Los Alamos
NATIONAL LABORATORY

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Los Alamos, New Mexico 87545

Date: February 25, 2002
In Reply Refer To: ESH-18/WQ&H:02-080
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General

Mr. John Young
Permits Management Program
Hazardous Waste Bureau
New Mexico Environment Department
2905 Rodeo Park Drive East, Building 1
Santa Fe, New Mexico, 87505-6303

SUBJECT: HYDROGEOLOGIC CHARACTERIZATION PROGRAM FY 01 DATA QUALITY OBJECTIVE ITERATION AND RESULTING PROPOSED AMENDMENTS TO THE HYDROGEOLOGIC WORKPLAN SCOPE

Dear Mr. Young:

From June through October 2001, the Groundwater Integration Team (GIT) conducted a comprehensive re-iteration of the Data Quality Objectives (DQOs) for the Laboratory's Hydrogeologic Workplan. The results of the DQO re-iteration were presented to you and others at the Hydrogeologic Characterization Program Quarterly Meeting on October 16-17, 2001 at the Cities of Gold Casino Hotel.

On November 27, 2001 a meeting was held at your office to review the entire DQO re-iteration and proposed scope refinement for the Hydrogeologic Workplan. As you may recall, those attending included Mat Johansen and Bob Enz, DOE/OLASO; John McCann, David Broxton, Pat Longmire, and me for the Laboratory. During that meeting, we discussed in detail the contents of the DQO re-iteration package, specifically: Table 2: Summary of Non-Well Planned Data Collection, Analysis, and Interpretation Activities and Table 3: Rationale for Selection Regional Aquifer Wells to Complete the Hydrogeologic Workplan. Subsequent to the meeting, by telephone you requested copies of the original DQO re-iteration package, including Appendix A, and summary information supporting the deletion of six regional aquifer wells from the Workplan.

Please find attached the complete DQO re-iteration package, with Appendix A and a summary of "reasons to install or not install" regional aquifer wells. This information will be fundamental to the decision-making in the near-future regarding the refinement of the final scope of work for completion of the Hydrogeologic Workplan. As you know, I am pursuing the development of a Core Team with representatives from the New Mexico Environment Department, Department of Energy, and the Laboratory so as to come to agreement on the final scope of the Workplan. Although I am anticipating discussions between the three organizations to occur this coming week, that will touch on the final scope of the Workplan, I would expect the Core Team to hold their first meeting in March 2001.

13605

Please feel free to contact me at 665-4681 if you have any questions regarding the attachments. Thank you.

Sincerely,

Charles L. Nylander

Charles L. Nylander
Program Manager
Hydgrogeologic Characterization Program
Water Quality and Hydrology Group

CN/am

Attachments: a/s

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WQ&H File, w/att., MS K497
IM-5, w/att., MS A150

Los Alamos National Laboratory
Hydrogeologic Characterization Program
FY01 Data Quality Objective Iteration and Resulting Amendments to the Hydrogeologic Workplan Scope

October, 2001
Revised: December 31, 2001

Los Alamos National Laboratory
Hydrogeologic Characterization Program
FY01 Data Quality Objective Iteration and Resulting Proposed Amendments to the Hydrogeologic Workplan
October, 2001

Introduction

The Hydrogeologic Workplan was developed as a response to multiple groundwater characterization needs identified by Los Alamos National Laboratory (LANL), Department of Energy (DOE), and New Mexico Environment Department (NMED). The primary purpose of the Hydrogeologic Workplan is to gain an understanding of the hydrogeologic setting adequate to design a monitoring network capable of detecting water quality threats to the regional aquifer. The Hydrogeologic Workplan provides for an iterative process of learning from each activity, especially wells that are installed, thus guiding the succeeding data quality objectives and the location and data collection of the succeeding wells. The interpretive process is equally as important as the well installation and data collection, although it is a process that is not as visible as data collection. Numerical modeling is a primary tool used to interpret the data collected from drilling and testing in the wells. The iteration process is done when sufficient new data and data interpretation has been accomplished to change the conceptual understanding. In FY01, the data collection and modeling reached the level of maturity to allow iteration on the Data Quality Objectives. This document describes the FY01 data quality objective process iteration and resulting proposed amendments to the scope of the Hydrogeologic Workplan. The iteration process will be conducted as often as the new data and interpretation warrant.

Hydrogeologic Workplan Background

In 1995, pursuant to DOE Order 5400.1, the LANL Groundwater Protection Management Plan (GWPMP) was developed that identified the need for site-wide hydrogeologic characterization. Also in 1995, the NMED denied the LANL groundwater monitoring waiver demonstrations on the basis that LANL did not have adequate understanding of the hydrogeologic system to demonstrate waiver of monitoring requirements. Accordingly, NMED requested site-wide hydrogeologic characterization. In addition, the Laboratory through the Environmental Restoration Project must fulfill the requirements of the1990 EPA/NMED RCRA Operating Permit, which includes a requirement in the HSWA Module VIII, Task III, Section A.1 to evaluate hydrogeologic conditions. Thus, in 1995 LANL began developing the Hydrogeologic Workplan that would collect data on the hydrogeologic setting that would be useful for making decisions regarding monitoring and environmental restoration using the Data Quality Objective (DQO) process. In March 1998, NMED approved the Hydrogeologic Workplan.

The ultimate objective of Hydrogeologic Workplan is to understand the hydrogeologic setting in order to design a monitoring network. The series of decisions established in the Hydrogeologic Workplan (flow diagram and DQO process outputs, Figure 1-3 and Appendix 4, respectively, of the Hydrogeologic Workplan) were intended to focus the data collection activities on information important to monitoring design. Thus, the

hydrogeologic data collection is more concentrated in areas with the highest potential for contaminant impacts. The resulting data and analyses are used in recognizing the pathways and rates of contaminant migration. Although one objective of the Hydrogeologic Workplan is to identify areas of groundwater contamination, determining the extent of contamination and the risk posed by that contamination is the responsibility of the LANL Environmental Restoration Project. Investigation of contaminant plumes is not within the scope of the Hydrogeologic Workplan. The workplan was intended to be the integrated characterization phase necessary for two different programs to carry out their related missions -- institutional environmental monitoring and environmental restoration -- in a coordinated and cost-effective fashion.

FY01 Iteration Process

The FY01 DQO iteration began with a comprehensive evaluation of all groundwater-related data collected, analyzed, and interpreted to date in the program in order to determine what is known and what data are necessary to complete the Hydrogeologic Workplan. This document is a compilation of the necessary data and analyses which forms the proposed revisions to the Hydrogeologic Workplan. The next step is to establish a small core group of LANL, DOE and NMED decision-makers to review and develop consensus on the proposed revisions.

The comprehensive evaluation took place between June and October 2001. It was intended to familiarize all of the LANL Groundwater Integration Team (GIT) members with the state of groundwater characterization knowledge and to develop a complete and consistent an understanding of the hydrogeologic system with the available information. To accomplish this task, each scientific discipline represented on the GIT (as subcommittees) provided a presentation that reflects an overview of the information collected to date. The presentations incorporated observations and findings in that discipline on a site-wide basis, what is known on an aggregate basis, and provided a status with respect to resolving the decisions in the Hydrogeologic Workplan. The notes from the presentations made during this process are included as Appendix A.

Following the comprehensive evaluation each GIT subcommittee developed a set of data needs and data collection activities to fill the data needs. From the subcommittee inputs, a list of data needs was compiled. The remaining regional aquifer wells and interpretive activities listed in the Hydrogeologic Workplan were reviewed by the GIT with respect to the list of data needs. The GIT as a whole determined which of the remaining wells and other studies were still necessary and added new studies as necessary to provide the data. Table 1 lists the regional aquifer wells, along with the rationale for the wells, which are proposed to complete the scope of the Hydrogeologic Workplan. Figure 1 shows the proposed locations of the wells. Table 2 lists the other field activities, analytical activities, and project management activities that are also necessary to complete the scope of the Hydrogeologic Workplan. Additionally, Table 2 provides a cross-walk of the non-

well based activities to the 1998 Hydrogeologic Workplan. Table 3 provides the rationale for selecting regional aquifer wells necessary to complete the scope of the Hydrogeologic Workplan.

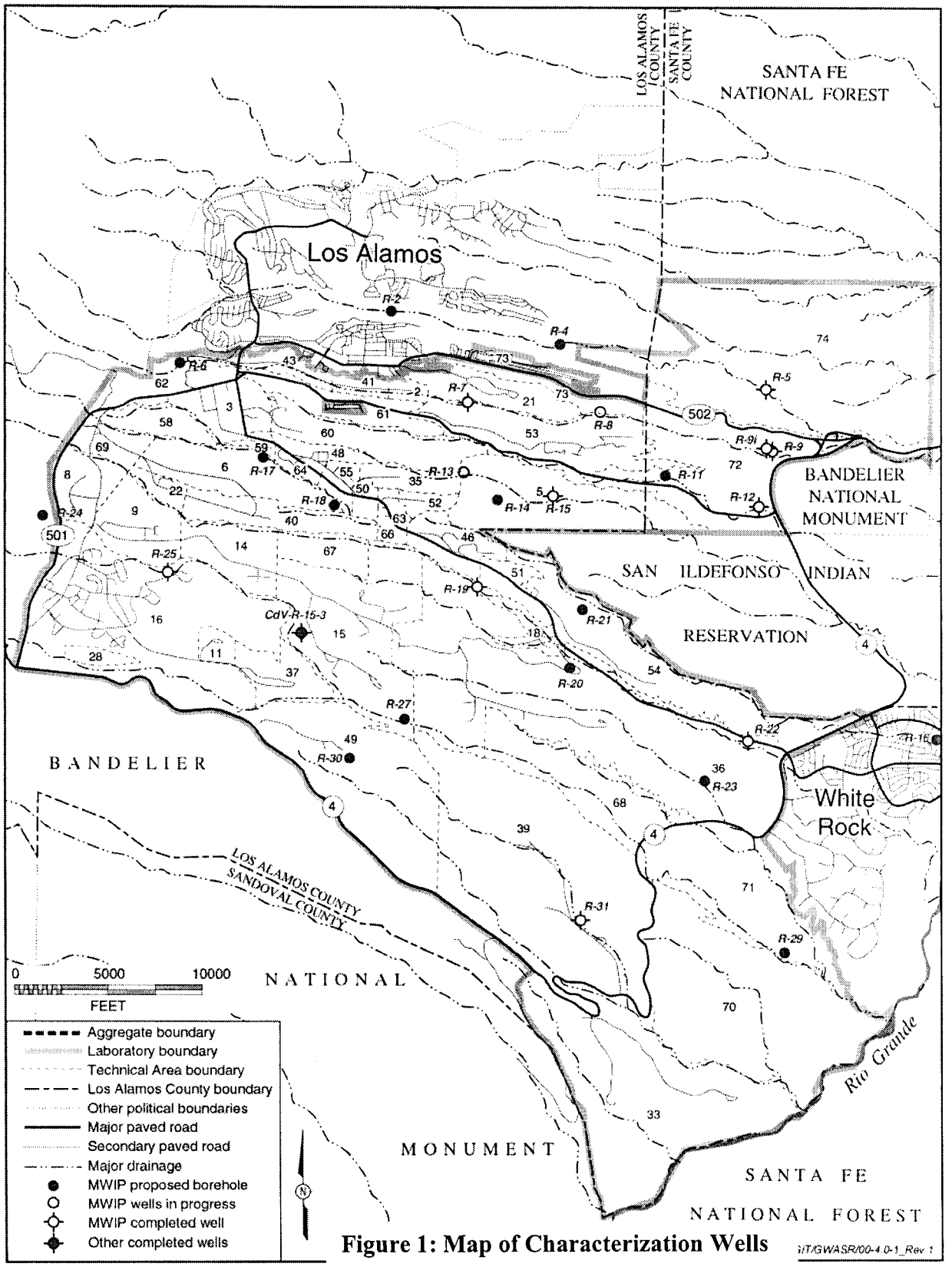


Figure 1: Map of Characterization Wells

Los Alamos National Laboratory
Hydrogeologic Characterization Program
FY01 Data Quality Objective Iteration and Resulting Proposed Amendments to the Hydrogeologic Workplan
October, 2001

