formula weight of oxalate ($C_2H_2O_4$), which comprises about 80% of this product.

[g] Assumes the rate of use per 100 gal. of water is as shown in Table 4-7.

Table 4-11
Category B: Questions and Criteria for Residual Organic Constituents of Drilling Fluids

Issue: Have residual organic drilling fluids been sufficiently removed such that groundwater samples are reliable and representative of the groundwater?

Screening Question	Assessment Criteria[a]	Consequence of "NO" response[b]
Are concentrations of the following organic indicators all below the threshold value representative of background concentrations in groundwater?	Are <u>all</u> of the following conditions met? • B1—Is acetone either below the method detection limit or less than 5 µg/L? • B2—Is ammonium[c] (as N) less than 0.05 mg/L? • B3—Is total Kjeldahl nitrogen (TKN)[d] less than 0.28 mg/L? • B4—Is total organic carbon (TOC) below 1 mg/L?	If NO, flag any <u>detected</u> concentrations of the following analytes as possibly <u>greater</u> than predrilling concentrations (J+) due to the presence of residual organic fluids: • DOC, TOC, TKN, ammonium (as N), acetone, sulfate, sulfide

[a] The assessment criteria are the same for the regional aquifer and the perched intermediate aquifer because there is not expected to be a significant difference between these two populations for these species. Threshold values are taken from Tables 4-3a and 4-3b, except for acetone. In the case of acetone, the threshold is selected for the practical reason that a significant proportion of the data for this analyte in the WQDB are reported relative to a reporting limit of 5 µg/L.

[b] Section 4.10.3 describes the assessment protocol for identifying analytes with the potential to be impacted by this residual effect of drilling products. The list shown here is based on analytes identified as potentially affected by category B in Tables A-4 through A-8. Under rare conditions, such as the presence of surfactant micelles, additional organic analytes could be impacted. However, as explained in Section 4.10.3, this possible impact is not been addressed in this report because the requisite conditions would be site-specific and have not been present in any postdevelopment water-quality samples.

[c] When dissolved in water, ammonia (NH_3) is most commonly present as the cation ammonium (NH_4^+).

[d] TKN = Total dissolved concentration of reduced nitrogen, which is the combination of organically-bound nitrogen and ammonia.

Table 4-12
Selected Redox Couples

	Redox Element		Oxidized Species	Reduced Species	Eh (mV)[a]	pE[a]
	Carbon	C(III/II)	PCA[b]	PCE[b]	1130	19.1
	Chloride	Cl(VII/-I)	ClO_4^-	Cl^-	976	16.5
→[c]	Oxygen	O(0/-II)	O_2(g)	H_2O	800	13.5
→	Nitrogen	N(V/0)	NO_3^-	N_2(g)	713	12.0
	Plutonium	Pu(V/IV)	PuO_2^+	PuO_2	634	10.7
	Carbon	C(II/II, 0)	PCE	TCE	580	9.8
	Plutonium	Pu(V/IV)	PuO_2^+	$Pu(OH)_4^0$	556	9.4
→	Manganese	Mn(IV/II)	MnO_2(s)	Mn^{2+}	544	9.2
	Carbon	C(II, 0/0)	TCE[b]	t-DCE[b]	540	9.1
→	Chromium	Cr(VI/III)	CrO_4^{2-}	$Cr(OH)_2^+$	500	8.4
	Selenium	Se(VI/IV)	SeO_4^{2-}	SeO_3^{2-}	446	7.5
	Carbon	C(0/-II)	t-DCE[b]	vinyl chloride	370	6.3
→	Uranium	U(VI/IV)	$UO_2(CO_3)_2^{2-}$	$USiO_4$(am)	73	1.2
→	Uranium	U(VI/IV)	$UO_2(CO_3)_2^{2-}$	UO_2(am)	64	1.1
	Plutonium	Pu(IV/III)	PuO_2	$PuCO_3^+$	15	0.3
→	Iron	Fe(III/II)	$Fe(OH)_3$	Fe^{2+}	14	0.2
	Molybdenum	Mo(VI/IV)	MoO_4^{2-}	MoS_2(s)	-203	-3.4
→	Sulfur	S(VI/-II)	SO_4^{2-}	H_2S(aq)	- 217	-3.7
	Arsenic	As(V/III)	$HAsO_4^{2-}$	H_3AsO_3(aq)	- 249	-4.2
	Carbon	C(IV/-IV)	HCO_3^-	CH_4(g)	- 260	-4.4
	TNT		TNT[b]	2-ADNT[b]	- 390	-6.6
	Hydrogen	H(I/0)	H_2O	H_2(g)	- 400	-6.8
	TNT		TNT[b]	4-ADNT[b]	- 430	-7.3

Notes: g = gas; s = solid, aq = aqueous, mV = millivolts.

[a] Redox potential at pH 7 and 25°C. Eh is the measured electron potential relative to the hydrogen electrode. pE is the negative log of electron activity, related to Eh by the relationship pE = Eh(mV) / 59.2 for pH 7 and 25°C.

Note: The Eh values listed for these redox couples are based solely on thermodynamic calculations. Many of these species can be reduced at Eh conditions well above the listed electron potential in the presence of appropriate microbial populations.

[b] 2-ADNT = 2-Amino-4,6-dinitrotoluene; 4-ADNT = 4-Amino-2,6-dinitrotoluene; PCA = perchloroethane (hexachloroethane); PCE = perchloroethylene; TCE = trichloroethylene; t-DCE = trans-dichloroethylene; TNT = 2,4,6-trinitrotoluene.

[c] → = Redox pairs used in this assessment as indicator species for in-situ redox conditions.

Table 4-13
Behavior of Inorganic and Organic Species under Reducing Conditions

Analytical Suite	Analytes That May Not Be Representative of Predrilling Concentrations Under Reducing Conditions				
	Sulfate Reducing Conditions (SO_4 below background)	**Iron-Reducing Conditions (Dissolved Fe concentrations elevated above background)**	**Manganese-Reducing Conditions (Dissolved Mn concentrations elevated above background)**	**Nitrate-Reducing Conditions (NO_3 below background)**	**Unaffected by Redox Conditions**
General Inorganics[a]	Nitrate, perchlorate, sulfate	Nitrate, perchlorate	Nitrate, perchlorate	Nitrate	Calcium, chloride, fluoride, magnesium, phosphorus, sodium
Metals[a]	Antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, molybdenum, nickel, selenium, silver, strontium, thallium, uranium, vanadium, zinc	Barium, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, molybdenum, nickel, selenium, silver, strontium, thallium, uranium, vanadium, zinc	Barium, beryllium, cadmium, chromium, cobalt, manganese, nickel, silver, strontium, thallium, zinc	—	—
Radionuclides[a]	Isotopes of americium, cerium, cesium, cobalt, europium, lanthanum, neodymium, plutonium, radium, strontium, technetium, uranium	Isotopes of americium, cerium, cesium, cobalt, europium, lanthanum, neodymium, plutonium, radium, strontium, uranium	Isotopes of americium, cerium, cesium, cobalt, europium, lanthanum, neodymium, plutonium, radium, strontium	—	Tritium
High Explosives and Degradation Products (HEXP)	Same list of analytes for all reducing conditions: All HEXP analytes: amino-dinitrotoluenes, dinitrobenzenes, dinitrotoluenes, nitrobenzenes, nitroglycerine, nitrotoluenes, DNX, HMX, MNX, PETN, RDX, tetryl, TNX, trinitrobenzene				Not determined
Dioxins and Furans	Same list of analytes for all reducing conditions: All chlorodibenzodioxins and chlorodibenzofurans				Not determined
Pesticides and PCBs	Same list of analytes for all reducing conditions: All pesticides and PCBs: Aldrin, Arochlors, BHCs, chlordanes, DDD, DDE, DDT, Dieldrin, Endosulfans, Endosulfan sulfate, Endrin, Endrin aldehyde, Endrin Ketone, Heptachlor, Heptachlor epoxide, Methoxychlor, Toxaphene				Not determined
Herbicides	Same list of analytes for all reducing conditions: All herbicides: Alachlor, Atrazine, MCPA, D[2,4-], DB[2,4-], Dalapon, DBCP, Dicamba, Dichlorprop, Dinoseb, Diquat, Endothall, Glyphosate, MCPP, Paraquat, Picloram, Simazine, T[2,4,5-], TP[2,4,5-]				Not determined

Table 4-13 (continued)

Analytical Suite	Analytes That May Not Be Representative of Predrilling Concentrations Under Reducing Conditions				
	Sulfate Reducing Conditions (SO_4 below background)	**Iron-Reducing Conditions (dissolved Fe concentrations elevated above background)**	**Manganese-Reducing Conditions (dissolved Mn concentrations elevated above background)**	**Nitrate-Reducing Conditions (NO_3 below background)**	**Unaffected by Redox Conditions**
Diesel Range Organics (if not included elsewhere)	Same list of analytes for all reducing conditions: Diesel Range Organics; Total Petroleum Hydrocarbons Diesel Range Organics (TPH-DRO)				Not determined
Polynuclear Aromatic Hydrocarbons (PAHs)	Same list of analytes for all reducing conditions: All PAHs: Acenaphthene, acenaphthylene, acetylamidofluorene[2-], anthracene, benz(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, bibenz(a,h)anthracene, fluoranthene, fluorene, indeno(1,2,3-cd)pyrene, methylcholanthrene[3-], methylnaphthalenes, naphthalene, phenanthrene, pyrene				Not determined
SVOCs and VOCs (if not already included in above categories)	Same list of analytes for all reducing conditions: All SVOCs/VOCs: acetone, benzene, benzidine, benzoic acid, benzyl alcohol, bis(2-ethylhexyl)phthalate, bromodichloromethane, bromoform, bromomethane, butanone[2-], butylbenzylphthalate, carbazole, carbon disulfide, carbon tetrachloride, chloro-3-methylphenol[4-], chlorobenzene, chloroethane, chloroform, chloromethane, chloronaphthalene[2-], chlorophenol[2-], dibenzofuran, dibromochloromethane, dichlorobenzenes, dichloroethanes, dichloroethenes, diethyl phthalate, dimethyl phthalate, di-n-butyl phthalate, di-n-octyl phthalate, diphenylhydrazine[1,2-], ethylbenzene, hexachlorobenzene, hexachlorobutadiene, isopropyltoluene[4-], methyl tert-butyl ether, methyl-2-penta[4-], methylene chloride, methylphenol[4-], nitrophenol[2-], pentachlorophenol, phenol, pyridine, tetrachloroethane[1,1,1,2-], tetrachloroethane[1,1,2,2-], tetrachloroethene, toluene, trichlorobenzenes, trichloroethanes, trichloroethene, trichlorofluoromethane [CFC-11], timethylbenzene[1,2,4-], vinyl chloride, xylenes				Not determined

[a] **Based on geochemical model calculations by Longmire and Fabryka-Martin (2007, 095818)**

Table 4-14
Category C: Questions and Criteria for Redox Conditions Near the Screen Interval

Issue: Have oxidizing conditions been re-established such that groundwater samples are reliable and representative of the groundwater?

Screening Question	Assessment Criteria[a]	Consequence of "NO" response[b,c]
Is sulfur present in its oxidized (SO_4) form?	Are all the following conditions met? • C1—Is sulfate present above 0.8 mg/L (1.0 mg/L)? • C2—Is sulfide less than 0.01 mg/L? • C3—Is oxidation-reduction potential (ORP) greater than 0 mV?	If NO, then flag the following analytes as possibly not reliable or representative of predrilling concentrations (J) due to chemical transformation, desorption from Fe/Mn (oxy)hydroxides, or mineral precipitation under sulfate-reducing conditions initiated by the presence of residual organic fluids: • General inorganic analytical suite: NO_3, SO_4, ClO_4 • Metals analytical suite: Ag, As, Ba, Be, Cd, Co, Cr, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Sb, Se, Sr, Tl, U, V, Zn • Radionuclide analytical suite: Cs-137, Co-60, Sr-90, Tc-99, and isotopes of Am, Ce, Eu, La, Nd, Pu, Ra, and U
Have redox conditions been restored to oxidizing conditions with respect to sulfate, iron, and manganese?	Are all the following conditions met? • C4—Is dissolved iron less than 102 µg/L? • C5—Is dissolved manganese less than 16 µg/L? • C6—Is perchlorate detected above 0.17 µg/L? • C7—Is uranium detected above 0.17 µg/L (0.1 µg/L)? • C8—Is dissolved nickel less than 5 µg/L (3 µg/L)? • C9—Is dissolved molybdenum less than 4 µg/L? • C10—Is dissolved chromium greater than 1 µg/L?	If NO, then flag the following analytes as possibly not reliable or representative of predrilling concentrations (J) due to chemical transformation, desorption from Fe/Mn (oxy)hydroxides, or mineral precipitation under reducing conditions initiated by the presence of residual organic fluids: • General inorganic analytical suite: NO_3, ClO_4 • Metals analytical suite: Ag, Ba, Be, Cd, Co, Cr, Cu, Fe, Mn, Mo, Ni, Pb, Se, Sr, Tl, U, V, Zn • Radionuclide analytical suite: Cs-137, Co-60, Sr-90, and isotopes of Am, Ce, Eu, La, Nd, Pu, Ra, and U
Have redox conditions been restored to oxidizing conditions with respect to nitrate and dissolved oxygen?	Are the following conditions met? • C11—Is nitrate + nitrite detected above 0.1 mg/L as N? • C12—Is dissolved oxygen greater than 2 mg/L?	If NO, then flag the following analytes as possibly not reliable or representative of predrilling concentrations (J) due to chemical transformation under reducing conditions initiated by the presence of residual organic fluids: • General inorganic analytical suite: NO_3

[a] The assessment criteria lists the threshold value for the regional aquifer first, followed by a value for the perched intermediate aquifer shown in parentheses, if different. Values are taken from Tables 4-3a and 4-3b, unless otherwise noted.