Proposed Amendments to the Hydrogeologic Workplan Scope

As an overview, the proposal is to install 15 more regional aquifer wells (Table 1) in the locations shown on Figure 1. This proposal would also eliminate 7 wells:

Regional Aquifer Wells- Summary	
Wells to be Installed	Wells to be Eliminated
R-2	R-1
R-4	R-3
R-11	R-6
R-16	R-10
R-24	R-26
R-29	R-32
R-17	R-28
R-18	
R-20	
R-21	
R-23	
R-27	
R-30	

The proposed scope also includes 13 other field-based activities, 11 analytical activities, and 3 project management activities (Table 2). Table 3 summarizes rationale for regional aquifer wells that were determined to be necessary to complete the scope of the Hydrogeologic Workplan and which of the originally proposed wells have been eliminated from the scope.

Table 4 summarizes the decisions in the Hydrogeologic Workplan for each aggregate, the data needed to resolve the decisions, and the proposed data collection activities. The combination of Tables 2 and 3 replaces Table 3-1 and Sections 3.2 and 3.3 in the 1998 Hydrogeologic Workplan and the combination of Tables 1 and 3 and Figure 1 replaces Tables 4-1 through 4-10 in the Hydrogeologic Workplan. Table 4 is a proposed schedule for completing the revised scope.

In most aggregates the first four decisions, which involve the presence of contaminants in saturated zones, are largely resolved. As anticipated, contamination of saturated zones has occurred in wet canyon systems (e.g. Los Alamos and Pueblo canyons) and is not seen in dry canyon systems (e.g. Ancho Canyon). The remaining decisions, which involve identification of pathways and prediction of the potential for contamination in the future, are not resolved.

For example, some conservative contaminants (e.g. tritium and perchlorate) are observed in the regional aquifer beneath Pueblo Canyon. It is not clear from these observations whether the contamination is moving through the vadose zone as a point source (intersecting the regional aquifer at a relatively small locus) or as a line source (intersecting the regional aquifer in a line below the length of the canyon). The resultant plume in the regional aquifer would be of substantially different proportions depending on the outline of the source. Similarly, the monitoring network design would be quite different in response to the anticipated shape of a plume. Thus, many of the proposed data collection activities are targeted at identifying the pathways and the factors that affect transport within the saturated zones. These activities are concentrated in wet canyons where contaminants were discharged because those are the areas where contamination of saturated zones is anticipated.

Data collection in dry canyon systems and upgradient of LANL is focused on regional aquifer hydrologic characteristics, particularly boundary conditions, permeability, porosity, vertical and horizontal gradients, and faulting effects on the hydrology. This information is critical for predicting the direction and rate of water flow and contaminant transport from any site at the Laboratory.

Table 1: Regional Aquifer Wells

Borehole	Original Start Date	Current Start Date	Funding Source	Rationale of Proposed Boreholes
R-14	FY02	FY02	NWT	R-14 is planned for installation as a water-supply protection well for PM-5. R-14 will provide information about the radius of influence of pumping from PM-5, and its location will be optimized to detect the migration of contaminants from Mortandad Canyon towards the water supply well. R-14 is part of a southeasterly traverse of reference wells that includes R-6 and R-16 and a north-south traverse that includes R-1 and R-28.
R-20	FY02	FY02	NWT	R-20 is planned for installation in lower Pajarito Canyon near water supply well PM-2. R-20 is expected to have multiple completions in the regional aquifer and be located close enough to PM-2 to allow cross-hole hydrologic testing. Intermediate perched zones may occur within the Bandelier Tuff, based on drilling logs for PM-2, and within basalts.
R-27	FY00	FY03	ER	R-27 is planned for installation in Water Canyon. The location will be further east of the location shown in the original Hydrogeologic Workplan because this well was combined with R-28 and moved to a location approximately half way between the two wells. The well is expected to have multiple completions in the regional aquifer. The purpose of the well is to characterize baseline water quality in intermediate perched zones and in the regional aquifer groundwater beneath this wet canyon. Moisture characteristics of the Bandelier Tuff will be measured to evaluate recharge and transport. R-27 also will provide baseline information on the geology, hydrology, and water quality for the poorly-characterized south-central part of the Laboratory.
R-18	FY99	FY03	ER	R-18 is planned for installation at the confluence of Pajarito and Twomile Canyons to provide information about intermediate perched zone groundwater, depth to the regional aquifer, and water quality of perched zones and the regional aquifer in the poorly-characterized west-central part of the Laboratory. The well is expected to have multiple completions in the regional aquifer. It is located downstream from Laboratory release sites at TA-8, TA-9, TA-14, TA-22, TA-40, and TA-69, but is in an area that has not been characterized for either groundwater or contaminants. The occurrence of surface flow through most of the year indicates perched alluvial groundwater is present in this part of the canyon.
R-2	FY00	FY03	NWT	R-2 is planned for installation in upper Pueblo Canyon within Los Alamos townsite. The location will be further west than shown in the original Hydrogeologic Workplan in order to intercept what is expected to be the maximum contamination. The well is expected to have multiple completions in the regional aquifer. R-2 is sited in Pueblo Canyon and is downgradient of the Rendija Canyon fault. Recharge contaminated from past releases may be reaching intermediate perched zones and the regional aquifer along this fault. Analyses of core and water samples collected from R-2 will be used to evaluate the fault as a preferential groundwater pathway. R-2 could replace TW-4 drilled by cable tool in 1950.
R-4	FY01	FY03	ER	R-4 is planned for installation to provide water-quality and water-level information for potential intermediate perched zones and for the regional aquifer beneath middle Pueblo Canyon. The location will be further east than shown in the original Hydrogeologic Workplan in order to complement the revised location of R-2. R-4 will provide information about the downgradient extent of groundwater contamination from former TA-45 and will place constraints on the lateral extent of the perched zone(s) and identify deeper perched zones within the Puye Formation and basalts in middle Pueblo Canyon near the northern Laboratory boundary. R-4 will also characterize groundwater water quality upgradient of the county's Bayo Sewage Treatment Plant.
R-11	FY03	FY04	NWT	R-11, planned for installation as a water-supply protection well for PM-3, is located in middle Sandia Canyon. R-11 is expected to have multiple completions in the regional aquifer and be located close enough to PM-3 to allow cross-hole hydrologic testing. PM-3 is downgradient from source terms with a long history of releases at TA-53 and TA-21. R-11 will be on the upgradient side of PM-3 to detect contaminants from release sites. R-11 will also provide information about groundwater gradients near PM-3.

Table 1: Regional Aquifer Wells

Borehole	Original Start Date	Current Start Date	Funding Source	Rationale of Proposed Boreholes
R-17	FY02	FY04	ER	R-17 is tentatively planned for installation in Twomile Canyon, a major tributary to Pajarito Canyon, to provide information about intermediate perched zones, depth to the regional aquifer, and water quality of intermediate perched zones and the regional aquifer in the poorly-characterized northwest part of the Laboratory. The well is expected to have multiple completions in the regional aquifer. It is located downstream from Laboratory release sites at TA-3, TA-6, TA-58, TA-59, TA-62, and TA-69, but is in an area that has not been characterized for either groundwater or contaminants. R-17 will also provide upgradient water-quality information for Aggregate 7.
R-6	FY03	FY04	NWT	R-6, planned for installation in upper Los Alamos Canyon, is designed to provide baseline information about the geology, hydrology, and water quality for the western boundary of the Laboratory. This borehole will determine background water quality for intermediate perched zones and the regional aquifer upgradient of Aggregate 1. The well is expected to have multiple completions in the regional aquifer. It also will provide information about the depth to the regional aquifer for the western part of the Laboratory, and contribute to the construction of accurate groundwater maps for placing monitoring wells in this part of the Laboratory. R-6 is part of a southeasterly traverse of reference wells that includes R-14 and R-16 and a north-south traverse that includes R-25.
R-23	FY02	FY04	ER	R-23, located near the southeastern Laboratory boundary, is planned for installation to provide water-quality and water-level data for potential intermediate perched zones and for the regional aquifer downgradient of active firing sites in Potrillo Canyon. The well is expected to have multiple completions in the regional aquifer. R-23 is sited within a hydrological sink, a broad area of infiltration on the canyon floor that typically marks the easternmost occurrence of surface water flow in this canyon. R-23 will evaluate the hydrological sink as a possible recharge zone for perched groundwater and for the regional aquifer. The final location of R-23 will be determined after chloride and stable isotope analysis of existing core from this area.
R-24	FY02	FY03	NWT	R-24 is planned for installation west of the trace of the Pajarito fault system and west of Aggregate 5. This borehole will provide water-quality and water-level data for intermediate perched zones and the regional aquifer on the upthrown block of a major splay of the Pajarito fault system. The location and occurrence of perched water and water level data for the regional aquifer, when compared with similar data from R-25 on the downthrown block, will be used to evaluate the influence of the Pajarito fault system on the regional piezometric surface and provide information about its role as a recharge zone. Moisture characteristics of the Bandelier Tuff will be measured to evaluate recharge and transport. Water quality data from intermediate perched zone and regional groundwater in R-24 will define background conditions upgradient from the Laboratory, and in particular for Aggregate 5. These background geochemical data will be used to define potential impacts on groundwater from Laboratory facilities and to provide input data for geochemical and hydrological modeling of different groundwater systems.
R-16	FY03	FY05	NWT	R-16, planned for installation in White Rock, will provide baseline information on the geology, hydrology, and water quality for a large uncharacterized area between the eastern boundary of the Laboratory and the Rio Grande. The current regional aquifer water level maps have an unexpected perturbation in this area that can only be resolved by measuring the water level in the vicinity of R-29 and R-16. The well is expected to have multiple completions in the regional aquifer. R-29 and R-16 will provide important information on clay, carbonate, and hydrothermal alteration in the Puye and Santa Fe, which affects contaminant transport. Numerous springs in White Rock Canyon probably represent discharge points for intermediate perched zones and the regional aquifer based on significant differences in major ion chemistry and stable isotopes. R-16 will determine background water quality for intermediate perched zones and the regional aquifer between the Laboratory and the Rio Grande, provide information about the depth to the regional aquifer for the eastern part the Laboratory, and clarify the relationship between springs in White Rock Canyon and various groundwater zones. R-16 is part of a southeasterly traverse of reference wells that includes R-6 and R-14.
R-21	FY02	FY05	ER	R-21 is planned for installation to provide upgradient water quality information for MDAs L and G. It will be located on the mesa above R-20 to examine the continuity of intermediate perched zones beneath the mesa. It is expected to have multiple completions in the regional aquifer.

Table 1: Regional Aquifer Wells

Borehole	Original Start Date	Current Start Date	Funding Source	Rationale of Proposed Boreholes
R-29	FY03	FY05	NWT	R-29 is planned for installation in lower Water Canyon. It will provide information about the depth to the regional aquifer in a poorly-characterized area. The current regional aquifer water level maps have an unexpected perturbation in this area that can only be resolved by measuring the water level in the vicinity of R-29 and R-16. The well is expected to have multiple completions in the regional aquifer. R-29 and R-16 will provide important information on clay, carbonate, and hydrothermal alteration in the Puye and Santa Fe, which affects contaminant transport. Data from this well will be used to understand the discharge boundary conditions in the regional aquifer model and to optimize the placement of downgradient monitoring wells along the eastern Laboratory boundary. Water quality data from perched and regional groundwaters in R-29 will be compared to similar data for springs in White Rock Canyon to identify potential groundwater flow paths near the Rio Grande.
R-30	FY02	FY05	ER	R-30 is planned to determine water quality in intermediate perched zones and in the regional aquifer beneath MDA AB, which was used for underground hydronuclear experiments. The final location of R-30 will be based on unsaturated zone modeling that has been completed for MDA AB.

Table 2: Summary of Non-Well Planned Data Collection, Analysis, and Interpretation Activities

Task ID Number	Task Name	Task Description	Cross-Walk to Hydrogeologic Workplan (Table 3-1)
Other Field (Non-Well) Activities			
OF-1	Spinner logs	Spinner logs, to determine the most productive zones in a well, should be run in water supply wells where a sentry well is planned. High priority wells for spinner logs are PM-3, PM-5, and O-1.	**Task:** Develop Hydrologic Model **Subtask:** Compile Hydraulic Characteristic Data 3) Hydrologic parameter estimation for Pajarito Plateau
OF-2	Multiple-Well Hydrologic Testing for Large-Scale Permeability	Multiple well pump test(s) to determine medium-to-large scale permeability & to reconcile model parameters with test data. R-20 and R-11 could be close enough to water supply wells to conduct testing.	**Task:** Develop Hydrologic Model **Subtask:** Compile Hydraulic Characteristic Data 3) Hydrologic parameter estimation for Pajarito Plateau
OF-3	Tracer test for Effective Porosity	Conduct cross-hole forced-gradient tracer tests to estimate field scale effective porosity. Requires construction of a test facility with two wells screened in intervals of interest.	**Task:** Develop Hydrologic Model **Subtask:** Compile Hydraulic Characteristic Data 3) Hydrologic parameter estimation for Pajarito Plateau
OF-4	In Situ Downhole Velocity Tests	Tests to be conducted in water supply wells if they become available. The test results would provide a check on the modeling.	**Task:** Develop Hydrologic Model **Subtask:** Compile Hydraulic Characteristic Data 3) Hydrologic parameter estimation for Pajarito Plateau
OF-5	Airborne Electromagnetic Survey	To map the extent of intermediate perched groundwater. The data collection is about 75% complete.	
OF-6	Percolation Rates	Install a number of approximately 300-feet deep wells in a canyon to look at moisture and contaminant distribution. The shallow wells would be used for estimating percolation rates and travel times.	**Task:** Develop Hydrologic Model **Subtask:** Compile and publish hydraulic characteristic data, 1) Bandelier Tuff
OF-7	Refine Groundwater Age Estimates	Determine age and groundwater travel times in regional aquifer (R wells). Perform this work activity during sampling of R wells. Need to obtain representative calcite samples from core collected at R wells and outcrops to correct $\delta^{13}C$ for recalculating C-14 dates.	**Task:** Develop Geochemical Model **Subtask:** Geochemical characteristics of key subsurface hydrogeologic units
OF-8	Sorption Parameters	Perform sorption experiments on uranium, strontium, plutonium, and americium using groundwater and core-cutting	**Task:** Develop Geochemical Model **Subtask:** Geochemical

Table 2: Summary of Non-Well Planned Data Collection, Analysis, and Interpretation Activities

Task ID Number	Task Name	Task Description	Cross-Walk to Hydrogeologic Workplan (Table 3-1)
		samples to determine adsorption constants (distribution coefficients and surface complexation parameters) from the Cerros del Rio basalt (perched groundwater zones) in Los Alamos Canyon and Mortandad Canyon.	characteristics of key subsurface hydrogeologic units
OF-9	Pre-Bandelier Sedimentology	Characterize the components of the Puye Formation and Santa Fe Group to develop a representative description of grain size, shape, sorting, and mineralology. The current descriptions based on drill cuttings are biased toward the larger grain sizes because the fines that wash out while drilling. Collect samples from outcrops of these units to determine the relative proportion of the size components.	**Task:** Develop Hydrologic Model **Subtask:** Compile Hydraulic Characteristic Data 3)Hydrologic parameter estimation for Pajarito Plateau
OF-10	Basalt Flow Geometry	Spatial refinement of the geometry of basalt flows, which are potential fast pathways, is uncertain. Use the airborne EM survey and surface mapping of Frijoles and Guaje Mountain (SE corner) quadrangles. Develop and consider multiple alternative geologic models and test them with flow model against water level data.	**Task:** Develop Geologic Model **Subtask:** Develop 3-dimensional database
OF-11	Range of measured permeability - small scale	Conduct pumping hydrologic tests in zones of interest. Slug tests may only test the filter pack materials.	**Task:** Develop Hydrologic Model **Subtask:** Water Quality Data 2) Evaluate water quality variations and vertical stratification
OF-12	Chemical stratification within the regional aquifer	Characterization wells completed with multiple screened intervals and sampling ports within the regional aquifer will be used to evaluate water quality variations and vertical stratification	**Task:** Develop Hydrologic Model **Subtask:** Water Quality Data 2) Evaluate water quality variations and vertical stratification
OF-13	Spring Flow and Quality Monitoring	Flow measurements and water quality analysis for springs in areas impacted by contamination, e.g. TA-16	**Task:** Develop Hydrologic Model **Subtask:** Inventory Springs Onsite
Analytical Activities			
A-1	Regional Aquifer Modeling - Facies Model & Aquifer Permeability	Review logs to see if anything is in logs related to permeability. Develop a method of logging to provide a correlation between textural deposits or depositional facies and permeability estimates. Incorporate hypotheses concerning fault zones, facies within sedimentary rocks, alternative realizations about structure of basalt flows, etc. quickly into 3-D geologic model so that they	**Task:** Develop Geologic Model **Subtask:** Develop 3-dimensional database **Task:** Develop Hydrologic Model **Subtask:** Compile Hydraulic Characteristic Data 3)Hydrologic parameter estimation for Pajarito

Table 2: Summary of Non-Well Planned Data Collection, Analysis, and Interpretation Activities

Task ID Number	Task Name	Task Description	Cross-Walk to Hydrogeologic Workplan (Table 3-1)
		can be tested against water level data using flow modeling.	Plateau **Task:** Develop Hydrologic Model **Subtask:** Groundwater flow modeling using FEHM code
A-2	Groundwater Pathway Assessment	Rank contaminants of potential risk-significance to groundwater receptors on a site-wide basis. Synthesize information from contaminant sources and hydrogeologic data to assess transport times and pathways.	**Task:** Develop Hydrologic Model **Subtask:** Groundwater modeling using FEHM code
A-3	Regional Aquifer Modeling - Local Perturbations of Flow Field	Potential effects of fault zones with data from R-25, R-24, R-2 and R-4; link canyons models to regional aquifer model through the water table boundary condition, examine effects of local recharge	**Task:** Develop Hydrologic Model **Subtask:** Groundwater modeling using FEHM code
A-4	Regional Aquifer Modeling - Future Water Quality and Quantity	Incorporate new data into model calibration; define capture zones for water supply wells; assess potential future changes in water quality due to pumping; predict future water level declines	**Task:** Develop Hydrologic Model **Subtask:** Groundwater modeling using FEHM code
A-5	Regional Aquifer Modeling - Support Monitoring Well Network Design	Incorporate all pertinent data into model calibration; calculate final sensitivity analyses to generate confidence intervals for all simulated flow directions and velocities for use in designing the monitoring well network.	**Task:** Develop Hydrologic Model **Subtask:** Groundwater modeling using FEHM code
A-6	Chloride and Stable Isotope Analysis	Determine recharge rates in core from boreholes in Potrillo Canyon, collected from the area where surface water disappears. Core is available for analysis.	**Task:** Develop Hydrologic Model **Subtask:** Compile Hydraulic Characteristic Data 2)Vadose Zone fluxes in Los Alamos mesas
A-7	Baseline Geochemistry	Finalize publication and make database available.	**Task:** Develop Geochemical Model **Subtask:** Hydrochemical and statistical evaluation of solute distributions
A-8	Geochemical Modeling	Understand the important processes occurring along flow paths using baseline water quality and characterization sampling data	**Task:** Develop Geochemical Model **Subtask:** Geochemical Modeling
A-9	Pajarito Plateau Water Balance	Refine plateau-wide water balance as part of regional aquifer modeling on an annual basis.	**Task:** Develop Hydrologic Model **Subtask:** Long-term water balance
A-10	Information Management	ER/ESH data exchange, system maintenance and administration, and project management to consolidate	**Task:** Develop Hydrologic Model **Subtask:** Water Quality Data,

Table 2: Summary of Non-Well Planned Data Collection, Analysis, and Interpretation Activities

Task ID Number	Task Name	Task Description	Cross-Walk to Hydrogeologic Workplan (Table 3-1)
		historical and newly collected water quality-related data	Consolidate historical water quality database
A-11	Three-Dimensional Geologic Model	Maintain three-dimensional geologic model to produce structure contour, isopach, water table maps and to provide geologic data for hydrologic modeling; update annually with new data	**Task:** Develop Geologic Model **Subtask:** Develop 3-dimensional database **Subtask:** Perform comprehensive review of 3-dimensional stratigraphy
Project Management Activities			
PM-1	GIT Activities	Quarterly meetings, annual meetings, annual groundwater status report	
PM-2	EAG Activities	Semi-annual project reviews, semi-annual reports	
PM-3	Field Support Facility	Maintain field support facility and core facility	