[b] In addition to the species listed below, also flag the following analytes if any condition listed in this table is not met: all HE and HE degradation products; all herbicides, pesticides, PCBs, dioxins, and furans; all Diesel Range Organics; all SVOCs and VOCs.

[c] Section 4.10.4 describes the assessment protocol for identifying analytes with the potential to be impacted by this residual effect of drilling products. The list shown here is based on analytes identified as potentially affected by category C in Tables A-1 through A-8.

Table 4-15
Adsorption Behavior of Inorganic and Organic Species on Sodium-Bentonite Drilling Mud

Analytical Suite	Tables of Relevant Analytes and Sorption Parameters	Partition Coefficient (K_d)[a]	
		Negligible Adsorption $K_d < 1$ mL/g	**Possibly Significant Adsorption $K_d > 1$ mL/g**
General Inorganics	Table A-1 Table A-11 Table A-12	Ammonia, bromide, chloride, fluoride, nitrate, perchlorate, phosphorus, sodium, sulfate	Calcium, magnesium
Metals	Table A-2 Table A-11 Table A-12	Antimony, arsenic, boron, chromate, copper, mercury, molybdenum, selenium, uranium, vanadium	Barium, beryllium, cadmium, cobalt, iron, lead, manganese, nickel, silver, strontium, thallium, zinc
Radionuclides	Table A-3 Table A-11 Table A-12	Tritium, technetium-99, uranium isotopes	Isotopes of americium, cerium, cesium, cobalt, europium, lanthanum, neodymium, plutonium, radium, strontium
High Explosives and Degradation Products (HEXP)	Table A-4	4-ADNT, 2-ADNT, dinitrobenzenes [1,2-, 1,3-, and 1,4-], dinitrotoluenes [2,4-, 2,6-, and 3,4-], nitrobenzene, nitroglycerine, nitrotoluene [2-, 3-, and 4-], RDX, trinitrobenzene [1,3,5-]	HMX, PETN, tetryl, trinitrotoluene[2,4,6-] K_d unknown: DNX, MNX, TNX
Dioxins and Furans	Table A-5	—	All chlorodibenzodioxins and chlorodibenzofurans
Pesticides and PCBs	Table A-5	—	All: Aldrin, Arochlors, BHCs, chlordanes, DDD, DDE, DDT, Dieldrin, Endosulfans, Endosulfan sulfate, Endrin, Endrin aldehyde, Endrin Ketone, Heptachlor, Heptachlor epoxide, Methoxychlor, Toxaphene
Herbicides	Table A-6	Alachlor, Atrazine, 2,4-D, Dalapon, 2,4-DB, DBCP, Dicamba, Dichloroprop, Dinoseb, Endothall, MCPA, MCPP, Picloram, 2,4,5-T, Simazine	Diquat, Glyphosate, 2,4,5-TP
Diesel Range Organics (analytes not included elsewhere)	Table A-6	—	Diesel Range Organics; Total Petroleum Hydrocarbons Diesel Range Organics (TPH-DRO)
Polynuclear Aromatic Hydrocarbons (PAHs)	Table A-7	Naphthalene	All: Acenaphthene, acenaphthylene, acetylamidofluorene[2-], anthracene, benz(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, dibenz(a,h)anthracene, fluoranthene, fluorene, indeno(1,2,3-cd)pyrene, methylcholanthrene[3-], methylnaphthalenes, phenanthrene, pyrene

Table 4-15 (continued)

Analytical Suite	Tables of Relevant Analytes and Sorption Parameters	Partition Coefficient (K_d)[a]	
		Negligible Adsorption **$K_d < 1$ mL/g**	**Possibly Significant Adsorption** **$K_d > 1$ mL/g**
SVOCs and VOCs (analytes not included elsewhere)	Table A-8	Acetone, benzene, benzoic acid, benzyl alcohol, bromodichloromethane, bromoform, bromomethane, 2-butanone, carbon disulfide, carbon tetrachloride, 4-chloro-3-methylphenol, chlorobenzene, chloroethane, chloroform, chloromethane, dibromochloromethane, 1,2-dichlorobenzene, dichlorethanes, dichloroethene, dichloroethylene, diethyl phthalate, 1,2-diphenylhydrazine, ethylbenzene, MTBE, methylene chloride, 4-methyl-2-pentanone, 4-methylphenol, 2-nitrophenol, phenol, pyridine, tetrachloroethanes, tetrachloroethylene, toluene, trichloroethanes, trichloroethene, trichlorofluoromethane, trimethylbenzene, vinyl chloride, xylenes	Benzidine, bis(2-ethylhexyl)phthalate, butylbenzylphthalate, carbazole, 2-chloronaphthalene, 2-chlorophenol, dibenzofuran, 1,3-dichlorobenzene, 1,4-dichlorobenzene, dimethyl phthalate, di-n-butyl phthalate, di-n-octyl phthalate, hexachlorobenzene, hexachlorobutadiene, 4-isopropyltoluene, pentachlorophenol, trichlorobenzenes

[a] The relevant K_d value is that determined or assumed for the dominant dissolved species of the analyte. For inorganic analytes, including radionuclides, the dominant species are listed in Tables A-1 through A-3. When an applicable measurement of the K_d values for an organic compound is not available, this parameter has been estimated in Tables A-4 through A-8 as the product of the organic compound's organic-carbon partition coefficient (K_{OC}) and an assumed organic-carbon fraction (f_{OC}) value of 0.001 for bentonite.

Table 4-16

Category D: Questions and Test Criteria for Changes in Adsorption Capacities of Surface-Active Minerals

Issue: Have residual surface-active minerals (primarily bentonite clay) been sufficiently removed such that they do not interfere with transport of contaminants into the screen interval?

Screening Question	Assessment Criteria[a]	Consequence of “NO” response[b]
Are water-quality data reliable and representative for general inorganics, metals, and radionuclides that would adsorb onto residual bentonite if present?	D1—Is the concentration of dissolved strontium above the minimum background concentration for groundwater (45 µg/L, 19 µg/L for perched intermediate zone)?	If NO, then flag the following analytes as possibly less than predrilling concentrations (J-) due to adsorption onto residual bentonite: • Ca, Mg, Sr, Sr-90
	D2—Is the concentration of dissolved uranium above the minimum background concentration (0.17 µg/L for regional aquifer, 0.1 µg/L for perched intermediate zone)?	If NO, then flag the following analytes as possibly less than predrilling concentrations (J-) due to adsorption onto residual bentonite: • U, U-234, 235, 236, 238
	D3—Is the concentration of dissolved barium above the minimum background concentration (4.7 µg/L for regional aquifer, 1.4 µg/L for perched intermediate zone)? Note: Ba is considered here to be the most appropriate indicator species for the adsorption behavior of Cs-137 and radium isotopes on bentonite clay. D4—Is the concentration of dissolved zinc above the instrument detection limit? Note: Zn is considered here to be an appropriate indicator species for the adsorption behavior of trace metals, Co-60, and isotopes of Eu, La, and Nd.	If NO, then flag any <u>nondetects</u> of the following analytes as possibly less than predrilling concentrations (UJ-) due to adsorption onto residual bentonite: Metals: Ag, Ba, Be, Cd, Co, Fe, Pb, Mn, Ni, Tl, Zn Radionuclides: Cs-137, Co-60, isotopes of Eu, La, and Nd
	Note: Some radionuclides adsorb so strongly to clays, including bentonite, that they are rarely detected in groundwater. As a result, we are not aware of any suitable indicator species that are routinely measured and that can be used to evaluate whether or not the nondetects are representative of groundwater concentrations.	Follow the protocol described in Section 4.10.5 to identify whether or not <u>nondetects</u> of the following analytes should be flagged as possibly less than predrilling concentrations (UJ-) due to adsorption onto residual bentonite: Am-241, Ce-139, Ce-141, Ce-144, Pu-238,239,240, Ra-226, Ra-228

Table 4-16 (continued)

Screening Question	Assessment Criteria[a]	Consequence of "NO" response[b]
Are water-quality data reliable and representative for HE and HE degradation products?	NO for HE and HE degradation products with an adsorption coefficient (K_d) greater than 1 mL/g. YES for all other relevant HE and HE degradation products because these do not adsorb or partition onto bentonite.	Follow the protocol described in Section 4.10.5 to identify whether or not nondetects of the following analytes should be flagged as possibly less than predrilling concentrations (UJ-) due to adsorption onto residual bentonite: DNX, HMX, MNX, PETN, tetryl, TNX, TNT
Are water-quality data reliable and representative for Herbicides, Pesticides, PCBs, Dioxins, and Furans?	NO for pesticides, PCBs, dioxins and furans. These species are assumed to partition or adsorb onto bentonite, with K_d values much greater than 1 mL/g. YES for most herbicides (except as listed in the right-hand column). These species adsorb poorly onto bentonite, with K_d values less than 1 mL/g.	Follow the protocol described in Section 4.10.5 to identify whether or not nondetects of any pesticides, PCBs, dioxins, and furans should be flagged as possibly less than predrilling concentrations (UJ-) due to adsorption onto residual bentonite. Follow the protocol described in Section 4.10.5 to identify whether or not nondetects of the following herbicides should be flagged as possibly less than predrilling concentrations (UJ-) due to adsorption onto residual bentonite: Diquat, glyphosate, TP[2,4,5-]
Are water-quality data reliable and representative for Diesel Range Organics?	NO for Diesel Range Organic species that are petroleum hydrocarbons. These long-chain aliphatic hydrocarbons are assumed to adsorb or partition strongly onto bentonite, with K_d values greater than 1 mL/g.	Follow the protocol described in Section 4.10.5 to identify whether or not nondetects of the DRO and TPH-DRO should be flagged as possibly less than predrilling concentrations (UJ-) due to adsorption onto residual bentonite.
Are water-quality data reliable and representative for SVOCs/VOCs (LANL Specific)?	NO for SVOCs/VOCs that have an adsorption coefficient (K_d) greater than 1 mL/g. YES for all other SVOCs/VOCs because these adsorb poorly onto bentonite, with Kd values less than 1 mL/g.	Follow the protocol described in Section 4.10.5 to identify whether or not nondetects of the following SVOCs/VOCs should be flagged as possibly less than predrilling concentrations (UJ-) due to adsorption onto residual bentonite: Polynuclear aromatic hydrocarbons (PAHs) (excluding naphthalene) Benzidine, bis(2-ethylhexyl)phthalate, butylbenzylphthalate, carbazole, chloronaphthalene[2-], chlorophenol[2-], dibenzofuran, dichlorobenzene[1,3-], dichlorobenzene[1,4-], dimethyl phthalate, di-n-butyl phthalate, di-n-octyl phthalate, hexachlorobenzene, hexachlorobutadiene, isopropyltoluene[4-], pentachlorophenol, trichlorobenzene[1,2,3-], trichlorobenzene[1,2,4-]

[a] The assessment criteria lists the threshold value for the regional aquifer first, followed by a value for the perched intermediate aquifer shown in parentheses, if different. Values are taken from Tables 4-3a and 4-3b, unless otherwise noted.

[b] Section 4.10.5 describes the assessment protocol for identifying analytes with the potential to be impacted by this residual effect of drilling products. Part of that protocol is to assume that, if a water-quality sample passes all other test categories, then nondetects of strongly-adsorbing analytes are assumed also to be reliable and representative of the predrilling groundwater. The list of affected analytes shown here is based analytes identified as potentially affected by category D in Tables A-1 through A-8.

Table 4-17

Category E: Questions and Criteria for Precipitation or Dissolution of Carbonate Minerals Near the Screen Interval

Issue: Are carbonate minerals stable in the screen interval such that groundwater samples are reliable and representative of predrilling groundwater?

Screening Question	Assessment Criteria[a]	Consequence of "NO" Response[b]
Are the following indicators of carbonate mineral stability representative of background conditions in groundwater?	• E1—Is dissolved barium within the range considered representative of background groundwater (4.7<x<69 µg/L; 1.4<x<71 µg/L)? • E2 Is dissolved calcium within the range considered representative of background groundwater (8.7<x<25 mg/L; 4.4<x<18 mg/L)? • E3—Is dissolved magnesium within the range considered representative of background groundwater (<6.1 mg/L, <4.8 mg/L)? • E4—Is dissolved strontium within the range considered representative of background groundwater (<180 µg/L; <155 µg/L)? • E5—Is dissolved uranium within the range considered representative of background groundwater (<1.5 µg/L; <0.72 µg/L)? • Gen1[c] —Is pH within the range considered representative of background groundwater? • Gen2[c] —Is alkalinity within the range considered representative of background groundwater (<105 mg/L, <52 mg/L)?	If NO, flag the following analytes as possibly not representative of predrilling concentrations (J) due to active dissolution or precipitation of carbonate minerals as a result of drilling-induced changes in water chemistry: • Ba, Ca, Cd, Cu, Fe, Mg, Mn, Ni, Pb, Sr, U, Zn • Isotopes of Am, Ce, Eu, La, Nd, Ra, U

[a] The assessment criteria lists the threshold value for the regional aquifer first, followed by a value for the perched intermediate aquifer shown in parentheses, if different. Values are taken from Tables 4-3a and 4-3b, unless otherwise noted.

[b] Section 4.10.6 describes the assessment protocol for identifying analytes with the potential to be impacted by this residual effect of drilling products. The list shown here is based analytes identified as potentially affected by category E in Tables A-1 and A-2.

[c] This test is neither required nor sufficient to establish the presence or absence of residual inorganic drilling fluids. However, it can determine the level of confidence that one should have in the outcome of the other test criteria.

Table 4-18
Category F: Questions and Criteria for Metal Corrosion of Well Components

Issue: Is the integrity of the well casing and screen intact such that groundwater samples are reliable and representative of the groundwater?

Screening Question	Assessment Criteria[a]	Consequence of "NO" Response[d]
Are concentrations of the following indicators of stainless steel corrosion all below the threshold value representative of background concentrations in groundwater?	• F1[b]—Is total iron less than 500 µg/L? • F2—If NO to the above question, then is the ratio of total to dissolved iron less than 10? • F3[b]—Is total chromium less than the upper threshold limit for background (10 µg/L, 5 µg/L)? • F4— If NO to the above question, then is the ratio of total chromium to dissolved chromium less than 5? • F5—Is dissolved nickel less than 50 µg/L? • F6[c] —Is turbidity less than 5 NTU?	If NO, flag detections of the following analytes as possibly greater than predrilling concentrations (J+) due to corrosion of the stainless steel well casing: Corrosion products: Cr, Fe, Mn, Mo, Ni Adsorption onto Fe corrosion products: • Ba, Cd, Co, Cu, Pb, Hg, Se, Ag, Sr, Tl, Zn • Cs-137, Co-60, Sr-90, isotopes of Ra

[a] The assessment criteria lists the threshold value for the regional aquifer first, followed by a value for the perched intermediate aquifer shown in parentheses, if different. Values are taken from Tables 4-3a and 4-3b, unless otherwise noted.

[b] This test is a qualifying condition that establishes whether or not the following test criterion is applicable.

[c] This test is neither required nor sufficient to establish the presence or absence of metal corrosion. However, it can determine the level of confidence that one should have in the outcome of the other test criteria.

[d] Section 4.10.7 describes the assessment protocol for identifying analytes with the potential to be impacted by this residual effect of drilling products. The list shown here is based analytes identified as potentially affected by category F in Tables A-1 and A-2.

Table 4-19
Analytes Potentially Impacted by Residual Water-Soluble Inorganic Constituents Leached from Drilling Products

	Concentration in Regional Aquifer[a] (µg/L)		Extent of increased concentration (µg/L) in drilling slurry when the indicated product quantity is added to 100 gallons water					
			AQUA-GEL GOLD SEAL (bentonite)	Bentonite (product not specified)	QUIK-GEL (bentonite)	PAC-L	N-SEAL	AQUA-CLEAR PFD
Constituent	Median	Upper limit	25 lb[b]	25 lb[b]	25 lb[b]	1 lb[b]	5 lb[b]	1 gal.[b]
Antimony (Sb)	0.25	1.0 Max	1.2	1.7	< 0.3	< 0.1	0.05	0
Arsenic (As)	3.0	16 Max	6.1	41	2.7	< 0.3	< 0.1	< 0.02
Barium (Ba)	20.8	69 UTL	3.5	0.5	3.0	1.3	1.3	0.4
Boron (B)	13.65	41 UTL	17	30	9.1	< 2.4	2.3	1.1
Chromium (Cr)	3.5	6.6 UTL	2.9	2.5	2.1	3.5	0.4	2.0
Copper (Cu)	1.5	62 Max	41	1.9	3.9	4.2	1.0	2.9
Iron (Fe)	9.0	915 Max	122	< 2.5	15	6.6	< 0.6	3.5
Lead (Pb)	0.25	4.6 Max	0.6	< 0.03	< 0.3	0.4	< 0.06	0.2
Manganese (Mn)	1.0	220 Max	0.6	0.5	2.4	20	5.1	2.9
Mercury (Hg)	0.03	0.26 Max	< 0.03	0.06	< 0.03	< 0.02	< 0.01	0.02
Molybdenum (Mo)	1.09	3.8 UTL	20	74	25	< 0.2	< 0.1	0.3
Nickel (Ni)	0.50	50 Max	2.6	0.5	1.2	0.4	0.1	0.6
Selenium (Se)	1.25	4.6 Max	2.6	2.8	5.7	< 0.2	0.4	0.1
Strontium (Sr)	55.6	180 UTL	35	0.9	60	0.7	6.8	0.6
Uranium (U)	0.45	1.5 UTL	1.2	2.1	1.2	< 0.2	0.1	< 0.02
Vanadium (V)	7.9	26 UTL	1.4	3.8	< 0.6	< 0.5	0.9	0.5
Zinc (Zn)	1.9	41 Max	3.8	< 0.3	< 0.6	< 0.5	< 0.1	0.5
Potentially impacted if residual drilling product is present[c]			Sb, As, Cr, Cu, Fe, Pb, Mo, Ni, Se, U	Sb, As, B, Cr, Cu, Hg, Mo, Se, U	Cr, Cu, Mo, Ni, Se, Sr, U	Cr, Cu, Pb, Mn	None	Cu

Notes: Concentration calculated assuming typical quantity used per 100 gallons drilling slurry. The concentrations shown above were calculated using the initial concentrations in the undiluted product reported in Table A-10.

[a] Median and maximum or UTL values from Table 4.2-3 in Groundwater Background Investigation Report, Rev. 2 (LANL 2007, 094856). Note that median values are calculated by substituting ½ MDL for nondetected concentrations.

[b] Assumed quantity added per 100 gallons is based on industry guidance summarized in Table B-3.

[c] Section 4.10 describes the assessment protocol for identifying analytes with the potential to be impacted. In this table, for the sake of simplicity, an analyte is listed simply if the increased concentration attributable to the product in the drilling fluid is greater than the median value for the regional aquifer.

Table 4-20
Residual Effects of Drilling Products on Water Quality

Product Name	Chemical Description	Indicators of Residual Product*	Potential Residual Effects of Product on Water Quality	Other Products Often Used with This One
AQUA-CLEAR AE	Acid and acid enhancers	Low pH	May kill off native bacteria in formation, thereby delaying biodegradation process for residual organic drilling fluids until population recovers	AQUA-CLEAR MGA Soda Ash
AQUA-CLEAR MGA	80% Sulfamic acid (H_3NO_3S) and 20% NaCl	NH_4, SO_4, S, Na, Cl, low pH	May kill off native bacteria in formation, thereby delaying biodegradation process for residual organic drilling fluids until population recovers	AQUA-CLEAR AE Soda Ash
AQUA-CLEAR PFD	Copolymer containing phosphate-free dispersant	Na, Alkalinity, Cl, PO_4, SO_4, TOC	Any residual copolymer left in the formation may not biodegrade quickly, and may cause TOC to stay slightly elevated for a long time	
AQUA-GEL	Sodium bentonite with 0.0125% polyacrylate polymer	SO_4, Na, NO_3, TKN, NH_4, Alkalinity, K, TOC, F, Cl, Ca	Any residual copolymer left in the formation may not biodegrade quickly, and may cause TOC to stay slightly elevated for a long time	MAGMA FIBER N-SEAL
AQUA-GEL GOLD SEAL	Pure sodium bentonite, no chemical treatment	SO_4, Na, NO_3, Alkalinity, K, F, Cl, Ca	Inorganic salts that occur naturally in the clay product leach into water Provides adsorption sites for a wide variety of inorganic and organic species Can plug formation porosity	
EZ-MUD	Partially hydrolyzed polyacrylamide / polyacrylate copolymer in hydrocarbon (long-chain alkanes) solution	TKN, NH_4, TOC	Coats clay particles Any residual hydrocarbons and copolymer left in the formation may not biodegrade quickly, and may cause TOC to stay slightly elevated for a long time	Soda Ash
EZ-MUD PLUS	High molecular weight version of EZ-Mud	TKN, NH_4, TOC	If formed, copolymer micelles could plug pores Any residual hydrocarbons and copolymer left in the formation may not biodegrade quickly, and may cause TOC to stay slightly elevated for a long time	Soda Ash
LIQUI-TROL	Modified natural cellulosic polymer suspended in oil.	TOC	Any residual cellulose and oil left in the formation may not biodegrade quickly, and may cause TOC to stay slightly elevated for a long time	Bentonite mud
MAGMA FIBER	Specially formulated extrusion spun mineral fiber.	Alkalinity, F, Ca, K, TOC	May physically plug pores in zones of lost circulation May chemically plug pores by precipitation of silica gel	Bentonite mud Hydrochloric and acetic acids

Table 4-20 (continued)

Product Name	Chemical Description	Indicators of Residual Product*	Potential Residual Effects of Product on Water Quality	Other Products Often Used with This One
N-SEAL	Specially formulated extrusion spun mineral fiber.	Alkalinity, F, Ca, K, TOC	May physically plug pores in zones of lost circulation May chemically plug pores by precipitation of silica gel	Bentonite mud Hydrochloric and acetic acids
PAC-L	Modified natural cellulosic polymer	TOC, PO_4, Cl, Na, F, Alkalinity	Coats clay Any residual cellulose or oil left in the formation may not biodegrade quickly, and may cause TOC to stay slightly elevated for a long time	Bentonite mud
PEL-PLUG	Compressed bentonite pellets, 100% pure, chemically untreated and unaltered.	Na, Alkalinity	Coarser than bentonite mud material, and thus effects may not be as significant. Inorganic salts that occur naturally in the clay product leach into water Provides adsorption sites for a wide variety of inorganic and organic species Can plug formation porosity	—
PEL-PLUG TR30/60	Bentonite pellet coated with a natural resin	Na, Alkalinity, TOC	Resin coating (composition unknown) may cause false indication of contaminant plume	—
QUIK-FOAM	Alcohol ethoxy sulfates (AES), in ammonium salt form	Acetone, TOC, NH_4, TKN	Any residual AES surfactant left in the formation may not biodegrade quickly, and may cause TOC to stay slightly elevated for a long time	—
QUIK-GEL	Sodium bentonite with 0.11% sodium polyacrylate polymer	SO_4, Na, Alkalinity, NO_3, TOC, Cl, F, Ca	Any residual polymer left in the formation may not biodegrade quickly, and may cause TOC to stay slightly elevated for a long time	Soda ash MAGMA FIBER N-SEAL
SAPP	Sodium acid pyrophosphate	Na, PO_4	Formation of PO4 complexes could modify transport characteristics of selected metals and radionuclides	—
SDI DEFOAMER	Organosilicone emulsion	TOC	Effect is expected to be minimal due to verysmall volumes involved	—
SODA ASH	Sodium carbonate	Na, Alkalinity, high pH	Precipitates Ca carbonates, and thereby shifts the groundwater's degree of saturation with Ba, Mg, and Sr carbonate minerals.	—
TORKEASE	Emulsion of complex stearates	TOC	Relatively negligible	—

* Indicators are listed approximately in order of the extent to which they are predicted to be elevated above their median background concentrations in the regional aquifer (Table 4-3a), based on concentrations measured in product leachate (Tables 4-7 and A-10).

Table 4-21
Indicator Species and Test Threshold Values for Identifying Drilling Fluid Impacts

Indicator	Analyte Code	Condition Being Evaluated	Test Code[a]	UOM	Test Threshold for Passing Test	
					Perched	Regional Aquifer
Acetone	Acetone	Residual organics	B1	µg/L	< 5	< 5
Alkalinity (HCO_3+CO_3) (field)	ALK-HCO_3+CO_3	General indicator	Gen-2	mg/L	< 52	< 105
Ammonium (as Nitrogen)	NH_3-N	Residual organics	B2	mg/L	< 0.05	< 0.05
Barium (dissolved)	Ba	Adsorption/desorption	D3	µg/L	> 1.4	> 4.7
Barium (dissolved)	Ba	Carbonate minerals	E2	µg/L	< 71	< 69
Calcium (dissolved)	Ca	Carbonate minerals	E1	mg/L	4.4 < x < 18	8.7 x < 25
Chloride	Cl	Residual inorganics	A1	mg/L	< 1.75	< 3.8
Chromium (dissolved)	Cr	Redox condition (Fe/Mn)	C10	µg/L	> 0.4	> 0.8
Chromium (total)	Cr (Total)	Metal corrosion	F3	µg/L	< 7.4	< 10
Chromium ratio (total/dissolved)	Cr (NF/F) ratio	Metal corrosion	F4	ratio	< 5	< 5
Dissolved oxygen	DO	Redox condition (NO_3)	C12	mg/L	> 2	> 2
Fluoride	F	Residual inorganics	A2	mg/L	< 0.23	< 0.53
Iron (dissolved)	Fe	Redox condition (Fe/Mn)	C4	µg/L	< 102	< 102
Iron (Total)	Fe (NF)	Metal corrosion	F1	µg/L	< 500	< 500
Iron ratio (total/dissolved)	Fe (NF/F) ratio	Metal corrosion	F2	ratio	< 10	< 10
Magnesium	Mg	Carbonate minerals	E4	mg/L	< 6.1	< 4.8
Manganese	Mn	Redox condition (Fe/Mn)	C5	µg/L	< 14	< 14
Molybdenum	Mo	Redox condition (Fe/Mn)	C9	µg/L	< 4	< 4
Nickel (dissolved)	Ni	Redox condition (Fe/Mn)	C8	µg/L	< 2.5	< 2.5
Nickel (dissolved)	Ni	Metal corrosion	F5	µg/L	< 50	< 50
Nitrate + Nitrite (as Nitrogen)	NO_3+NO_3-N	Redox condition (NO_3)	C11	mg/L	> 0.2	> 0.1
Oxidation Reduction Potential	ORP	Redox condition (SO_4)	C3	meV	> 0	> 0
Perchlorate	ClO_4	Redox condition (Fe/Mn)	C6	µg/L	> 0.17	> 0.17

Table 4-21 (continued)

Indicator	Analyte Code	Condition Being Evaluated	Test Code[a]	UOM	Test Threshold for Passing Test	
					Perched	Regional Aquifer
pH (field)	pH	General indicator	Gen-1	SU	6.7< x < 8.8	6.9 < x < 8.6
Phosphate (as phosphorus)	PO_4-P	Residual inorganics	A3	mg/L	< 0.08	< 0.34
Sodium	Na	Residual inorganics	A4	mg/L	< 12.2	< 29
Strontium (dissolved)	Sr	Adsorption/desorption	D1	µg/L	> 19	> 44
Strontium (dissolved)	Sr	Carbonate minerals	E3	µg/L	< 155	< 180
Sulfate	SO_4	Residual inorganics	A5	mg/L	< 4.5	< 62
Sulfate	SO_4	Redox condition (SO_4)	C1	mg/L	> 1.07	> 0.8
Sulfide	S	Redox condition (SO_4)	C2	mg/L	< 0.01	< 0.01
Total Kjeldahl Nitrogen	TKN	Residual organics	B3	mg/L	< 0.28	< 0.28
Total organic carbon	TOC	Residual organics	B4	mg/L	< 1	< 1
Turbidity	Turbidity	General indicator	Gen-3	NTU	< 5	< 5
Uranium (dissolved)	U	Redox condition (Fe/Mn)	C7	µg/L	> 0.1	> 0.17
Uranium (dissolved)	U	Adsorption/desorption	D2	µg/L	> 0.1	> 0.17
Uranium (dissolved)	U	Carbonate minerals	E5	µg/L	< 0.72	< 1.5
Zinc (dissolved)	Zn	Adsorption/desorption	D4	µg/L	> DL[b]	> DL

Source of threshold values: Tables 4-3a and 4-3b, with lower limits set by truncating the lower statistical limit to two significant figures, and with upper limits set by rounding the upper statistical limit up to the nearest two significant figures (three significant figures in the case of alkalinity in the regional aquifer).