Table 3: Rationale for Selection Regional Aquifer Wells to Complete the Hydrogeologic Workplan

Well	Reasons to install the well(s)	Reasons not to install the well(s)	Other comments
R-1	• May provide a "background" well, demonstrating water quality upgradient of the Lab • *Fault zone*[1] • *Southerly flow component in the regional aquifer*	• Mapping in the Guaje Mountain Quadrangle may reduce the need for the well. • Close to Guaje wells and would not provide new information. • R-1 is *not* identified as an anticipated monitoring well for the ER Project. • There is sufficient number of wells planned for LA/Pueblo Canyon that R-1 is not needed for additional characterization.	• The location of R-1 is not useful for looking at the effects of faulting. • R-1, to the north of the Lab, was originally conceived as a 4,000-foot deep well for evaluating water resources and regional aquifer flow, but would not have very much utility completed in the regional aquifer water table. • R-1 should be installed only if water levels and/or geology in R-2 is not as expected.
R-1 Proposal: Eliminate R-1.			
R-2 R-3 R-4	• *R-2 was replacement for TW-4* • Pueblo Canyon has contamination, it is wet, has short travel times due to the rocks at the surface, so it is important to investigate. • Wells along the length of the canyon would be useful for demonstrating Monitored Natural Attenuation. • Contamination has already reached the regional aquifer, so we need regional aquifer and contaminant distribution information. • 2 or 3 wells in Pueblo Canyon useful	• TW-1A, TW-2A, and TW-4 provide perched zone chemistry, so there is some information, but there are still questions. • TW-2 is on the canyon floor and completed in the regional aquifer - it does not have huge evidence of contamination - stable chemistry, no nitrate, low tritium.	• NMED has indicated in casual conversations that 3 wells (R-2, R-3, and R-4) may not be necessary. • Structural mapping of the fault zone would be useful in siting R-2. • Would like to collect cores of the Bandelier Tuff in Pueblo Canyon, but do not need regional aquifer wells for that. • For Monitored Natural Attenuation, EPA recommends demonstration that contaminants are removed. Need core samples, e.g. Puye clay encountered in R-9 would adsorb

[1] Italics refer to data needs listed in the Hydrogeologic Workplan

Table 3: Rationale for Selection Regional Aquifer Wells to Complete the Hydrogeologic Workplan

Well	Reasons to install the well(s)	Reasons not to install the well(s)	Other comments
	for pathway characterization and monitored natural attenuation: ▪ 1 well up-canyon ▪ 1 well above County wastewater treatment plant ▪ 1 more well if necessary for monitored natural attenuation. • Tb2 basalt is near the top of the water table, but is poorly constrained around R-2. • TW-2A (perched zone completion) has had high tritium for a long time and a few indications of plutonium (not reproduced). • R-2, 3, 4 all identified as anticipated monitoring wells by ER Project. • R-2 should be moved down canyon to intercept maximum contamination.		contaminants and it would be important to know if the same clay is present under Los Alamos and Pueblo canyons. • There are two potential hypotheses about contamination in Pueblo Canyon. The corrective action or monitoring would be different for each hypothesis. More than 2 wells are needed to determine which hypothesis is correct: 1. "Tunnel" hypothesis: Isolated source of contaminated water recharge to the regional aquifer that has resulted in an isolated plume that is affected by geologic features (basalts). 2. "Distributed flow" hypothesis: Contaminants spread out along the surface forming a line source of recharge that has reached the regional aquifer in some places but not in others. • The existing 5 wells are not useful in distinguishing between hypotheses because the mass of the plume, in water and adsorbed, has not been identified.

Table 3: Rationale for Selection Regional Aquifer Wells to Complete the Hydrogeologic Workplan

Well	Reasons to install the well(s)	Reasons not to install the well(s)	Other comments
<u>R-2, R-3, R-4 Proposal:</u> Drill R-2 and R-4 as multiple completion wells to understand vertical gradients. Eliminate R-3. Install separate wells for intermediate zones.			
R-6 R-24 R-26	• *R-6: Fully cored; lined up with 5 other wells across the Lab; background chemistry, vertical gradients in regional aquifer.* • *R-24, R-26: straddle fault system, recharge, boundary flux.* • The Pajarito Fault zone could divert water to the south; need geochemical data to determine flow paths. • Hydrologic testing could determine if the fault was acting as a barrier to flow. • R-6 is in a graben structure and would be different than R-24 or R-26. • R-24 is identified as anticipated monitoring well by ER Project.	• Water samples from R-7 did not contain contaminants, so R-6 is not needed for background. • If R-6 was a single completion well, it would not provide additional information on water levels beyond what was measured in H-19. • Hydrologically it is not important to have a well in the middle of the fault zone; e.g. the R-25 well is close to the fault zone, but it is not clear what is happening with the thick "perched" zone. • R-6 is *not* identified as anticipated monitoring well by ER Project. • R-26 is *not* identified as anticipated monitoring well by ER Project.	• H-19 (near R-6) was drilled deep and encountered different lavas; logs form the well show Totavi-like gravels between the lavas. It would be important to the conceptual model - demonstrating the river was next to the mountains and was pushed eastward by outbuilding of alluvial fans. It is important if the Totavi gravels control flow because the gravels could be much further west and deeper than currently thought. • Important to collect core from any well around the fault. • R-6 could provide more useful geologic information than R-1. • Only drill R-6 and R-26 if needed after drilling R-24.
<u>R-6, R-24, R-26 Proposal:</u> Drill R-24 west of the fault zone. Eliminate R-6 and R-26.			
R-10 R-11	• *R-10 originally proposed to determine is there is an intermediate zone in the Guaje Pumice bed and if it is the same perched zone as in Los Alamos Canyon.* • *R-11 was proposed as a sentry water well for PM-3.*	• No need for R-10 to look for water in the Guaje Pumice bed because in R-12 there was no water in the Guaje Pumice bed. • Only one well is anticipated to be necessary in Sandia Canyon to evaluate flow paths for	• Regional aquifer tritium was 50 pCi/L. • Another well in Mortandad Canyon would be more useful than two wells in Sandia Canyon. • R-11 could be located close enough to PM-3 to conduct cross-

Table 3: Rationale for Selection Regional Aquifer Wells to Complete the Hydrogeologic Workplan

Well	Reasons to install the well(s)	Reasons not to install the well(s)	Other comments
	• Need one well to find pathway for contaminants found in R-12 • R-10 identified as anticipated monitoring well by ER Project • R-11 identified as anticipated monitoring well by ER Project	contaminants found in R-12.	hole testing.
R-10, R-11 Proposal: Relocate R-11 to act as sentry well for PM-3. Eliminate R-10.			
R-16 R-29 R-32	• *All were originally proposed as boundary condition wells.* • NMED has expressed concerns that there are insufficient number of wells after water analyses on R-22 and Area G. • The equipotential lines in the regional aquifer are not parallel to the river as expected; R-16 and R-29 are both needed for flow direction. • R-16 and R-29 are identified as anticipated monitoring wells by ER Project.	• R-32 *not* identified as anticipated monitoring well by ER Project.	• Downstream concerns: San Ildefonso, Buckman wells, Rio Grande water quality. • Uncertain what the source of water for springs in White Rock Canyon: regional aquifer or perched intermediate. • There are upward vertical gradients in the regional aquifer in this area, so if there were contamination, single completion wells would be acceptable. • Multiple completion wells may be useful for flow paths in the regional aquifer. • If these down-gradient boundary wells are part of the regional monitoring network, single completion may result in higher quality samples for water chemistry. • Drill R-32 only if on water level

Table 3: Rationale for Selection Regional Aquifer Wells to Complete the Hydrogeologic Workplan

Well	Reasons to install the well(s)	Reasons not to install the well(s)	Other comments
			information from R-16 and R-32 is different than expected.
<u>R-16, R-29, R-32 Proposal</u>: Install R-16 and R-29 as single completion wells. Eliminate R-32.			
R-17 R-18	• *R-17 and R-18 were proposed to provide information on presence, occurrence and quality of perched zones and depth to regional aquifer in poorly understood part of the Lab.* • These wells are necessary because there are no wells in Pajarito Canyon. • In R-22 there was elevated Tc-99 and tritium. • R-17 could detect HE; the springs in the tuff have HE. • Move R-17 to east of TA-18 to get information on saturation in the Cerros del Rio and complete the well in the regional aquifer.	• Due to access, R-18 can not be drilled where it is shown on the map.	• If R-17 is left where it is, it would strengthen the geologic model. • Move R-16 closer to Pajarito Canyon because no wells are planned for Pajarito Canyon floor. • NMED has expressed an interest in having a well where the flow in Pajarito disappears, at about the confluence with 2-Mile Canyon • Subpart X units - have to demonstrate no potential for groundwater contamination, so up- and down-gradient information is needed. Otherwise, monitoring could be required.
<u>R-17, R-18 Proposal</u>: Install R-17 where it is shown in the Hydrogeologic Workplan as a multiple completion well. Relocate R-18 to confluence of Pajarito and 2-Mile Canyons and complete with multiple intervals.			
R-20 R-21	• *R-20 sentry well for PM-2* • *R-21 detect releases from Areas G and L and match up with data from R-20* • R-20 is a candidate for cross-hole hydrologic testing with PM-2. • Place one in the canyon and one on	• There are 3 wells (R-20, -21, -22) in a very small area of the Lab, seems like inappropriate coverage. • R-20 and R-21 are not necessary for characterization. There is lots of information for this area and there is no good justification for two wells so	• Check for data from wells installed in and around TA-54, some may be in the Cerros del Rio and would provide information on continuity of perched zones. • There has been monitoring of moisture content in the Area G

Table 3: Rationale for Selection Regional Aquifer Wells to Complete the Hydrogeologic Workplan

Well	Reasons to install the well(s)	Reasons not to install the well(s)	Other comments
	the mesa to evaluate the continuity of perched zones. • NMED has indicated that at least 3 wells (R-20, -21, and -22) are necessary to define the regional aquifer water table in this area. • R-20 is a good long-term monitoring point for PM-2, particularly in the canyon bottom. • R-21 would be good to determine whether perched zones are present upgradient of Areas L and G and the water quality.	close together in a regional hydrogeologic characterization. • R-13 is already in that area; complete R-14 before deciding on R-21.	expansion area, but not in the regional aquifer. • R-21 should be upgradient of both Areas L and G because the entire the mesa maybe considered a single site for monitoring. • Move R-21 north to potentially intersect flow lines form Mortandad Canyon. The flow paths are complicated by the pumping wells. The well would have to be on San Ildefonso Pueblo land to do any good. ▪ A well between TA-54 and Mortandad Canyon is needed to sort out contaminants because R-13 does not have detectable contaminants.
<u>R-20, R-21 Proposal</u>: Install R-20 in the canyon, multiple completion, potentially near enough to PM-2 for hydrologic testing. Install R-21 on the mesa upgradient of Areas L and G as a multiple completion well.			
R-23	• *Evaluate recharge, presence of perched zones and influence of the regional aquifer in the area of the "hydrologic sink"* • It will address a recharge question and it is in an area with little existing information • It is unknown whether perched zones are present beneath Potrillo	• The location of R-23 is not good for evaluating flow in the regional aquifer because it is too close to R-22.	• There is core available from boreholes in this area of Potrillo Canyon; they will be analyzed soon • Move the well to the confluence with Fence Canyon to spread out the coverage - but that would be outside of the "hydrologic sink"

Table 3: Rationale for Selection Regional Aquifer Wells to Complete the Hydrogeologic Workplan

Well	Reasons to install the well(s)	Reasons not to install the well(s)	Other comments
	Canyon.		
<u>R-23 Proposal</u>: Install R-23, location to be determined after the analysis of existing core has been completed. Expected multiple completion to measure vertical gradients.			
R-27 R-28	• Both LANL and NMED have agreed to combine R-27 and R-28		
<u>R-27, R-28 Proposal</u>: Install R-27, location to be halfway between the locations for R-27 and R-28 shown in the Hydrogeologic Workplan. R-27 is expected to be a multiple completion well. Eliminate R-28.			
R-30	• *Deepen existing TA-49 borehole to determine water quality in perched and regional aquifer below Area AB*	• Chloride and isotope work has been done on the core from that borehole and not much movement is seen. • There is good information on the borehole that is available in reports that are soon to be published.	• Better to start a new borehole than trying to deepen an existing borehole. • Location should be based on the modeling that has been completed.
<u>R-30 Proposal</u>: Install R-30, location to be determined by consultation with modelers. Completion should be left open.			