[a] The test code is keyed to the table in which this indicator is used. The letter indicates the drilling effects category, and the number indicates the sequence in which this indicator is listed in the table of tests for that category (Table 4-8 for Category A, Table 4-11 for Category B, Table 4-14 for Category C, Table 4-16 for Category D, Table 4-17 for Category E, and Table 4-18 for Category F).

[b] DL = Detection limit.

Table 4-22
Applicability of Indicator Species Used in this Report*

Indicator	Test	Applicability to Categories of Drilling Effects	Comments on Adequacy, Qualifications, and Limitations
Acetone	*B1*	Cat B—indicator of residual organics • Highly useful for the first year or two following development because readily detectable • Stays in solution due to its high solubility and negligible adsorption onto mineral surfaces	• Due to its very high solubility, acetone is removed to a much greater extent during development than are other larger and more adsorptive organics • The value of acetone as an indicator of residual organics decreases with time after development because it biodegrades much more quickly than most other organic species of concern • Measured value can be biased high because acetone is ubiquitous in the environment and therefore often present in field trip and laboratory blanks
Alkalinity (carbonate)	*Gen-2*	Cat A—indicator of residual inorganics (e.g., soda ash) Cat B—indicator of residual organics because CO_2, the primary control on alkalinity concentrations, is a biodegradation product of organic substances Cat B—indicator of reducing conditions because CO_2, the primary control on alkalinity concentrations, is a biodegradation product Cat D—can affect adsorption behavior of analytes which form carbonate complexes with differing ionic charges Cat E—controlling factor for carbonate mineral solubility	• The most relevant alkalinity measurement is that obtained in the field or a nearby onsite laboratory because changes in concentrations can occur during transit to an offsite laboratory. However, field measurements are not always obtained or reported in the WQDB. • Difficult to obtain reliable and representative alkalinity measurements from Westbay systems • Can be difficult to interpret as indicator species due to multiple sources and interacting controls • May be significantly affected by presence of contaminant plume • Test outcome can be biased low under highly-reducing (methanogenic) conditions because dissolved inorganic carbonate can be reduced to methane (CH_4)
Ammonium	*B3*	Cat B—indicator of residual organic drilling fluids that contain nitrogen (e.g., EZ-Mud)	• Residual organic sources of NH_3 may not be immediately apparent if the source material has a long biodegradation half-life (e.g., residual polyacrylamide from EZ-Mud), if microbial populations are not acclimated, or if microbial activity if suppressed under the prevailing geochemical conditions • May not always monotonically improve with time. If biodegradation is delayed until suitable environmental conditions develop, then this parameter may increase in concentration after first decreasing • Biodegradation rate affected by redox conditions

Table 4-22 (continued)

Indicator	Test	Applicability to Categories of Drilling Effects	Comments on Adequacy, Qualifications, and Limitations
Barium	*D3, E1*	Cat D—surrogate for strongly adsorbing species proposed by NMED and EPA Cat E—indicator for carbonate mineral stability because dissolved Ba concentrations are controlled primarily by alkalinity and sulfate concentrations	• Very limited utility as surrogate for strongly adsorbing species in local groundwaters. The mobility of Ba in local groundwaters is enhanced by its formation of neutral complexes with carbonate and sulfate. • Test outcome can be biased high if this species is present in a contaminant plume at the sampled location • Test threshold values may not be valid if pH, alkalinity, and redox conditions are outside the range of background values • Can be difficult to interpret as indicator species due to multiple interacting controls • Reliable interpretation may require geochemical modeling
Calcium	*E2*	Cat E—primary indicator of carbonate mineral stability	• Test threshold values may not be valid if pH, alkalinity, and redox conditions are outside the range of background values • May be present as residual inorganic drilling fluid • Can be difficult to interpret as indicator species due to multiple interacting controls • Interpretation may require geochemical modeling
Chloride	*A3*	Cat A—indicator of residual inorganics	• Test outcome can be biased high if this species is present in a contaminant plume at the sampled location
Chromium	*C10, F3, F4*	Cat C—negligibly low concentration indicates reducing conditions Cat F—highly elevated concentration is an indicator of stainless steel corrosion	• Test outcome can be biased high if this species is present in a contaminant plume at the sampled location • Data for both filtered and nonfiltered samples not always available but are required for reliable interpretation with respect to corrosion
Fluoride	*A4*	Cat A—indicator of residual inorganics	• Test outcome can be biased high if this species is present in a contaminant plume at the sampled location
Iron	*F1,F2*	Cat C—elevated concentrations indicates reducing conditions that dissolve Fe/Mn oxyhydroxide minerals and release adsorbed metals Cat F—highly elevated total concentration in presence of low dissolved concentration is an indicator of stainless steel corrosion	• May be biased low due to precipitation of metal sulfides under highly reducing conditions • Data for both filtered and nonfiltered samples not always available but are required for reliable interpretation with respect to corrosion
Magnesium	*E4*	Cat E—indicator for carbonate mineral stability because dissolved Mg concentrations are controlled primarily by Ca and alkalinity concentrations	• None noted

Table 4-22 (continued)

Indicator	Test	Applicability to Categories of Drilling Effects	Comments on Adequacy, Qualifications, and Limitations
Manganese	*C5*	Cat C—negligibly low concentration indicates reducing conditions	• Test outcome can be biased high if this species is present in a contaminant plume at the sampled location • May be biased low due to precipitation of metal sulfides under highly reducing conditions
Molybdenum	*C9*	Cat C—elevated concentrations indicates reducing conditions that dissolve Fe/Mn oxyhydroxide minerals and release adsorbed metals	• Test outcome can be biased high if this species is present in a contaminant plume (such as cooling water discharge) at the sampled location • Elevated concentrations might be attributable to leaching from bentonite drilling mud (Table A-10)
Nickel	*C8, F5*	Cat C—elevated concentrations indicates reducing conditions that dissolve Fe/Mn oxyhydroxide minerals and release adsorbed metals Cat F—highly elevated concentration is an indicator of stainless steel corrosion	• None noted
Nitrate + Nitrite	*C11*	Cat C—negligibly low concentration indicates reducing conditions	• Test outcome can be biased high if this species is present in a contaminant plume at the sampled location
Oxidation Reduction Potential	*C3*	Cat C—negligibly low value indicates reducing conditions. May be the most reliable indicator of SO_4-reducing conditions if this condition is obscured by the presence of SO_4 in a contaminant plume	• Difficult to obtain reliable measurements from Westbay systems • Not available for older water samples • Can be difficult to use as indicator species due to multiple sources and interacting controls • May be biased high due to aeration of cascading water as water level drops during purging, in screens located at or near the top of a saturated zone
Oxygen, Dissolved	*C12*	Cat C—low concentration indicates reducing conditions. May be the most reliable indicator of NO_3-reducing conditions if this condition is obscured by the presence of NO_3 in a contaminant plume	• Difficult to obtain reliable measurements from Westbay systems • Not routinely obtained for Westbay screens • May be biased high due to aeration of cascading water as water level drops during purging, in screens located at or near the top of a saturated zone
Perchlorate	*C6*	Cat C—negligibly low concentration indicates reducing conditions	• Commonly present in contaminant plumes

Table 4-22 (continued)

Indicator	Test	Applicability to Categories of Drilling Effects	Comments on Adequacy, Qualifications, and Limitations
pH (field)	*Gen-1*	General qualitative indicator, not tied to a specific residual drilling effect Cat A—indicator of residual inorganics (e.g., acids) Cat B—low pH can be an indicator of residual organics because H is a biodegradation product of organic substances Cat D—can affect adsorption behavior of analytes by pH controls on speciation Cat E—controlling factor for carbonate mineral solubility	• Most appropriate measurement is obtained in the field or onsite laboratory due to changes that can occur in transit to offsite laboratory. However, onsite measurements are not always obtained or available for Westbay screens. • Difficult to obtain reliable measurements from Westbay systems • Can be difficult to interpret as indicator species due to multiple interacting controls
Phosphate	*A9*	Cat A—indicator of residual inorganics	• Not present in very many drilling products
Sodium	*A6*	Cat A—indicator of residual inorganics	• Test outcome can be biased high if this species is present in a contaminant plume at the sampled location
Strontium	*D1, E3*	Cat D—surrogate for adsorption of Strontium-90 Cat E—indicator for carbonate mineral stability because dissolved Sr concentrations are controlled primarily by Ca and alkalinity concentrations	• Test threshold values may not be valid if pH, alkalinity, and redox conditions are outside the range of background values • Can be difficult to interpret as indicator species due to multiple interacting controls • Reliable interpretation may require geochemical modeling
Sulfate	*A5, C1*	Cat A—indicator of residual inorganics Cat C—low concentration indicates SO_4-reducing conditions	• Can be biased high due to fast oxidation of any dissolved sulfide upon exposure to atmosphere, or during transit to offsite laboratory • Test outcome can be biased high if this species is present in a contaminant plume at the sampled location
Sulfide	*C2*	Cat C—elevated concentration indicates SO_4-reducing conditions. May be the most reliable indicator of SO_4-reducing conditions if this condition is obscured by the presence of SO_4 in a contaminant plume	• Most appropriate measurement is obtained in the field or onsite laboratory due to rapid oxidation to sulfate during transit to an offsite laboratory. • Field or other onsite measurements are not always obtained for Westbay screens. • May be biased low due to degassing of water when exposed to atmosphere • May be biased low due to precipitation of metal sulfides under highly reducing conditions
Total Kjeldahl Nitrogen	*B2*	Cat B—indicator of residual organic drilling fluids that contain nitrogen (e.g., EZ-Mud)	• Test outcome can be biased low if the residual organic species adsorb to minerals or are otherwise not in solution

Table 4-22 (continued)

Indicator	Test	Applicability to Categories of Drilling Effects	Comments on Adequacy, Qualifications, and Limitations
Total Organic Carbon	*B1*	Cat B—indicator of residual organics	• Test outcome can be biased low if the residual organic species adsorb to minerals or are otherwise not in solution
Turbidity	*Gen-3*	General qualitative indicator, not tied to a specific residual drilling effect Cat F—high turbidity is a qualifying condition for application of tests for metal corrosion	• High turbidity may be caused by a quickly dropping water level (i.e., cascading water), if the screen interval intercepts the water table • Multiple causes of turbidity may complicate its interpretation as an indicator
Uranium	*C7, D2, E5*	Cat C—negligibly low concentration indicates reducing conditions Cat D—surrogate for adsorption of uranium isotopes Cat E—indicator for carbonate mineral stability because dissolved U concentrations are controlled primarily by Ca and alkalinity concentrations	• Test outcome can be biased high if this species is present in a contaminant plume at the sampled location • Not reliable test for adsorption if reducing conditions are present
Zinc	*D4*	Cat D—surrogate for strongly adsorbing metals	• Applicability as a surrogate may be limited in some geochemical environments in which the mobility of zinc may be enhanced by complexation with carbonate and other ligands • Test outcome can be biased high if this species is present in a contaminant plume at the sampled location

* A listed test code signifies that this analyte is used as one of the indicators for that category.

Table 5-1
Constituents Identified as Principal Components in Groundwater Data Sets

Data Set	PC 1	PC 2	PC 3	PC 4	Total Variation Explained by PCs 1, 2,& 3
Metals UF	Fe, Mn	B, Sr	Zn, Cr		65%
Metals F	Fe, Mn, Mo	B, Sr, Ba	Cr, Zn		65%
Major ions UF	Ca, Cl, K, Mg, total alkalinity	F, SO_4	Na vs. NO_3		72%
Major ions F	Na, K	Cl, SO_4, NO_3	Mg, total alkalinity, Ca		72%
Merged Metals and Major Ions UF	B, Ba, Sr Ca, Cl, K, Mg, total alkalinity	Fe, Mn vs V, NO_3, U	F	Na, SO_4	78% (includes PC4)
Merged Metals and Major Ions F	Fe, Mn vs Cr, V, NO_3, U	Ba, Sr, Ca, Cl, K	Na vs Mg	Zn	71% (includes PC4)

Notes: F = Filtered, UF = unfiltered, PC = principal component.