Table 4: Summary of Hydrogeologic Workplan Decision Status, Data Needs, and Planned Data Collection Activities

Decision	Aggregate 1: Los Alamos/ Pueblo	Data Needs	Planned Data Collection (Tables 1 and 2)
Are there sources of sufficient magnitude to cause contamination of groundwater?	Yes		
Are the alluvial sediments and uppermost subsurface water at contaminant concentrations > regulatory risk limit or risk level?	Yes		
Is the intermediate perched groundwater at contaminant concentrations > regulatory limit or risk level?	Yes		
Is the regional aquifer as affected by the canyon systems by contaminant concentrations > regulatory limit or risk limit?		• Regional aquifer water quality • Geochemical modeling • Information management • 3-D geologic model	• R-2, R-4, R-6, R-24 • A-7, A-8, A-10, A-11
What are the pathways for exposure to contaminants from alluvial sediments and uppermost subsurface water?		• Distribution and rates of percolation. • Sorption parameters • Range of measured permeability - small scale • Mappable perched zones • Geochemical modeling • Information management • 3-D geologic model	• R-2, R-4, R-6, R-24 • OF-5, OF-6, OF-8, OF-10, OF-11 • A-2, A-7, A-8, A-10, A-11 • PM-1, PM-2, PM-3
Are there sufficient source terms to cause contamination if moved along the pathways in 1000 years?		• Range of measured permeability - large scale • Spinner logs • Pre-Bandelier sedimentology • Effective porosity on a field scale. • Head Data - Horizontal Gradients • Head Data -Vertical Gradients • Chemical stratification in regional aquifer • Determine age and groundwater travel times in regional aquifer • Regional aquifer modeling • Baseline geochemistry • Geochemical modeling • Information management • 3-D geologic model	• R-2, R-4, R-6, R-24 • OF-1, OF-2, OF-3, OF-4, OF-7, OF-9, OF-10, Of-11, OF-12 • A-1, A-2, A-3,A-4, A-5, A-7, A-8, A-9, A-10, A-11 • PM-1, PM-2, PM-3

Table 4: Summary of Hydrogeologic Workplan Decision Status, Data Needs, and Planned Data Collection Activities

Decision	Aggregate 2: Ca™ada del Buey/Pajarito	Data Needs	Planned Data Collection (Tables 1 and 2)
Are there sources of sufficient magnitude to cause contamination of groundwater?	Yes		
Are the alluvial sediments and uppermost subsurface water at contaminant concentrations > regulatory risk limit or risk level?		• Presence of alluvial aquifer water • Quality of alluvial aquifer water • Geochemical modeling • Information management • 3-D geologic model	• R-6, R-16, R-18, R-24, R-27 • A-7, A-9, A-10
Is the intermediate perched groundwater at contaminant concentrations > regulatory limit or risk level?		• Presence of intermediate perched water • Quality of intermediate perched water • Geochemical modeling • Information management • 3-D geologic model	• R-6, R-16, R-18, R-24, R-27 • OT-5 • A-7, A-9, A-10
Is the regional aquifer as affected by the canyon systems by contaminant concentrations > regulatory limit or risk limit?		• Regional aquifer water quality • Geochemical modeling • Information management • 3-D geologic model	• R-6, R-16, R-18, R-24, R-27 • A-7, A-9, A-10
What are the pathways for exposure to contaminants from alluvial sediments and uppermost subsurface water?		• Sorption parameters • Range of measured permeability - small scale • Mappable perched zones • Geochemical modeling • Information management • 3-D geologic model	• R-6, R-16, R-18, R-24, R-27 • OF-5, OF-6, OF-8, OF-10, OF-11 • A-2, A-7, A-8, A-10, A-11 • PM-1, PM-2, PM-3
Are there sufficient source terms to cause contamination if moved along the pathways in 1000 years?		• Range of measured permeability - large scale • Spinner logs • Pre-Bandelier sedimentology • Effective porosity on a field scale. • Head Data - Horizontal Gradients • Head Data -Vertical Gradients • Chemical stratification in regional aquifer • Determine age and groundwater travel times in regional aquifer • Regional aquifer modeling • Baseline geochemistry • Geochemical modeling • Information management • 3-D geologic model	• R-6, R-16, R-18, R-24, R-27 • OF-1, OF-2, OF-3, OF-4, OF-7, OF-9, OF-10, OF-11, OF-12 • A-1, A-2, A-3,A-4, A-5, A-7, A-8, A-9, A-10, A-11 • PM-1, PM-2, PM-3

Table 4: Summary of Hydrogeologic Workplan Decision Status, Data Needs, and Planned Data Collection Activities

Decision	Aggregate 3: TA-49	Data Needs	Planned Data Collection (Tables 1 and 2)
Are there sources of sufficient magnitude to cause contamination of groundwater?	Yes		
Are the alluvial sediments and uppermost subsurface water at contaminant concentrations > regulatory risk limit or risk level?		• Presence of alluvial aquifer water • Quality of alluvial aquifer water • Geochemical modeling • 3-D geologic model	• R-6, R-24,R-30 • A-7, A-9, A-10
Is the intermediate perched groundwater at contaminant concentrations > regulatory limit or risk level?		• Presence of intermediate perched water • Quality of intermediate perched water • Geochemical modeling • 3-D geologic model	• R-6, R-24, R-30 • OT-5 • A-7, A-9, A-10
Is the regional aquifer as affected by the canyon systems by contaminant concentrations > regulatory limit or risk limit?		• Regional aquifer water quality • Geochemical modeling • 3-D geologic model	• R-6, R-24, R-30 • A-7, A-9, A-10
What are the pathways for exposure to contaminants from alluvial sediments and uppermost subsurface water?		• Sorption parameters • Range of measured permeability - small scale • Mappable perched zones • Geochemical modeling • 3-D geologic model • Information management	• R-6, R-24, R-30 • OF-5, OF-6, OF-8, OF-10, OF-11 • A-2, A-7, A-8, A-10, A-11 • PM-1, PM-2, PM-3
Are there sufficient source terms to cause contamination if moved along the pathways in 1000 years?		• Range of measured permeability - large scale • Pre-Bandelier sedimentology • Effective porosity on a field scale. • Head Data - Horizontal Gradients • Head Data -Vertical Gradients • Chemical stratification in regional aquifer • Determine age and groundwater travel times in regional aquifer • Regional aquifer modeling • Geochemical modeling • 3-D geologic model • Information management	• R-6, R-24, R-30 • OF-2, OF-3, OF-4, OF-7, OF-9, OF-10, OF-11, OF-12 • A-1, A-2, A-3,A-4, A-5, A-7, A-8, A-9, A-10, A-11 • PM-1, PM-2, PM-3

Table 4: Summary of Hydrogeologic Workplan Decision Status, Data Needs, and Planned Data Collection Activities

Decision	Aggregate 4: Ancho/Indio/ Chaquehui	Data Needs	Planned Data Collection (Tables 1 and 2)
Are there sources of sufficient magnitude to cause contamination of groundwater?	Yes		
Are the alluvial sediments and uppermost subsurface water at contaminant concentrations > regulatory risk limit or risk level?	No		
Is the intermediate perched groundwater at contaminant concentrations > regulatory limit or risk level?	No		
Is the regional aquifer as affected by the canyon systems by contaminant concentrations > regulatory limit or risk limit?	No		
What are the pathways for exposure to contaminants from alluvial sediments and uppermost subsurface water?		• Mappable perched zones • Geochemical modeling • Pre-Bandelier sedimentology • Information management • 3-D geologic model	• R-6, R-24, R-29, R-30 • OF-6, OF-8, OF-10, OF-11 • A-2, A-7, A-8, A-10, A-11 • PM-1, PM-2, PM-3
Are there sufficient source terms to cause contamination if moved along the pathways in 1000 years?		• Range of measured permeability - large scale • Pre-Bandelier sedimentology • Effective porosity on a field scale • Head Data - Horizontal Gradients & Vertical Gradients • Chemical stratification in regional aquifer • Determine age and groundwater travel times in regional aquifer • Regional aquifer modeling Information management • 3-D geologic model • Information management • Baseline geochemistry	• R-6, R-24, R-29, R-30 • OF-2, OF-3, OF-4, OF-7, OF-9, OF-10, OF-11, OF-12 • A-1, A-2, A-3,A-4, A-5, A-7, A-8, A-9, A-10, A-11 • PM-1, PM-2, PM-3

Table 4: Summary of Hydrogeologic Workplan Decision Status, Data Needs, and Planned Data Collection Activities

Decision	Aggregate 5: Ca™on del Valle	Data Needs	Planned Data Collection (Tables 1 and 2)
Are there sources of sufficient magnitude to cause contamination of groundwater?	Yes		
Are the alluvial sediments and uppermost subsurface water at contaminant concentrations > regulatory risk limit or risk level?	Yes		
Is the intermediate perched groundwater at contaminant concentrations > regulatory limit or risk level?	Yes		
Is the regional aquifer as affected by the canyon systems by contaminant concentrations > regulatory limit or risk limit?		• Regional aquifer water quality • Geochemical modeling • Information management • 3-D geologic model	• R-6, R-18, R-24, R-27 • A-7, A-9, A-10
What are the pathways for exposure to contaminants from alluvial sediments and uppermost subsurface water?		• Mappable perched zones • Geochemical modeling • Pre-Bandelier sedimentology • Information management • 3-D geologic model • Spring flow and quality monitoring	• R-6, R-18, R-24, R-27 • OF-5, OF-6, OF-8, OF-10, OF-11 • A-2, A-7, A-8, A-10, A-11 • PM-1, PM-2, PM-3
Are there sufficient source terms to cause contamination if moved along the pathways in 1000 years?		• Range of measured permeability - large scale • Pre-Bandelier sedimentology • Effective porosity on a field scale • Head Data - Horizontal Gradients & Vertical Gradients • Chemical stratification in regional aquifer • Determine age and groundwater travel times in regional aquifer • Regional aquifer modeling Information management • 3-D geologic model • Information management • Baseline geochemistry	• R-6, R-18, R-24, R-27 • OF-2, OF-3, OF-4, OF-7, OF-9, OF-10, OF-11, OF-12 • A-1, A-2, A-3,A-4, A-5, A-7, A-8, A-9, A-10, A-11 • PM-1, PM-2, PM-3

Table 4: Summary of Hydrogeologic Workplan Decision Status, Data Needs, and Planned Data Collection Activities

Decision	Aggregate 6: Water/ Potrillo/Fence	Data Needs	Planned Data Collection (Tables 1 and 2)
Are there sources of sufficient magnitude to cause contamination of groundwater?	Yes		
Are the alluvial sediments and uppermost subsurface water at contaminant concentrations > regulatory risk limit or risk level?		• Presence of alluvial aquifer water • Quality of alluvial aquifer water • Chloride and stable isotope analysis • Geochemical modeling • Information management • 3-D geologic model	• R-6, R-18, R-23, R-24, R-27, R-29 • A-5, A-7, A-9, A-10
Is the intermediate perched groundwater at contaminant concentrations > regulatory limit or risk level?		• Presence of intermediate perched water • Quality of intermediate perched water • Geochemical modeling • Chloride and stable isotope analysis • Geochemical modeling • Information management • 3-D geologic model	• R-6, R-18, R-23, R-24, R-27, R-29 • OT-5 • A-5, A-7, A-9, A-10
Is the regional aquifer as affected by the canyon systems by contaminant concentrations > regulatory limit or risk limit?		• Regional aquifer water quality • Geochemical modeling • Information management • 3-D geologic model	• R-6, R-18, R-23, R-24, R-27, R-29 • A-7, A-9, A-10
What are the pathways for exposure to contaminants from alluvial sediments and uppermost subsurface water?		• Mappable perched zones • Geochemical modeling • Chloride and stable isotope analysis • Geochemical modeling • Pre-Bandelier sedimentology • Information management • 3-D geologic model •	• R-6, R-18, R-23, R-24, R-27, R-29 • OF-5, OF-6, OF-8, OF-10, OF-11 • A-2, A-6, A-7, A-8, A-10, A-11 • PM-1, PM-2, PM-3
Are there sufficient source terms to cause contamination if moved along the pathways in 1000 years?		• Range of measured permeability - large scale • Pre-Bandelier sedimentology • Effective porosity on a field scale • Head Data - Horizontal Gradients & Vertical Gradients • Chemical stratification in regional aquifer • Chloride and stable isotope analysis • Geochemical modeling and baseline geochemistry • Determine age and groundwater travel times in regional aquifer • Regional aquifer modeling • 3-D geologic model and information management	• R-6, R-18, R-23, R-24, R-27, R-29 • OF-2, OF-3, OF-4, OF-7, OF-9, OF-10, OF-11, OF-12 • A-1, A-2, A-3, A-4, A-5, A-7, A-8, A-9, A-10, A-11 • • PM-1, PM-2, PM-3

Table 4: Summary of Hydrogeologic Workplan Decision Status, Data Needs, and Planned Data Collection Activities

Decision	Aggregate 7: Mortandad	Data Needs	Planned Data Collection (Tables 1 and 2)
Are there sources of sufficient magnitude to cause contamination of groundwater?	Yes		
Are the alluvial sediments and uppermost subsurface water at contaminant concentrations > regulatory risk limit or risk level?	Yes		
Is the intermediate perched groundwater at contaminant concentrations > regulatory limit or risk level?	Yes		
Is the regional aquifer as affected by the canyon systems by contaminant concentrations > regulatory limit or risk limit?		• Regional aquifer water quality • Geochemical modeling • Information management • 3-D geologic model	• R-6, R-14, R-16, R-24 • A-7, A-9, A-10
What are the pathways for exposure to contaminants from alluvial sediments and uppermost subsurface water?		• Mappable perched zones • Geochemical modeling • Pre-Bandelier sedimentology • Information management • 3-D geologic model •	• R-6, R-14, R-16, R-24 • OF-5, OF-6, OF-8, OF-10, OF-11 • A-2, A-7, A-8, A-10, A-11 • PM-1, PM-2, PM-3
Are there sufficient source terms to cause contamination if moved along the pathways in 1000 years?		• Range of measured permeability - large scale • Pre-Bandelier sedimentology • Effective porosity on a field scale • Head Data - Horizontal Gradients & Vertical Gradients • Determine age and groundwater travel times in regional aquifer • Regional aquifer modeling • Information management • 3-D geologic model • Information management • Baseline geochemistry	• R-6, R-14, R-16, R-24 • OF-2, OF-3, OF-4, OF-7, OF-9, OF-10, OF-11 • A-1, A-2, A-3,A-4, A-5, A-7, A-8, A-9, A-10, A-11 • PM-1, PM-2, PM-3

Table 4: Summary of Hydrogeologic Workplan Decision Status, Data Needs, and Planned Data Collection Activities

Decision	Aggregate 8: Guaje/Bayo/ Rendija	Data Needs	Planned Data Collection (Tables 1 and 2)
Are there sources of sufficient magnitude to cause contamination of groundwater?	No		
Are the alluvial sediments and uppermost subsurface water at contaminant concentrations > regulatory risk limit or risk level?	No		
Is the intermediate perched groundwater at contaminant concentrations > regulatory limit or risk level?	No		
Is the regional aquifer as affected by the canyon systems by contaminant concentrations > regulatory limit or risk limit?	No		
What are the pathways for exposure to contaminants from alluvial sediments and uppermost subsurface water?	No		
Are there sufficient source terms to cause contamination if moved along the pathways in 1000 years?	No		

Table 4: Schedule for Proposed Workplan Activities

ID	Task Name	2002 Qtr 1	2002 Qtr 2	2002 Qtr 3	2002 Qtr 4	2003 Qtr 1	2003 Qtr 2	2003 Qtr 3	2003 Qtr 4	2004 Qtr 1	2004 Qtr 2	2004 Qtr 3	2004 Qtr 4	2005 Qtr 1
1	**Regional Aquifer Wells**													
2	R-27													
3	R-18													
4	R-2													
5	R-20													
6	R-4													
7	R-11													
8	R-17													
9	R-6													
10	R-23													
11	R-29													
12	R-16													
13	R-21													
14	R-24													
15	R-30													

Table 4: Schedule for Proposed Workplan Activities

ID	Task Name
1	**Other Field Activities**
2	Spinner logs/Velocity Tests
3	Multiple Well Hydrologic Testing - R-11
4	Multiple Well Hydrologic Testing - R-21
5	Tracer Tests
6	EM Survey
7	Percolation Rates
8	Refine Groundwater Age Estimates
9	Sorption Parameters
10	Pre-Bandelier Sedimentology
11	Large-Scale Permeability
12	Small-Scale Permeability
13	Chemical Stratification in Regional Aquifer
14	Spring Flow and Quality

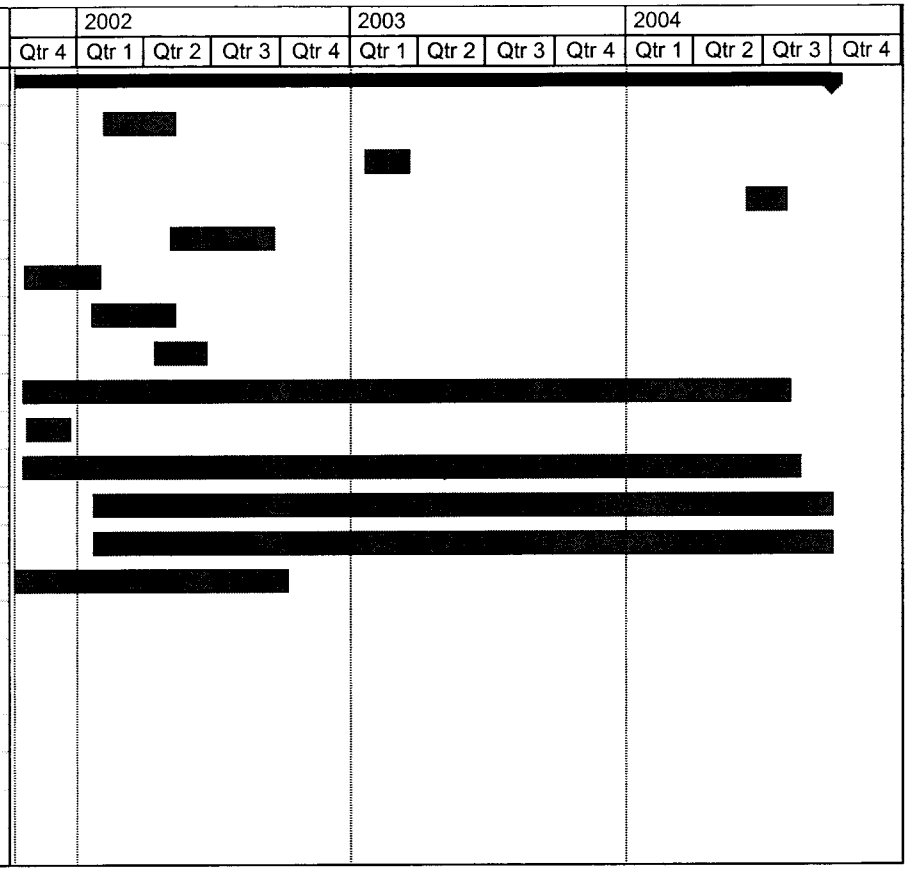
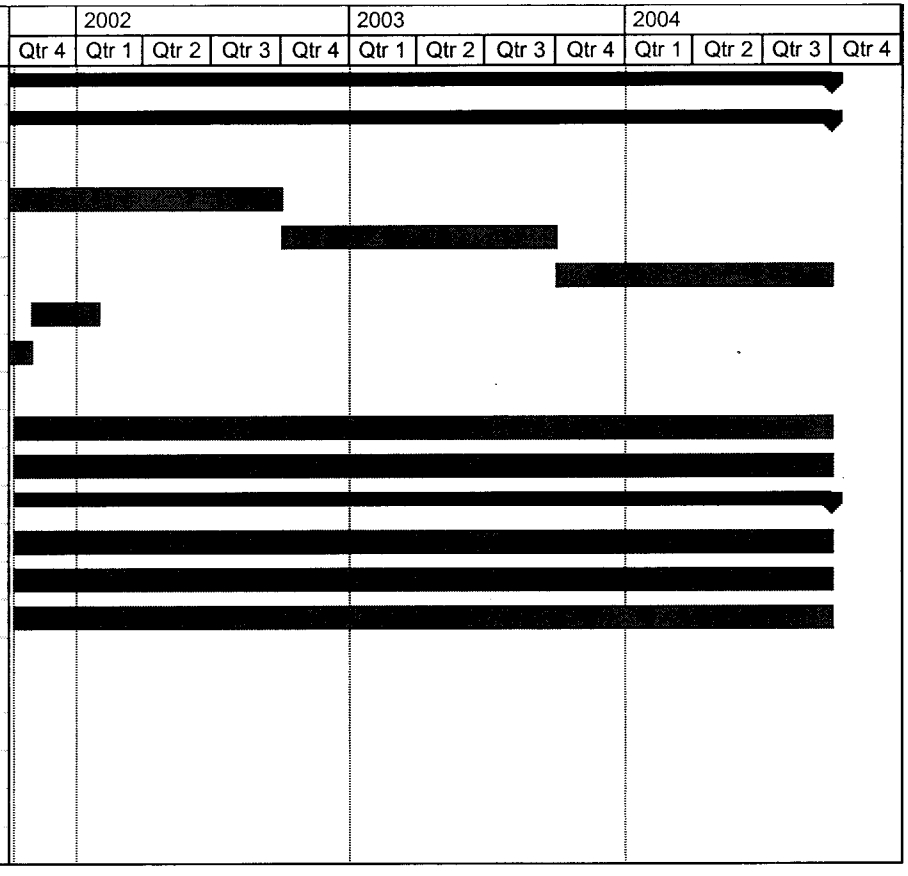