Table 5-2
Mean Concentrations in Clusters Identified for the Most Recent Nonfiltered Samples

Cluster	Total Carbonate Alkalinity (mg/L)	Ba (µgL)	Ca (µgL)	Fe (µgL)	Mn (µgL)	Na (mg/L)	$NO_3 + NO_2$-N (mg/L)	Sr (µgL)	U (µgL)	V (µgL)	Likely Drilling Effects
1	143	162	34	3802	874	255	0.07	397	0.43	1	Significant reducing conditions; carbonate minerals; possible residual bentonite (Na)
2	71	36	5	1251	329	35	0.01	31	0.66	1	Moderate reducing conditions
3	65	23	13	90	11	40	0.39	67	0.52	14	Minimal
4	102	86	24	57	23	19	0.47	140	1.48	13	Minimal; indication of naturally elevated Alk, Ba, Sr (PM-1, -3)

Notes: Cluster 1 Members: R-12-3, R-19-5, R-22-1, R-22-4, R-22-5, R-22-6, R-25-5
Cluster 2 Members: R-7-3, R-19-6, R-19-7
Cluster 3 Members: R-13, R-19-3, R-19-4, R-25-6, R-25-7, R-25-8, G-1A, G-2A, G-3A, G-5A
Cluster 4 Members: R-9, R-22-3, PM-1, PM-3

Table 5-3
Mean Concentrations in Clusters Identified for the Most Recent Filtered Samples

Cluster	Total Carbonate Alkalinity (mg/L)	Ba (µgL)	Ca (µgL)	Fe (µgL)	Mn (µgL)	Na (mg/L)	$NO_3 + NO_2$-N (mg/L)	Sr (µgL)	U (µgL)	V (µgL)	Likely Drilling Effects
1	203	233	38	424	654	39	0.01	698	0.79	1	Significant; highly elevated carbonates, reducing conditions
2	61	80	12	4320	600	14	0.01	114	0.07	2	Highly reducing conditions
3	91	51	20	8	2	17	0.78	143	1.19	12	Minimal; oxidizing conditions; indication of naturally elevated Sr (PM-1, -3)
4	87	26	15	95	23	28	0.27	128	0.83	16	Slight to moderate; elevated Sr, some reducing conditions
5	64	24	12	20	12	12	0.34	61	0.53	8	Minimal

Notes: Cluster 1 Members: R-5-4, R-12-3, R-20-2, R-22-4, R-31

Cluster 2 Members: CdV-R-15-3-5, CdV-R-15-3-6, CdV-R-37-2-2, CdV-R-37-2-4, R-14-2, R-20-2

Cluster 3 Members: R-4, R-8-2, R-16-3, Spring 3, Spring 3A, Spring 4, Spring 4A, Spring 5, Spring 5A, Spring 8, PM-1, PM-3

Cluster 4 Members: R-16-2, R-16-4, R-19-7, Spring 1, Spring 3AA, G-1A, G-2A, G-3A, G-5A

Cluster 5 Members: CdV-R-15-3-4, CdV-R-37-2-3, G-4A, PM-2, PM-5, PM-5, R-1, R-2, R-14-1, R-19-3, R-21, R-23, R-25-8, Spring 5B, Spring 6, Spring 6A, Spring 9A

Table 5-4
Results of Principal Component Analysis for Wells

Well Screen	Interpretation of PCA Results for Most Recent Sampling Event: Identification of Potential Impacts			
	Metals UF (Figure 5-1)	Metals F (Figure 5-2)	Major Ions UF (Figure 5-3)	Major Ions F (Figure 5-4)
CdV-15-3-4	√[a]	√	—[b]	√
CdV-15-3-5	Possible to Slight	Possible to Slight	—	√
CdV-15-3-6	√	√	—	√
CdV-37-2-2	Significant	Significant	—	√
CdV-37-2-3	√	√	—	√
CdV-37-2-4	√	√	—	√
R-1	√	√	—	√
R-2	√	√	—	√
R-4	√	√	—	Possible to Slight
R-5-3	Possible to Slight	√	—	Possible to Slight
R-5-4	Possible to Slight	Possible to Slight	—	Possible to Slight
R-7-3	Moderate	—	√	—
R-8-1	√	√	—	√
R-8-2	Possible to Slight	Possible to Slight	—	Moderate
R-9	Possible to Slight	—	Moderate	—
R-11	√	√	—	Possible to Slight
R-12-3	Possible to Slight	Moderate	Moderate	Possible to Slight
R-13	√	—	√	—
R-14-1	√	√	—	√
R-14-2	Moderate	Moderate	—	√
R-15	√	√	Possible to Slight	Possible to Slight
R-16-2	√	√	—	Moderate
R-16-3	√	√	—	Moderate
R-16-4	Possible to Slight	Possible to Slight	—	Significant
R-19-3	√	√	√	√
R-19-4	√	√	√	√
R-19-5	Possible to Slight	—	Moderate	—
R-19-6	√	—	√	—
R-19-7	Moderate	√	Significant	Possible to Slight
R-20-1	√	Possible to Slight	—	Possible to Slight
R-20-2	Significant	Significant	—	Significant
R-20-3	Moderate	Moderate	—	Possible to Slight
R-21	√	√	—	√
R-22-1	Significant	Significant	Significant	Significant
R-22-2	√	√	Possible to Slight	√
R-22-3	Possible to Slight	Possible to Slight	Moderate	Possible to Slight
R-22-4	Significant	Moderate	Moderate	Significant
R-22-5	Possible to Slight	Moderate	Moderate	Significant

Table 5-4 (continued)

Well Screen	Interpretation of PCA Results for Most Recent Sampling Event: Identification of Potential Impacts			
	Metals UF (Figure 5-1)	**Metals F (Figure 5-2)**	**Major Ions UF (Figure 5-3)**	**Major Ions F (Figure 5-4)**
R-23	√	√	—	Moderate
R-25-4	—	—	—	√
R-25-5	Possible to Slight	Moderate	Significant	—
R-25-6	√	—	√	—
R-25-7	√	—	√	—
R-25-8	√	√	√	√
R-28	Significant	Moderate	—	Significant
R-31-2	Significant	Significant	—	Significant
R-32-1	√	√	—	√
R-32-3	Moderate	Moderate	—	√
R-33-1	Moderate	√	√	√
R-33-2	√	√	√	—
R-33-3	—	—	—	—
R-34	√	√	—	√

Source: Results plotted in Figures 5-1 through 5-4.

[a] √ = Chemistry appears to be consistent with that for existing wells or White Rock Canyon springs.

[b] — = Well screen samples not evaluated.

Table 5-5
Comparison of Water-Quality Assessment Outcomes and PCA Results for Recent Sampling Events

	Outcome of Water-Quality Assessment Method (% of Tests Passed)				
	Outcome	**< 60%**	**60% – 80%**	**80% – 90%**	**91% – 100%**
Outcome of PCA Method	Not analyzed by principal component analysis	R-9i-1 R-12-1 (pre-rehab)[a] R-23i-3 (P) R-25-2	CdV-16-2(i)r R-3i (P)[b] R-5-2 R-9i-2 R-12-2 (pre-rehab) R-17-1 (P) R-17-2 (P) R-23i-2 (P) R-24 (P) R-25-1 R-31-3 (P)	MCOBT-4.4 R-6i R-10a R-19-2	CdV-16-1i R-6[c] R-10-1 R-10-2 R-16r R-18 R-26-1 R-27 (P) R-31-4 (P) R-31-5 (P)
	Consistent with White Rock Canyon springs or existing wells		CdV-R-37-2-4 R-19-6 R-25-4	CdV-R-15-3-6 R-14-1 R-19-3 R-25-6 R-25-7 R-25-8 R-33-2	CdV-R-15-3-4 CdV-R-37-2-3 R-1 R-2[c] R-8-1 R-13 R-19-4 R-21 R-32-1[c] R-34
	Possible to slight impacts	R-20-1[c] (pre-rehab)	CdV-R-15-3-5 R-5-3 R-5-4		R-4[c] R-11 R-15[c] R-22-2
	Moderate impacts	R-19-5 R-20-3[c] (pre-rehab)	R-7-3 R-12-3 (pre-rehab) R-14-2[c] R-16-3[c] (pre-rehab) R-22-3 R-32-3[c]	R-8-2 R-9 R-16-2[c] (pre-rehab) R-33-1	R-23
	Significant impacts	CdV-R-37-2-2 R-16-4[c] (pre-rehab) R-19-7 R-20-2[c] (pre-rehab) R-22-1 R-22-4 R-22-5 R-31-2	R-25-5		R-28

Sources: Tables 5-4 and G-1.

Notes: Shaded cells indicate consistent outcomes. The water-quality assessment rating is based on test outcomes using only the applicable criteria, which differs from the PCA approach in which all data are used to define clusters. Table 2-2 lists screen intervals for which some test criteria are not applicable due to the known presence of a contaminant plume.

[a] Pre-rehab=Percent of tests passed is based on water quality data obtained before pilot rehabilitation activities began at this well.

[b] (P) = Result considered preliminary either because less than 3 sample events were available or because the most recent event occurred more than 2 years ago.

[c] Screen interval drilled with bentonite drilling mud.

Table 6-1
Summary of Evaluation Outcomes for Composite Samples and for Most Recent Sample

Well Screen				Composite[b]		Most Recent Event				Conditions Present in Screen Interval (as described in section 6.2)									
ID[a]	Well	Port depth (ft)	Scr #	Nr	% of tests passed	Date	% of tests passed	Overall Trend	Level of confidence	Mod water	Plume	Outside pH-Alk range	Resid Inorg	Resid Org	Redox stage	Enhanced adsorption	Fe mineral	CO_3 mineral	Steel corrosion
1	CdV-16-1(i)	624	1	4	85	Mar-06	91	Improving	High	■	■	—	—	—	Oxic	—	—	—	—
2	CdV-16-2(i)r	850	1	4	77	May-06	79	Variable	Moderate	■	■	—	■	—	Oxic	—	—	—	■
3	CdV-R-15-3	1254	4	6	98	Mar-06	97	Stable	High	—	—	—	—	—	Oxic	—	—	—	—
4	CdV-R-15-3	1350	5	6	62	Mar-06	63	Stable	High	—	—	■	—	■	SO_4	—	—	■	—
5	CdV-R-15-3	1640	6	6	79	Mar-06	84	Improving	High	—	—	—	—	—	Mn	—	—	—	—
6	CdV-R-37-2	1200	2	6	51	Mar-06	50	Stable	High	—	—	■	—	■	SO_4	—	■	■	—
7	CdV-R-37-2	1359	3	6	98	Mar-06	91	Stable	High	—	—	—	—	—	Oxic	—	—	—	?
8	CdV-R-37-2	1551	4	6	72	Mar-06	74	Stable	High	—	—	—	—	—	Fe	Sr	■	—	—
9	MCOBT-4.4	485	1	4	84	Jun-05	80	Variable	Moderate	■	■	—	—	■	Oxic	—	—	■	—
10	R-1	1031	1	7	99	Oct-06	100	Stable	High	—	—	—	—	—	Oxic	—	—	—	—
11	R-2	918	1	5	89	Jul-06	94	Improving	High	—	—	—	—	■	Oxic	—	—	—	—
12	R-3i	215	1	1	61	Aug-06	61	Indeter	Low	■	■	■	■	■	Oxic	—	—	■	—
13	R-4	793	1	5	93	Jul-06	94	Stable	High	■	■	—	■	■	Oxic	—	—	—	—
14	R-5	384	2	4	77	Jul-06	75	Stable	High	—	■	■	—p	—p	Oxic	—	—	■	—
15	R-5	719	3	4	83	Jul-06	79	Stable	Moderate	—	■	—	—p	■	Oxic	—	—	■	—
16	R-5	861	4	3	66	May-05	70	Stable	Moderate	—	—	■	—	—	Fe	—	—	■	—
17	R-6	1205	1	5	95	Jul-06	97	Stable	High	—	—	—	—	■	Oxic	—	—	—	—
18	R-6i	602	1	5	73	Jul-06	73	Stable	Moderate	■	■	■	—[c]	■	Oxic	—	—	■[c]	—
19	R-7	915	3	4	62	Jul-06	63	Stable	High	—	—	■	—	—	SO_4	Sr	■	■	—
20	R-8	711	1	4	96	Aug-06	94	Stable	High	—	—	—	—	—	Oxic	—	—	—	—
21	R-8	825	2	4	87	Aug-06	89	Stable	Moderate	—	—	■	—	—	Oxic	—	—	■	—
22	R-9	684	1	6	76	Jul-06	82	Improving	Moderate	■	■	■	—	—	Mn	—	—	■	—
23	R-9i	199	1	4	54	Aug-06	56	Improving	Moderate	■	■	■	■	■	Mn	—	—	■	—

Table 6-1 (continued)