Table 4: Schedule for Proposed Workplan Activities

ID	Task Name
1	**Analytical Activities**
2	**Regional Aquifer Modeling**
3	Facies Model
4	Local Perturbations
5	Quality and Quantity
6	Monitoring Network Design
7	Chloride and Stable Isotopes
8	Baseline Geochemistry
9	Water Balance
10	Information Management
11	3-D Geologic Model
12	**Project Management Activities**
13	GIT Activities
14	EAG Activities
15	Field Support Facility



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A.1 Introduction

This appendix records the overview portion of the DQO iteration comprehensive evaluation. The following sections are notes taken during presentations made to the LANL Groundwater Integration Team (GIT) between June and October 2001. The presentations were intended to familiarize all of the GIT members with the state of groundwater characterization knowledge and to develop a complete and consistent an understanding of the hydrogeologic system with the available information. The sections in this appendix are:

- Geologic Overview (Greg Cole and David Vaniman)
- Geochemical Overview (Pat Longmire)
- Vadose Zone Hydrology and Modeling (David Rogers and Bruce Robinson)
- Regional Aquifer Hydrology and Modeling (Elizabeth Keating)

A.2 Geological Overview of the Pajarito Plateau

(I) STATUS OF THE 3-D GEOLOGIC MODEL

The site-wide 3-D Geologic Model has been updated and refined several times. Early in FY01, the geology group held a series of meetings to evaluate our understanding of the LANL Site geology, especially with regards to hydrogeology. These meetings identified those data most needed to support conceptual and spatial models and adequate for risk-assessment activities. Some of the data deficiencies have been met by new data from the characterization wells, by reassessment of data and samples from earlier drill holes, by new geologic maps of the Puye and Frijoles Quadrangles, and by Seismic Hazards Program studies.

a) Structure

The current Hydrogeologic Workplan places special emphasis on faults and fractures. There are faults to the north and south of the Laboratory, known from surface mapping, but structure beneath the Laboratory is poorly known. North-south trending faults and other fault sets near the rift margin bound basins and present structures that affect paleogeography, sedimentation (alluvial, volcanic), and possibly the locations of basaltic volcanic centers and of fossil hydrothermal systems.

Information on faults comes from surface mapping and from the Seismic Hazards boreholes. Two faults were identified in core from SHB-1 (near TA-55), one in a

lava (Cerros del Rio?) and one in Bandelier Tuff. Both faults had abundant sheared clay. Faults along the western boundary of the Laboratory (the Pajarito Fault and splays) are best known, where the Seismic Hazards Program has focused its efforts. These western faults are often filled with clay but have secondary fractures that are transmissive. Clay-filled fault zones may impact flow paths. However, as hydrogeologic entities faults may be most important as pathways in the vadose zone, linking canyons and perched horizons with the regional aquifer. For future work, the new digital elevation model is accurate within ± 0.5 feet and inflections in the surface may be examined to infer buried structure.

b) Stratigraphy

New data from FY00 and FY01 have not yet been incorporated in the current model, and will significantly change both our understanding of the conceptual model and of spatial realization as modeled by the enhanced set of geologic contact information.

Bandelier Tuff

The Bandelier Tuff is reasonably well represented in the 3-D Geologic Model, but thickness and nature of the Otowi remains the least well known part of the Bandelier system. Model thicknesses under canyon bottoms remain suspect (*e.g.*, misprediction of Otowi thickness at R-31). Data from Los Alamos Canyon (LAOI-1.1) show that the Otowi may be extensively altered under some canyon reaches; this alteration may be provide mappable evidence of groundwater incursion into the Bandelier Tuff beneath canyon bottoms. The structure contour map of the base of the Bandelier Tuff suggests possible flow in the Guaje Pumice Bed toward a low in the south-central part of the Laboratory, stratigraphically higher than but coincident with the Purtymun high-yield aquifer. This low crosses between canyons, but it is unknown whether flow can be diverted between canyons at this horizon.

Cerros del Rio

Cerros del Rio lavas and cinder deposits in R-22 were over 1000 feet thick, twice as thick as predicted by the current geologic model. When these new data for the Cerros del Rio are evaluated within the existing set of observations, the impact of paleotopography of ancestral river channels on the deeper spatial distribution of these units will become clearer. These units are important hydrogeologically, as fractures within these basalts can provide laterally extensive zones of high hydraulic conductivity. In addition, preliminary

groundwater chemistry data suggest differences between Cerros-hosted and Puye-hosted groundwater hydrochemistry.

In Cerros del Rio time (principally 2.3 to2.8 million years ago), volcanic flows and cinder deposits extended out over the Puye fanglomerates. Erosional surfaces on the fanglomerates probably led to significant topographic variability entombed at the base of the Cerros del Rio volcanic deposits. River gravels are present beneath the thicker basalts at R-31 but not at R-22; channels beneath the basalt appear to include both local and through-going stream systems. On a broader site-wide basis, contours for the base of the Cerros del Rio define a paleosurface that generally slopes toward the south. In the vicinity of Mortandad Canyon, flow of perched water in the Cerros del Rio basalt may be to the south, following the dip of the unit. Cerros del Rio flows can produce confined/perched aquifers and may provide tabular zones of enhanced flow beneath the water table. Volcanic deposits of the Cerros del Rio have varied hydrogeologic impact because they can occur above, at, and below the water table.

Puye

The Puye Formation is poorly defined beneath the Laboratory. Interplay between fanglomerates shed from the west and the ancestral Rio Grande is not well understood and could be a significant factor in determining groundwater flow transitions between different lithologies. The deeper Puye Formation is vitric to the south and clay-rich to the northeast; clay-altered zones could affect the flow of groundwater. The sources of sediment in the "traditional" Puye Formation show a distinct progression from north to west through time; newly-recognized older (pre-Tschicoma) Puye deposits complicate this picture. The ratio of Rb to Sr is useful in tracking Puye source areas. The transition to deeper pumiceous material in the Puye Formation drops in elevation to the south, consistent with the presence of a major basinal structure under the central-southern Laboratory.

There is a continuum of Keres/Polvadera volcanic activity that provided volcanics and volcanogenic sediments and fanglomerates from the west, mixing with axial gravels from the north and plutonic/metamorphic detritus from the east. Axial river gravels may or may not provide a contiguous hydrostratigraphic unit. If the gravel units maintain continuity through significant portions of the lab area, they could provide buried channels of focused groundwater flow.

Deeper Units

The nature of the Puye/Santa Fe contact is poorly defined stratigraphically. Much of the deeper sedimentary material previously classified as Santa Fe is in fact earlier Puye-type volcanogenic material provided by sources that were closer

and depositionally more energetic than the Santa Fe system. Spatial and compositional anisotropy where the Santa Fe depositional system abuts the Puye may be more properly represented as interfingering, provenance-distinct wedges that can be mapped into the 3-D Geologic Model.

(II) ALTERATION AND CONTAMINANT SYSTEMS

a) Alteration and Contaminant Identification

Hydrothermal alteration is suspected in the lower Puye beneath the northeastern portion of the Laboratory, where clay-rich Puye sediments from R-9 and R-12 are alkali-depleted when compared with comparable unaltered pumiceous Puye sediments from R-19. Equivalent clay zones in the Totavi type locality include zeolites and complex manganese-oxides. These alteration features are associated with enrichments of some elements (*e.g.*, Ba and Sr) that can also occur as contaminants and could be misinterpreted as such. Understanding of alteration zones with perturbed chemical signatures is vital if confusion is to be avoided.

Generally, rocks that make up the Pajarito Plateau (Bandelier Tuff, Cerros del Rio lavas, Puye Formation, Santa Fe Group) have a strong coherence in U/Th ratios. A sample from R-9 at 283 feet depth has 39% clay and abnormally high uranium content, suggesting that deviations from regional geochemical trends might be used to determine mechanisms, locations, and amounts of contaminant accumulation in the natural system (a test of natural retardation).

b) How the Hydrogeologic System Behaves Geochemically

There are clay zones in R-9, R-12, O-1, and R-5 where extensive alteration has occurred, but such alteration is missing at R-19, CdV-R-15-3, R-22, and R-31. The newly-recognized lower pumiceous subunit of the Puye is completely clay altered at R-9 and R-12, but apparently not to the west and south, though the depths and extents of these clay zones are not yet known. The spatial restriction of alteration is an important component of site geology that is poorly understood. Preservation of glass in the pumiceous Puye well below the current water table contrasts with significant alteration of glass above the water table in the Otowi beneath some canyons (*e.g.*, LAOI-1.1). The pumiceous Puye above the current water table to the east in Los Alamos Canyon (*e.g.*, R-9) is also altered, but the type and extent of alteration differs from that in the Otowi. Preservation or loss of glass, and the alteration products formed from glass, are hydrogeologic parameters that provide information about reactive transport pathways that is yet to be interpreted.

c) Pathways and Mechanisms of Movement

The translocation of clays in Cerros del Rio basalts can be seen in the clay content in intermediate boreholes MCOBT-4.5 and MCOBT-8.5. In MCOBT-4.5 clay has accumulated near the top of Cerros del Rio basalt. In MCOBT-8.5, there is not much clay near the top, but there is a peak in clay content in the lower part of the Cerros del Rio. This may be the result of translocation of clay through fractures, but this has yet to be demonstrated. Lanthanide-element signatures and other geochemical parameters could be used to assess whether the clay formed in situ or was translocated. Generally the lanthanides behave as a family, but Ce can be segregated where oxidizing groundwater or mineral-surface oxidation occurs (especially on Mn-oxide mineral surfaces). Flow directions and redox reaction rates can be determined from studies of clay, Mn-oxide, and other secondary mineral systems. Most importantly, clays are likely to be the predominant colloid formers in the flow system.