Well Screen				Composite[b]		Most Recent Event				Conditions Present in Screen Interval (as described in section 6.2)									
ID[a]	Well	Port depth (ft)	Scr #	Nr	% of tests passed	Date	% of tests passed	Overall Trend	Level of confidence	Mod water	Plume	Outside pH-Alk range	Resid Inorg	Resid Org	Redox stage	Enhanced adsorption	Fe mineral	CO_3 mineral	Steel corrosion
24	R-9i	279	2	4	67	Aug-06	71	Improving	Moderate	■	■	—	■	■	Mn	—	—	■	—
25	R-10	874	1	2	95	Oct-06	97	Indeter	Low	—	—	—	—	■	Oxic	—	—	—	—
26	R-10	1042	2	3	98	Oct-06	97	Indeter	Low	—	—	—	—	■	Oxic	—	—	—	—
27	R-10a	690	1	5	78	Oct-06	83	Improving	Moderate	—	■	■	—p	—	Oxic	—	—	■	—
28	R-11	855	1	7	93	Oct-06	93	Stable	Moderate	■	■	—	—p	—	Oxic	—	—	—	—
29	R-12	468	1	6	49[d]	Sep-06	63[d]	Improving	Moderate	■	■	■	—p	■	Mn	—	—	■	—
30	R-12	507	2	6	65[d]	Oct-06	84[d]	Improving	Moderate	■	■	■	—	—	Oxic	—	—	—	—
31	R-12	811	3	7	60[d]	Oct-06	87[d]	Improving	Moderate	■	■	—	—	—	Oxic	—	—	■	—
32	R-13	958	1	7	99	Oct-06	100	Stable	High	—	—	—	—	—	Oxic	—	—	—	—
33	R-14	1204	1	6	91	Oct-06	97	Improving	High	—	—	—	—	—	Mn	—	—	—	—
34	R-14	1288	2	6	70	Oct-06	70	Stable	High	—	—	—	■	—	Fe	—	■	■	—
35	R-15	959	1	6	97	Oct-06	100	Stable	High	■	■	—	—	—	Oxic	—	—	—	—
36	R-16	866	2	10	80[d]	Dec-06	77[d]	Degrading	Moderate	—	?	—	■	—	Mn	—	—	—	—r
37	R-16	1018	3	10	77[d]	Dec-06	82[d]	Improving	Moderate	—	?	—	■	—	Oxic	—	—	■	—
38	R-16	1238	4	9	52[d]	Dec-06	67[d]	Improving	Moderate	—	?	■	■	—	Mn	—	—	■	—
39	R-16r	600	1	7	91	Nov-06	91	Improving	High	—	—	—	—	—	Oxic	—	—	—	—
40	R-17	1057	1	2	84	Oct-06	86	Indeter	Low	—	—	—	—	—	SO_4	—	—	—	—
41	R-17	1124	2	1	83	Oct-06	83	Indeter	Low	—	—	—	—	—	Fe	Sr	—	—	—
42	R-18	1358	1	6	98	Dec-06	100	Stable	High	—	—	—	—	—	Oxic	—	—	—	—
43	R-19	909	2	5	79	Dec-06	81	Stable	Moderate	—	—	—	■	—	Oxic	—	—	—	—
44	R-19	1191	3	6	95	Dec-06	90	Stable	Moderate	—	—	—	—	?	NO_3	—	—	—	—
45	R-19	1413	4	6	95	Dec-06	97	Stable	Moderate	—	—	—	—	—	Oxic	Sr	—	—	—
46	R-19	1586	5	5	47	Dec-06	50	Stable	Moderate	—	—	■	—	■	SO_4	—	■	■	—
47	R-19	1730	6	5	64	Dec-06	67	Stable	Moderate	—	—	■	—	■	Fe	Sr	■	■	—
48	R-19	1835	7	6	47	Dec-06	40	Stable	Moderate	—	—	■	■	■	Fe	Sr	—	■	—
49	R-20	907	1	7	58[d]	Oct-06	80[d]	Improving	Moderate	—	—	—	—	■	Fe	—	—	■	—
50	R-20	1150	2	5	39[d]	Jul-06	88[d]	Improving	High	—	—	—	—	■	Fe	—	—	■	—
51	R-20	1330	3	6	58[d]	Oct-06	68[d]	Improving	High	—	—	—	■	■	Fe	—	■	■	—
52	R-21	889	1	5	99	Nov-06	100	Stable	High	—	—	—	—	—	Oxic	—	—	—	—
53	R-22	907	1	5	38	Dec-06	35	Stable	High	■	—	■	—p	?	SO_4	—	■	■	—
54	R-22	963	2	5	98	Dec-06	100	Stable	High	—	—	—	—	—	Oxic	—	—	—	—
55	R-22	1273	3	6	73	Dec-06	75	Stable	High	—	—	■	■	■	Oxic	—	—	■	—
56	R-22	1378	4	6	43	Dec-06	50	Stable	High	—	—	■	■	■	Fe	—	■	■	—

Table 6-1 (continued)

Well Screen				Composite[b]		Most Recent Event				Conditions Present in Screen Interval (as described in section 6.2)									
ID[a]	Well	Port depth (ft)	Scr #	Nr	% of tests passed	Date	% of tests passed	Overall Trend	Level of confidence	Mod water	Plume	Outside pH-Alk range	Resid Inorg	Resid Org	Redox stage	Enhanced adsorption	Fe mineral	CO_3 mineral	Steel corrosion
57	R-22	1448	5	5	47	Dec-06	50	Stable	High	■	—	■	■	■	Fe	—	■	■	—
58	R-23	816	1	5	98	Dec-06	100	Stable	High	—	■	—	—	—	Oxic	—	—	—	—
59	R-23i	470	2	2	66	Oct-06	64	Indeter	Low	■	■	■	■	—	SO_4	—	—	■	—
60	R-23i	524	3	2	59	Oct-06	57	Indeter	Low	■	■	■	■	■	SO_4	—	—	■	■
61	R-24	825	1	5	71	Jul-06	73	Stable	High	—	?	■	—p	■	SO_4	—	■	■	—
62	R-25	755	1	4	66	Aug-05	66	Degrading	Low	■	■	■	—	—	Fe	—	■	—p	■
63	R-25	892	2	4	51	Aug-05	45	Degrading	Low	■	■	■	■	■	Fe	Ba	■	—	■
64	R-25	1192	4	3	75	Aug-05	77	Indeter	Low	■	■	■	■	—	Oxic	—	—	■	—
65	R-25	1303	5	4	63	Aug-05	76	Improving	Low	■	■	—	—	—	Fe	—	■	—	—
66	R-25	1406	6	3	89	Dec-03	92	Indeter	Low	■	—	—	—	—	Oxic	—	—	—	—
67	R-25	1606	7	3	95	Dec-03	96	Indeter	Low	—	—	—	—	—	Oxic	—	—	—	—
68	R-25	1796	8	3	95	Aug-05	94	Stable	Low	—	—	—	■	—	Oxic	—	—	—	—
69	R-26	659	1	4	95	Feb-06	100	Stable	High	—	—	—	—	—	Oxic	—	—	—	—
70	R-27	852	1	4	92	Jul-06	97	Improving	High	—	—	—	—	—	Oxic	—	—	—	—
71	R-28	934	1	7	90	Oct-06	90	Stable	High	■	■	—	—	—	Oxic [e]	—	—	—p [e]	—
72	R-31	532	2	3	50	Nov-06	50	Stable	High	—	—	■	—	■	SO_4	—	■	■	—
73	R-31	670	3	2	65	Nov-06	68	Stable	Moderate	No data	—	—	—	■	Fe	—	■	—	—
74	R-31	831	4	2	97	Dec-06	97	Stable	Moderate	No data	—	—	—	—	Oxic	—	—	—	—
75	R-31	1011	5	2	93	Dec-06	97	Stable	Moderate	No data	—	■	—	—	Oxic	—	—	—	—
76	R-32	871	1	5	92	Dec-06	94	Stable	High	—	—	—	—	—	Oxic	—	—	—	—
77	R-32	976	3	5	68	Dec-06	77	Improving	High	—	—	—	—	■	Fe	—	—	■	—
78	R-33	995	1	4	89	Oct-06	89	Stable	High	—	—	—	—	—	Oxic	—	—	—	—
79	R-33	1112	2	5	89	Nov-06	89	Stable	High	—	—	—	?	—	Oxic	—	—	—	—
80	R-34	895	1	6	92	Oct-06	97	Improving	High	—	—	—	—	—	Oxic	—	—	—	—

Nr=number, Scr #=screen number

Gray-shaded rows indicate single-screen wells.

? means the constituent is detected at this location and is likely to be a plume constituent but incontrovertible evidence for this origin is lacking at the present time.

"Indeter" means that the presence or absence of a plume at this location cannot be determined with confidence, although the water quality is definitely not representative of uncontaminated groundwater. The screens to which this designation applies are R-16 and R-24, which are each located next to one of the county's two sewage treatment facilities (in White Rock and Bayo Canyon, respectively).

P means one of the indicators is detected at this location but that the test is not applicable because the indicator is known to be a plume constituent..

r means the indicators for this category of effects are not reliable due to disturbances to the screen interval during recent pilot rehabilitation activities.

Table 6-1 (continued)

Note: A black filled square (■) in a table column indicates that the condition is inferred as likely to be present in the most recent water sample from that screen, based on a review of relevant geochemical data and their trends. These inferences about the likely presence or absence of drilling effects are subject to change as additional information is obtained. The criteria for designating a condition as being present are summarized below:

- “Mod water”=modern water, in which tritium is present at consistently detectable (> 1 pCi/L) activities, based on a review of data in Table C-3. Although this is not a residual drilling impact, this information nonetheless may influence geochemical interpretations and levels of confidence in the outcome. “■” in this column indicates that tritium (^3H) is detected at this location, indicating the presence of a component of water less than 60 years old.
- “Plume”=a contaminant plume is present at this location, based on information compiled in Table 2-1.
- “Outside pH-Alk range”=pH and/or carbonate alkalinity values extend significantly above the upper limits for background groundwater, or pH extends below its lower background limit, based on field and laboratory data compiled in Table C-3 and summarized in Table C-8 in the column labeled “General Indicators.”
- “Resid Inorg”=residual inorganic constituents from downhole drilling products (Category A), based on geochemical data compiled in Appendix C and summarized in Table C-8 in the column labeled “Category A - Residual Inorganics.”
- “Resid Org”=residual organic constituents derived from downhole drilling products (Category A), based on geochemical data compiled in Table C-4 and summarized in Table C-8 in the column labeled “Category B - Residual Organics.”
- “Redox Stage”=most probable redox stage based on a review of relevant indicators compiled in Appendix C and summarized in Table C-8 in the column labeled “Category C – Redox Stages” to determine which redox stage is most consistent with the observed concentrations and trends.
- “Fe mineral”=geochemical evidence indicates a high probability that the predrilling iron mineralogy has been significantly altered, e.g., as iron sulfides or iron carbonates, as a result of an extended period of very reducing conditions in the presence of an adequate in-situ reserve of accessible iron (III) in the formation mineralogy. Identifying where this condition may have developed cannot be determined with confidence based on data from a single water sample, but rather requires a review of redox data trends extending over several months to a year or more. Entries in Table 6-1 are based on a review of redox data compiled in Appendix C and summarized in Table C-8 in the column labeled “Category C – Redox.”
- “Enhanced adsorption”=geochemical evidence indicates that adsorption of some species may be enhanced above that expected for adsorption onto formation materials, due to the presence of residual clays or other adsorbant introduced with drilling fluids. Based on review of data compiled in Appendix C and summarized in able C-8 in the column labeled “Category D – Adsorption.”
- “CO_3 mineral”=Barium, calcium, magnesium, strontium, and/or sulfate values extend significantly outside the limits for background groundwater, based on field and laboratory data compiled in Appendix C and summarized in Table C-8 in the column labeled “Category E – Carbonate Minerals.”
- “Steel corrosion”=corrosion of the stainless steel well casing or screen appears to be present, based on data compiled in Appendix C and summarized in Table C-8 in the column labeled “Category F – Steel Corrosion.”

[a] Screen ID—unique identifier assigned to each screen addressed by this report in order to simplify management of information

[b] Composite—average percent of all tests passed (i.e., score has not been weighted for any variability in the number of outcomes per event). However, see footnote d below for exceptions.

[c] R-6i—F, Na and Ca in samples from this single-screen well consistently exceed the upper threshold limits for these analytes but these exceedances are probably not due to residual drilling fluids. Because the concentrations are fairly stable and not decreasing with time, the more likely explanations are either (a) the sampling locations used to establish background levels for these analytes did not capture the full range of their variability in intermediate perched zones, or (b) these analytes may be part of, or affected by, the contaminant plume intersected by this well, which contains Cl, ClO_4, NO_3, and tritium.

[d] The composite percentages of passed tests for screens in R-12, R-16, and R-20 are calculated using sampling events that occurred prior to the rehabilitation pilot studies. The rehabilitation activities occurred at R-12 from 23-Sep-2006 to 19-Oct-2006 (isolation packers were installed until a dedicated sampling system can be re-installed); at R-16 from 2-Aug-2006 to 12-Aug-2006 (Westbay was reinstalled and completed on 28-Aug-2006); and at R-20 from 29-Jun-2006 to 17-Oct-2006. The percent of tests passed for the most recent samples from these well screens all apply to post-rehabilitation samples.

[e] R-28—The failed test outcomes for Ca, Mg, and Ni are probably not attributable to residual drilling effects. In the case of Ca and Mg, the stability of their concentrations in R-28 suggests that the sampling locations used to establish background levels for Ca and Mg did not capture the full range of their variability in the top of the regional aquifer. Secondly, the lack of Fe-reducing conditions in R-28 suggests that the failed test for elevated Ni is not due to desorption from dissolution of iron-bearing minerals but rather from its possible presence in the contaminant plume at this screen. Hence, the negative test outcomes for these three analytes are not valid at this site.

Table 6-2a
Comparison of Test Outcomes for Most Recent Sample

		Outcome for "Most Recent Sample" (as of Dec-06) assessed in this Report (% of Tests Passed)			
		91% – 100%	**80% – 90%**	**60% – 80%**	**< 60%**
Test Outcomes for "Most Recent Sample" (as of Aug-05) in the Well Screen Analysis Report (WSAR) Rev 0	91% – 100%	CdV-R-37-2 Screen 3 CdV-16-1(i) R-1 R-8 Screen 1 R-11 R-15 R-18 R-21 R-22 Screen 2 R-23 R-28 R-32 Screen 1 R-34	MCOBT-4.4 R-9 R-14 Screen 1 R-25 Screen 6 R-25 Screen 7 R-33 Screen 2	R-5 Screen 2 R-5 Screen 3 R-25 Screen 4	—
	80% – 90%	CdV-R-15-3 Screen 4 R-2 R-4 R-6 R-13 R-19 Screen 4 R-26 Screen 1	R-6i R-16 Screen 3 R-25 Screen 8	R-16 Screen 2 R-22 Screen 3	—
	60% – 80%	—	CdV-R-15-3 Screen 6 R-8 Screen 2 R-12 Screen 3 R-19 Screen 2 R-19 Screen 3 R-25 Screen 5 R-33 Screen 1	CdV-R-37-2 Screen 4 R-5 Screen 4 R-9i Screen 2 R-20 Screen 3 R-25 Screen 1	R-9i Screen 1 R-19 Screen 7 R-25 Screen 2
	< 60%	—	—	CdV-R-15-3 Screen 5 R-7 Screen 3 R-12 Screen 1 R-14 Screen 2 R-16 Screen 4 R-19 Screen 6 R-20 Screen 1 R-20 Screen 2 R-32 Screen 3	CdV-R-37-2 Screen 2 R-19 Screen 5 R-22 Screen 1 R-22 Screen 4 R-22 Screen 5 R-31 Screen 2
	Not tested in WSAR R0	R-10 Screen 1 R-10 Screen 2 R-16r R-27 R-31 Screen 4 R-31 Screen 5	R-10a R-12 Screen 2	CdV-R-16-2(i)r R-3i (p) R-17 Screen 1 R-17 Screen 2 R-23i Screen 2 R-24 R-31 Screen 3	R-23i Screen 3

Note: Shaded cells indicate that the "most recent sample" from this screen fell within the same percent passing category in both revisions of the well screen analysis report.

— = None.

Table 6-2b
Comparison of Test Outcomes in WSAR R0 and in this Report, for the “Most Recent Sample” as of August 2005

		Outcome for “Most Recent Sample” (as of Aug-05) assessed in this Report (% of Tests Passed)			
		91% – 100%	**80% – 90%**	**60% – 80%**	**< 60%**
Test Outcomes in Well Screen Analysis Report (WSAR) Rev 0	91% – 100%	CdV-R-37-2 Sc 3 R-1 R-4 R-8 Sc 1 R-11 R-14 Sc 1 R-15 R-18 R-21 R-22 Sc 2 R-23 R-25 Sc 6 R-25 Sc 7 R-32 Sc 1	CdV-16-1(i) MCOBT-4.4 R-5 Sc 3 R-28 R-33 Sc 2	R-5 Sc 2 R-9 R-25 Sc 4	—
	80% – 90%	CdV-R-15-3 Sc 4 R-6 R-13 R-19 Sc 4 R-25 Sc 8 R-26 Sc 1	R-2 R-34	R-6i R-16 Sc 3 R-22 Sc 3	—
	60% – 80%	R-19 Sc 3	CdV-R-15-3 Sc 6 R-8 Sc 2 R-16 Sc 2 R-25 Sc 5 R-33 Sc 1	CdV-R-37-2 Sc 4 R-5 Sc 4 R-9i Sc 1 R-9i Sc 2 R-12 Sc 3 R-19 Sc 2 R-20 Sc 3 R-25 Sc 1	R-25 Sc 2 R-19 Sc 7
	< 60%	—	—	R-7 Sc 3 R-14 Sc 2 R-19 Sc 6 R-32 Sc 3	CdV-R-15-3 Sc 5 CdV-R-37-2 Sc 2 R-12 Sc 1 R-16 Sc 4 R-19 Sc 5 R-20 Sc 1 R-20 Sc 2 R-22 Sc 1 R-22 Sc 4 R-22 Sc 5 R-31 Sc 2

Note: Shaded cells indicate that the “most recent sample” from this screen fell within the same percent passing category in both revisions of the well screen analysis report.

— = None.

Table 6-2c
Evaluation for Residual Inorganic Drilling Fluids (Category A in this report) in WSAR R0 and in this Report, for the "Most Recent Sample" as of August 2005

		Outcome in this Report			
		Residual Inorganics are Absent		**Residual Inorganics are Present**	
Outcomes in Well Screen Analysis Report (WSAR) Rev 0	Residual Inorganics are Absent	R-2 R-6 R-32 Sc 1		R-4 R-20 Sc 3 R-32 Sc 3	
	Residual Inorganics are Present	R-16 Sc 2 R-16 Sc 3		R-14 Sc 2 R-16 Sc 4 R-20 Sc 1 R-20 Sc 2	
	Not evaluated for Residual Inorganics in WSAR R0	CdV-R-15-3 Sc 4	R-19 Sc 5	CdV-16-1(i)	R-11
		CdV-R-15-3 Sc 6	R-19 Sc 6	CdV-R-15-3 Sc 5	R-12 Sc 1
		CdV-R-37-2 Sc 2	R-21	MCOBT-4.4	
		CdV-R-37-2 Sc 3	R-22 Sc 1	R-5 Sc 2	R-19 Sc 2
		CdV-R-37-2 Sc 4	R-22 Sc 2	R-5 Sc 3	R-19 Sc 7
		R-1	R-22 Sc 5	R-5 Sc 4	R-22 Sc 3
		R-7 Sc 3	R-25 Sc 1	R-6i	R-22 Sc 4
		R-8 Sc 2	R-25 Sc 5	R-8 Sc 1	R-23
		R-12 Sc 3	R-25 Sc 6	R-9	R-25 Sc 2
		R-13	R-25 Sc 7	R-9i Sc 1	R-25 Sc 4
		R-14 Sc 1	R-28	R-9i Sc 2	R-25 Sc 8
		R-15	R-31 Sc 2		R-26 Sc 1
		R-18	R-33 Sc 1		
		R-19 Sc 3	R-33 Sc 2		
		R-19 Sc 4	R-34		

Note: Shaded cells indicate that the same conclusion was reached about the presence or absence of this residual drilling condition for the "most recent sample" from this screen in both revisions of the well screen analysis report.

Table 6-2d
Evaluation for Residual Organic Drilling Fluids (Category B in this report) in WSAR R0 and in this Report, for the "Most Recent Sample" as of August 2005

		Outcome in this Report			
		Residual Organics are Absent			**Residual Organics are Present**
Outcomes in Well Screen Analysis Report (WSAR) Rev 0	**Residual Organics are Absent**	CdV-R-37-2 Sc 3 CdV-R-15-3 Sc 4 CdV-R-15-3 Sc 6 R-1 R-2 R-4 R-5 Sc 2 R-5 Sc 3 R-5 Sc 4 R-8 Sc 1 R-8 Sc 2 R-9	R-11 R-12 Sc 3 R-13 R-14 Sc 1 R-15 R-16 Sc 2 R-18 R-19 Sc 4 R-21 R-22 Sc 2 R-23 R-25 Sc 1	R-25 Sc 6 R-25 Sc 7 R-25 Sc 8 R-26 Sc 1 R-28 R-32 Sc 1 R-33 Sc 1 R-33 Sc 2 R-34	CdV-R-37-2 Sc 2 R-6 R-7 Sc 3 R-16 Sc 3 R-19 Sc 3 CdV-16-1(i) MCOBT-4.4 R-6i R-9i Sc 1 R-9i Sc 2 R-25 Sc 4 R-25 Sc 5
	Residual Organics are Present	—			CdV-R-15-3 Sc 5 CdV-R-37-2 Sc 4 R-12 Sc 1 R-14 Sc 2 R-16 Sc 4 R-19 Sc 2 R-19 Sc 5 R-19 Sc 6 R-19 Sc 7 R-20 Sc 1 R-20 Sc 2 R-20 Sc 3 R-22 Sc 1 R-22 Sc 3 R-22 Sc 4 R-22 Sc 5 R-25 Sc 2 R-31 Sc 2 R-32 Sc 3

Note: Shaded cells indicate that the same conclusion was reached about the presence or absence of this residual drilling condition for the "most recent sample" from this screen in both revisions of the well screen analysis report.

— = None.

Table 6-2e
Apparent Redox Condition (Category C in this report) Determined in WSAR R0 and in this Report, for the "Most Recent Sample" as of August 2005

		Redox Condition in this Report			
		Oxic	**NO_3-Reducing**	**Fe/Mn Reducing**	**SO_4-Reducing**
Redox Outcomes in Well Screen Analysis Report (WSAR) Rev 0	**Oxic**	CdV-16-1(i) MCOBT-4.4 R-1 R-4 R-5 Sc 3 R-8 Sc 1 R-15 R-18 R-21 R-22 Sc 2 R-23 R-25 Sc 6 R-25 Sc 7 R-28 R-32 Sc 1	—	R-9 R-19 Sc 7	—
	NO_3-Reducing	R-11	—	—	—
	Fe/Mn Reducing	R-5 Sc 2 R-13 R-19 Sc 2 R-22 Sc 3 R-25 Sc 8	—	R-5 Sc 4 R-9i Sc 1 R-9i Sc 2 R-12 Sc 3 R-22 Sc 4 R-25 Sc 1 R-25 Sc 4 R-25 Sc 5 R-33 Sc 2	CdV-R-15-3 Sc 6 R-16 Sc 2
	SO_4-Reducing	CdV-R-15-3 Sc 4 CdV-R-37-2 Sc 3 R-6 R-6i R-8 Sc 2 R-19 Sc 3 R-19 Sc 4 R-26 Sc 1 R-34	—	CdV-R-37-2 Sc 4 R-2 R-12 Sc 1 R-14 Sc 1 R-16 Sc 3 R-16 Sc 4 R-25 Sc 2 R-33 Sc 1	CdV-R-15-3 Sc 5 CdV-R-37-2 Sc 2 R-7 Sc 3 R-14 Sc 2 R-19 Sc 5 R-19 Sc 6 R-20 Sc 1 R-20 Sc 2 R-20 Sc 3 R-22 Sc 1 R-22 Sc 5 R-31 Sc 2 R-32 Sc 3

Note: Shaded cells indicate that the same conclusion was reached about the presence or absence of this residual drilling condition for the "most recent sample" from this screen in both revisions of the well screen analysis report.

— = None.

Table 6-3

Effect of Residual Drilling Impacts on Selected Chemicals of Potential Concern

Inorganic Analyte	Speciation in Native Groundwater	Not Affected	pH or Alkalinity Outside Bounds[a]	Category A	Category B	Category C				Category D					Category E	Category F
				Residual Inorganics	Residual Organics	SO_4-reducing	Fe-reducing	Mn-reducing	NO_3-reducing	Sr	U	Ba	Zn	None[b]	Carbonate Disequilibrium	Steel corrosion
Barium	Ba^{+2}	—	—	—	—	●	●	●	—	—	—	●	—	—	●	(—)
Cesium-137	Cs^{+}	—	—	—	—	●	●	●	—	—	—	●	●	—	—	(—)
Chloride	Cl^{-}	—	—	●	—	—	—	—	—	—	—	—	—	—	—	—
Chromium	CrO_4^{-2}	—	—	●	—	●	●	●	—	—	—	—	—	—	—	●
Nitrate	NO_3^{-}	—	—	●	—	●	●	●	●	—	—	—	—	—	—	—
Perchlorate	ClO_4^{-}	—	—	—	—	●	●	●	—	—	—	—	—	—	—	—
Plutonium	PuO_2^{+}, $PuO_2CO_3^{-}$	—	●	—	—	●	●	●	—	—	—	—	—	(●)	—	—
RDX	RDX	—	—	—	—	●	●	●	●	—	—	—	—	—	—	—
Strontium-90	Sr^{2+}	—	—	—	—	●	●	●	—	●	—	—	—	—	—	—
TNT	TNT	—	—	—	—	●	●	●	●	—	—	—	—	(●)	—	—
Tritium	H_2O	●	—	—	—	—	—	—	—	—	—	—	—	—	—	—
VOCs	Mostly neutral species	—	—	—	(—)	●	●	●	●	—	—	—	—	(●)	—	—
Zinc	Zn^{+2}, $ZnCO_3$	—	●	—	—	●	●	●	—	—	—	—	●	—	●	(—)

● Analytical data for this COPC may not be reliable or representative of predrilling conditions if this condition is present.

(—) Analytical data for this COPC is probably reliable or representative of predrilling conditions even if this condition is present. However, the circumstances under which this may be applicable are case-specific and their evaluation requires site-specific data.

(●) Analytical data for this COPC may not be reliable or representative of predrilling conditions if this condition is present in the screen interval. However, the circumstances under which this may be applicable are uncommon and case-specific. Consequently, this aspect has not taken into account in this report. See discussion for this category in Section 4.10.

● ? Analytical data for this COPC may not be reliable or representative of predrilling conditions if this condition is present in the screen interval, but there is uncertainty associated with this judgment because of the complex factors affecting the biodegradation rate of this compound.

— The reliability or representativeness of analytical data for this COPC are not affected by this condition, even if present.

[a] An entry in this column signifies only that the analyte's speciation may differ significantly from that expected under pH/alkalinity conditions that are characteristic of native groundwater, such that some entries for this analyte may not be valid.

[b] An entry in this column signifies that the analyte may adsorb onto bentonite clay but that it has no suitable indicator species tojudge whether or not this effect is present. See discussion in Section 4.10.

Source: Tables A-1 through A-8. Section 4.10 discusses the basis for the identification of analytes potentially affected by a particular category of residual drilling effects.

Table 6-4
Capability of Screen to Provide Reliable and Representative Samples for Selected Chemicals of Potential Concern

Well Screen				Most recent event		Capable of providing reliable and representative sample for COPC[b]												
ID[a]	Well	Port depth (ft)	Scr	Date	% of Tests Passed	3H	Ba	Cl	ClO_4	Cr	NO_3	Zn	VOCs	Cs-137	Pu	Sr-90	RDX	TNT
1	CdV-16-1(i)	624	1	Mar-06	91	■	■	■	■	■	■	■	■	■	■	■	■	■
2	CdV-16-2(i)r	850	1	May-06	79	■	■	■	■	■?	■?	■?	■	■	■	■	■	■
3	CdV-R-15-3	1254	4	Mar-06	97	■	■	■	■	■	■	■	■	■	■	■	■	■
4	CdV-R-15-3	1350	5	Mar-06	63	■	—	■	—	—	—	■?	—	—	—	—?	—	—
5	CdV-R-15-3	1640	6	Mar-06	84	■	—	■	—	—	—	■?	—	—	—	■	—	—
6	CdV-R-37-2	1200	2	Mar-06	50	■	—	■	—	—	—	—	—	—	—	■	—	—
7	CdV-R-37-2	1359	3	Mar-06	91	■	■	■	■	■	■	■	■	■	■	■	■	■
8	CdV-R-37-2	1551	4	Mar-06	74	■	—	■	—	—	—	—	—	—	—	—	—	—
9	MCOBT-4.4	485	1	Jun-05	80	■	—?	■	■	■	■	■	■	■	■	■	■	■
10	R-1	1031	1	Oct-06	100	■	■	■	■	■	■	■	■	■	■	■	■	■
11	R-2	918	1	Jul-06	94	■	■	■	■	■	■	■	■	■	■	■	■	■
12	R-3i	215	1	Aug-06	61	■	—	■	■	■	■	■	■	■	■	■	■	■
13	R-4	793	1	Jul-06	94	■	■	■	■	■	■	■	■	■	■	■	■	■
14	R-5	384	2	Jul-06	75	■	—	■	■	■	■	■?	■	■	■	■	■	■
15	R-5	719	3	Jul-06	79	■	—	■	■	■	■	■?	■	■	■	■	■	■
16	R-5	861	4	May-05	70	■	—	■	—	—	—	—	—	—	—	■	—	—
17	R-6	1205	1	Jul-06	97	■	■	■	■	■	■	■	■	■	■	■	■	■
18	R-6i	602	1	Jul-06	73	■	—	■	■	■	■	■?	■	■	■	■	■	■
19	R-7	915	3	Jul-06	63	■	—	■	—	—	—	—	—	—	—	—	—	—
20	R-8	711	1	Aug-06	94	■	■	■	■	■	■	■	■	■	■	■	■	■
21	R-8	825	2	Aug-06	89	■	—	■	■	■	■	■?	■	■	■	■	■	■
22	R-9	684	1	Jul-06	82	■	—	■	—	—	—	—	—	—	—	■	—	—
23	R-9i	199	1	Aug-06	56	■	—	■	—	—	—	—	—	—	—	■	—	—
24	R-9i	279	2	Aug-06	71	■	—	■	—	—	—	—	—	—	—	■	—	—
25	R-10	874	1	Oct-06	97	■	■	■	■	■	■	■	■	■	■	■	■	■
26	R-10	1042	2	Oct-06	97	■	■	■	■	■	■	■	■	■	■	■	■	■
27	R-10a	690	1	Oct-06	83	■	—	■	■	■	■	—	■	■	■	■	■	■
28	R-11	855	1	Oct-06	93	■	■	■	■	■	■	■	■	■	■	■	■	■
29	R-12	468	1	Sep-06	63	■	—	■	—	—	—	—	—	—	—	■	—	—
30	R-12	507	2	Oct-06	84	■	—	■	■	■	■	■	■	■	■	■	■	■
31	R-12	811	3	Oct-06	87	■	—	■	■	■	■	—?	■	■	■	■	■	■

Table 6-4 (continued)

Well Screen				Most recent event		Capable of providing reliable and representative sample for COPC[b]												
ID[a]	Well	Port depth (ft)	Scr	Date	% of Tests Passed	3H	Ba	Cl	ClO_4	Cr	NO_3	Zn	VOCs	Cs-137	Pu	Sr-90	RDX	TNT
32	R-13	958	1	Oct-06	100	■	■	■	■	■	■	■	■	■	■	■	■	■
33	R-14	1204	1	Oct-06	97	■	■	■	—	—	—	■	—	—	—	■	—	—
34	R-14	1288	2	Oct-06	70	■	—	—	—	—	—	—	—	—	—	■	—	—
35	R-15	959	1	Oct-06	100	■	■	■	■	■	■	■	■	■	■	■	■	■
36	R-16	866	2	Dec-06	77	■	—	—	—	—	—	—	—	—	—	■	—	—
37	R-16	1018	3	Dec-06	82	■	—	—	■	■?	■?	—	■	■	■	■	■	■
38	R-16	1238	4	Dec-06	67	■	—	—	—	—	—	—	—	—	—	■	—	—
39	R-16r	600	1	Nov-06	91	■	■	■	■	■	■	■	■	■	■	■	■	■
40	R-17	1057	1	Oct-06	86	■	—	■	—	—	—	—	—	—	—	■	—	—
41	R-17	1124	2	Oct-06	83	■	—	■	—	—	—	—	—	—	—	—	—	—
42	R-18	1358	1	Dec-06	100	■	■	■	■	■	■	■	■	■	■	■	■	■
43	R-19	909	2	Dec-06	81	■	■	—	■	■	■?	■	■	■	■	■	■	■
44	R-19	1191	3	Dec-06	90	■	■	■	■	■	—	■	■?	■	■	■	■	■
45	R-19	1413	4	Dec-06	97	■	■	■	■	■	■	■	■	■	■	■?	■	■
46	R-19	1586	5	Dec-06	50	■	—	■	—	—	—	—	—	—	—	■	—	—
47	R-19	1730	6	Dec-06	67	■	—	■	—	—	—	—	—	—	—	—	—	—
48	R-19	1835	7	Dec-06	40	■	—	—	—	—	—	—	—	—	—	—	—	—
49	R-20	907	1	Oct-06	80	■	—	■	—	—	—	—	—	—	—	■	—	—
50	R-20	1150	2	Jul-06	88	■	—	■	—	—	—	—	—	—	—	■	—	—
51	R-20	1330	3	Oct-06	68	■	—	—	—	—	—	—	—	—	—	■	—	—
52	R-21	889	1	Nov-06	100	■	■	■	■	■	■	■	■	■	■	■	■	■
53	R-22	907	1	Dec-06	35	■	—	■	—	—	—	—	—	—	—	■	—	—
54	R-22	963	2	Dec-06	100	■	■	■	■	■	■	■	■	■	■	■	■	■
55	R-22	1273	3	Dec-06	75	■	—	—	■	■?	■?	■?	■?	■	■	■	■	■
56	R-22	1378	4	Dec-06	50	■	—	—	—	—	—	—	—	—	—	■	—	—
57	R-22	1448	5	Dec-06	50	■	—	—	—	—	—	—	—	—	—	■	—	—
58	R-23	816	1	Dec-06	100	■	■	■	■	■	■	■	■	■	■	■	■	■
59	R-23i	470	2	Oct-06	64	■	—	—?	—	—	—	—	—	—	—	■	—	—
60	R-23i	524	3	Oct-06	57	■	—	—?	—	—	—	—	—	—	—	■	—	—
61	R-24	825	1	Jul-06	73	■	—	■	—	—	—	—	—	—	—	■	—	—
62	R-25	755	1	Aug-05	66	■	—	■	—	—	—	—	—	—	—	■	—	—
63	R-25	892	2	Aug-05	45	■	—	■	—	—	—	—	—	—	—	■	—	—
64	R-25	1192	4	Aug-05	77	■	—	■	■	—	—	■	■	■	■	■	■	■

Table 6-4 (continued)

Well Screen				Most recent event		Capable of providing reliable and representative sample for COPC[b]												
ID[a]	Well	Port depth (ft)	Scr	Date	% of Tests Passed	3H	Ba	Cl	ClO_4	Cr	NO_3	Zn	VOCs	Cs-137	Pu	Sr-90	RDX	TNT
65	R-25	1303	5	Aug-05	76	■	—	■	—	—	—	—	—	—	—	■	—	—
66	R-25	1406	6	Dec-03	92	■	■	■	■	■	■	■	■	■	■	■	■	■
67	R-25	1606	7	Dec-03	96	■	■	■	■	■	■	■	■	■	■	■	■	■
68	R-25	1796	8	Aug-05	94	■	■	■	■	■	■	■	■	■	■	■	■	■
69	R-26	659	1	Feb-06	100	■	■	■	■	■	■	■	■	■	■	■	■	■
70	R-27	852	1	Jul-06	97	■	■	■	■	■	■	■	■	■	■	■	■	■
71	R-28	934	1	Oct-06	90	■	■	■	■	■	■	■	■	■	■	■	■	■
72	R-31	532	2	Nov-06	50	■	—	■	—	—	—	—	—	—	—	■	—	—
73	R-31	670	3	Nov-06	68	■	—	■	—	—	—	—	—	—	—	■	—	—
74	R-31	831	4	Dec-06	97	■	■	■	■	■	■	■	■	■	■	■	■	■
75	R-31	1011	5	Dec-06	97	■	■	■	■	■	■	■	■	■	■	■	■	■
76	R-32	871	1	Dec-06	94	■	■	■	■	■	■	■	■	■	■	■	■	■
77	R-32	976	3	Dec-06	77	■	—	■	—	—	—	—	—	—	—	■	—	—
78	R-33	995	1	Oct-06	89	■	■	■	■	■	■	■	■	■	■	■	■	■
79	R-33	1112	2	Nov-06	89	■	■	■	■	■	■	■	■	■	■	■	■	■
80	R-34	895	1	Oct-06	97	■	■	■	■	■	■	■	■	■	■	■	■	■
Number of screens that are capable of providing reliable and representative sample for COC																		
Screens in single-screen wells						22	16	22	20	20	20	19	20	20	20	22	20	20
Screens in multiple-screen wells						58	19	46	26	25	24	27	26	26	26	52	26	26
Total						80	35	68	46	45	44	46	46	46	46	74	46	46
Percent of all screens						100%	44%	85%	58%	56%	55%	58%	58%	58%	58%	92%	58%	58%

Notes: COPC = Chemical of potential concern.

■ = Screen can provide reliable and representative sample for this COPC.

■? = Screen probably can provide reliable and representative sample for this COPC but there is uncertainty associated with this judgement.

— = Screen cannot provide reliable and representative sample for this COPC.

—? = Screen probably cannot provide reliable and representative sample for this COPC but there is uncertainty associated with this judgement. .

Gray-shaded rows indicate single-screen wells.

[a] Screen ID—unique identifier assigned to each screen addressed by this report in order to simplify management of information.

Table 6-5
Trends in Water-Quality Assessment Outcomes

		Composite Sample (Average Percent of Tests Passed)			
	Outcome	**91% – 100%**	**80% – 90%**	**60% – 80%**	**< 60%**
Trend	Stable	CdV-R-15-3 Sc 4 CdV-R-37-2 Sc 3 R-1 R-4[a] R-6[a] R-8 Sc 1 R-11 R-13 R-15 R-18 R-19 Sc 3 R-19 Sc 4 R-21 R-22 Sc 2 R-23 R-26 Sc 1 R-31 Sc 4 R-31 Sc 5 R-32 Sc 1	CdV-16-1(i) R-5 Sc 3 R-6i R-8 Sc 2 R-19 Sc 2 R-25 Sc 8 R-28 R-33 Sc 1 R-33 Sc 2	CdV-R-15-3 Sc 5 CdV-R-37-2 Sc 4 R-5 Sc 2 R-5 Sc 4 R-7 Sc 3 R-14 Sc 2[a] R-19 Sc 6 R-22 Sc 3 R-24 R-31 Sc 3 R-32 Sc 3	CdV-R-37-2 Sc 2 R-19 Sc 5 R-19 Sc 7 R-22 Sc 1 R-22 Sc 4 R-22 Sc 5 R-31 Sc 2
	Improving	R-16r R-27 R-34	R-2[a] R-14 Sc 1[a]	CdV-R-15-3 Sc 6 R-9 R-9i Sc 2 R-10a (P)[b] R-12 Sc 2 R-12 Sc 3 R-16 Sc 3[a] R-25 Sc 5	R-9i Sc 1 R-12 Sc 1[a] R-16 Sc 4[a] R-20 Sc 1[a] R-20 Sc 2[a] R-20 Sc 3[a]
	Degrading	—[c]	R-16 Sc 2[a]	R-25 Sc 1	R-25 Sc 2
	Indeterminate or variable	R-10 Sc 1 (P) R-10 Sc 2	MCOBT-4.4 R-17 Sc 1 (P) R-25 Sc 6 R-25 Sc 7	CdV-16-2(i)r R-3i (P) R-17 Sc 2 (P) R-23i Sc 1 (P) R-25 Sc 4	R-23i Sc 2 (P)

Source: Tables 6-1 and E-2.

[a] Screen interval drilled with bentonite drilling mud.

[b] (P) = Result considered preliminary if it is based on less than 3 sample events, or if the most recent event occurred more than 2 years prior to this assessment.

[c] — = None; Sc = screen.