Near-surface (to 20 m depth) clays studied at Pajarito Mesa show that heavy metals that are redox-sensitive are strongly held by Mn oxides. This phenomenon was studied at Yucca Mountain by examining what happens to Ce (a Pu analog) in the presence of Mn oxides. These studies show that Ce is removed from groundwater by manganese oxides along all vadose-zone pathways within flow distances of a few tens of meters. Positive Ce anomalies can be used to identify those portions of the hydrogeologic system where redox-sensitive heavy metals (particularly PU may accumulate.

(III) Evaluation of Data Needs (Geologic System): Some New Directions

Some key components of the geological system to be considered in DQO reassessment are:

(1) What are the relations between lithology and permeability and does lithology play a role in flow (this question needs to be addressed in both the vadose zone and in the regional aquifer)?

(2) What role does lithology play in transport (reactive transport)?

(3) What role does lithology play in groundwater chemistry (cation composition, phase saturation, Eh, and colloid formation in particular)?

(4) What do we need to provide to show that we have addressed the need to understand "basic geology, hydrogeology, and pathways for contaminant transport" (NMED, 1995)?

A.3 Geochemical Overview of the Pajarito Plateau

Purpose and Scope

The purpose of this presentation is to provide a detailed discussion on data quality objectives (DQOs) relevant to geochemical investigations conducted by the Geochemistry Subcommittee of the Groundwater Integration Team (GIT). To date (FY2001), the Laboratory has drilled 15 characterization wells (R wells) to address technical and regulatory issues presented in the Hydrogeologic Workplan, the Hazardous and Solid Waste Amendments (HSWA) permit, and ER Project Workplans for canyons. These DQOs provide input to well drilling, well design, well development, analytical methods, data validation, characterization and monitoring parameters, monitored natural attenuation (MNA), potential groundwater remediation strategies, and pathway analysis for contaminant transport. During the evolution of well drilling, the type and quality of geochemical data have changed depending on well-specific DQOs. It is very appropriate to reevaluate geochemical data needs and to define future data needs for the remaining characterization wells.

Overview

Groundwater occurs in three zones beneath the Pajarito Plateau: alluvium, perched intermediate, and the regional aquifer. Due to geochemical processes (precipitation/dissolution and adsorption/desorption) and residence time, the natural composition of groundwater can vary between and within these zones.

Groundwater Flow and Contaminant Distributions

Alluvial groundwater flows down canyons, generally to the east-southeast, including Los Alamos Canyon, Water Canyon, Cañon de Valle, and Pajarito Canyon. Alluvial groundwater also occurs within canyons that were dry but have received long-term discharges from the Laboratory. These include Mortandad Canyon and Sandia Canyon. Alluvial aquifer materials provide the largest reservoir for effluent-derived constituents such as strontium-90, cesium-137, plutonium-238, plutonium-239/240, and americium-241. These constituents adsorb onto clay- and silt-sized materials resulting in decreased mobility. Non- and semi-sorbing constituents can migrate from alluvial groundwater to perched intermediate zones eventually reaching the regional aquifer. These constituents include perchlorate, tritium, nitrate, and high explosive compounds and associated degradation products.

Adsorption processes dominate over mineral precipitation for removing metals and radionuclides from groundwater, based on field investigations and geochemical modeling. However, in isolated cases where effluent discharges have changed the alkalinity, solute concentrations, and pH elements such as strontium and barium may precipitate as $SrCO_3$, $BaCO_3$, and coprecipitate as $(Sr\text{-}Ba)SO_4$ in alluvial groundwater. Strontium-90 is influenced by both processes due to the moderately low solubility ($10^{-9.27}$ moles/liter) of $SrCO_3$.

Impacts from the Cerro Grande Fire

The Cerro Grande fire (May 2000) is example of a process that has significantly perturbed surface water and alluvial groundwater chemistry. Ash produced from the fire has been transported within canyons reacting with rain and surface water. Increasing concentrations of dissolved organic carbon, carbonate alkalinity, calcium, potassium, iron, manganese, and other solutes occur in surface water and alluvial groundwater since the Cerro Grande fire. Oxidation and reduction reactions between organic-rich ash and metals and radionuclides, in addition to carbonate complexation, influence aqueous speciation of solutes. Alkalinity affects the mobility (increases desorption) of radionuclides such as uranium, plutonium, and americium. In most canyons, carbonate alkalinity in surface water has increased by a factor of 5-6 since the fire. Surface water and alluvial groundwater have shown increases in turbidity due to the ash and enhanced erosion. Colloid transport in the subsurface is possible under these conditions depending on particle size, surface chemistry of the particles, and aquifer porosity.

Perched Saturated Zones, Flow Paths, and Residence Time (Age)

Perched intermediate zones of saturation occur beneath several canyons, including Pueblo Canyon, Los Alamos Canyon, Sandia Canyon, Mortandad Canyon, and Cañon de Valle. Perched zones possibly occur beneath Pajarito Canyon, however, there are no wells at present to verify this. Based on hydrostratigraphy, hydraulic gradient, hydraulic conductivity, and porosity, shallow groundwater infiltrates below the alluvium/bedrock contact. This provides a line source of recharge to underlying saturated zones within canyons.

A component of groundwater within perched intermediate zones and the regional aquifer (at and near the regional water table) is less than 60 years old, based on measurable tritium activities that are considerably above the cosmogenic baseline of 1 pCi/L. The Laboratory began operations in 1941 and aqueous effluents were associated with the Manhattan Project. Other chemicals such as perchlorate and nitrate provide additional information on recent recharge to perched zones and the regional aquifer. Portions of the regional aquifer also contain groundwater in excess of 10,000 years based on preliminary ^{14}C dating. Portions of the regional aquifer are dead with respect to tritium (<0.5 pCi/L).

Flow path(s) for alluvial groundwater, which recharge underlying aquifers can be represented by a stepwise function based on permeability contrasts due to the presence of clay minerals and fine-grained material (silt). These materials serve as perching layers and aquitards. Clay minerals can adsorb contaminants (cations) and need to be included in evaluation of monitored natural attenuation (MNA).

The aqueous chemistry of the regional aquifer changes with depth and position along the flow path(s). Groundwater varies from calcium-sodium bicarbonate to sodium-calcium bicarbonate compositions with pH values typically between 6.5 and 8.5. Concentrations of calcium, sodium, and bicarbonate contribute to increasing TDS within perched zones and the regional aquifer. Residence times of groundwater and chemical solutes (mass of water or solute/flux of water or solute) increase with depth and from west to east across the Pajarito Plateau. The TDS increase with depth is remarkably consistent. The TDS also increases from west, near recharge zones within the Sierra de los Valles, to east along the groundwater flow paths. Discharge zones for perched systems and the regional aquifer occur along cliff faces above and at the Rio Grande, respectively, within White Rock Canyon. Concentrations of trace elements including arsenic, barium, boron, bromide, and strontium increase with depth.

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Summary of Borehole and R Well Chemistry (FY2001)

To date, 15 wells have been drilled, developed, and sampled for characterization and investigation. The data obtained from characterization samples, including borehole and well samples, is provided in Table A-1.

Table A-1: Summary of Selected Constituents Measured at Boreholes and R Wells (Screening Samples)

Well	Zone	Sample	Contaminant	Concentration
R-9	perched	borehole	uranium	48 µg/L
R-9I	perched	well	uranium	0.64 and 0.07 µg/L
R-9	perched	borehole	tritium	106 and 347 pCi/L
R-9I	perched	well	tritium	246 and 167 pCi/L
R-9	regional	borehole	tritium	14.43 pCi/L
R-9	regional	well	tritium	4.84 pCi/L
R-12	perched	borehole	nitrate (N)	4.93 and 5.50 mg/L
R-12	perched	well	nitrate (N)	<0.10 and 0.13 mg/L
R-12	perched	borehole	tritium	255, 208, and 249 pCi/L
R-12	perched	well	tritium	189 and 111 pCi/L
R-12	regional	borehole	tritium	46.9 pCi/L
R-12	regional	well	tritium	64 pCi/L
R-15	perched	borehole	perchlorate	12 µg/L
R-15	perched	borehole	tritium	3770 pCi/L
R-15	regional	borehole	tritium	1.12 pCi/L
R-15	regional	well	tritium	0.77 pCi/L
R-15	regional	borehole	nitrate	<0.01 mg/L
R-15	regional	well	perchlorate	4.19 µg/L
R-15	regional	well	nitrate	2.30 mg/L
R-19	perched	borehole/well	none	
R-19	regional	borehole/well	none	
R-22	regional	borehole	tritium	109 pCi/L
R-22	regional	well	tritium	2.0 pCi/L
R-22	regional	well	uranium	16.9 µg/L
R-22	regional	well	technicium-99	4.9 pCi/L
R-25	perched	borehole	HMX, RDX, TNT	12, 84, and 19 µg/L
R-25	perched	borehole	tritium	77.2, 81.4, 44.7 pCi/L
R-25	perched	well	tritium	16.5, 43.5, 21.1, 13.1 pCi/L
R-25	perched	well	HMX, RDX, TNT	4.9, 65, 0.36 µg/L
R-25	perched	well	PCE, TCE, toluene	1.3, 1.8, 15 µg/L
R-25	regional?	borehole	HMX, RDX, TNT	9.7, 62, 7.1 µg/L
R-25	regional?	well	HMX, RDX, TNT	4.1, 28, 2.2 µg/L
R-25	regional?	well	TCE, Toluene	1.2, 2.5 µg/L
R-25	regional?	well	tritium	8.4, 8.1 11, 11.7 pCi/L
CdV-15-3	perched	borehole/well	none	
CdV-15-3	regional	borehole/well	none	

R-31	perched	borehole/well	none	
R-31	regional	borehole/well	none	
MCO-BT-4.4	perched	borehole	perchlorate, tritium, nitrate (N)	120 ppb, 2020 pCi/L, 7-10 mg/L

Uranium, tritium, high explosive compounds, perchlorate, nitrate, and chlorinated solvents have been detected in R wells completed either in perched zones and/or the regional aquifer. These chemicals are mobile in the subsurface and are not completely removed from groundwater by dispersion, mixing, and biodegradation.

Sources of tritium discharged into Los Alamos Canyon include TA-2 and TA-21. At R-9, activities of tritium range from 100 to 300 pCi/L, which confirms that the regional aquifer has been recharged by surface water since the early 1940s. Elevated concentrations of nitrate (R-12) and high explosive compounds (R-25) also provide evidence of surface water infiltrating to perched groundwater and, in some cases, to the regional aquifer.

In 1999, elevated activities of tritium occur in alluvial (80-29,300 pCi/L) and perched groundwater (2,020 and 3,770 pCi/L) in Mortandad Canyon. Tritium activities, however, are much lower in the regional aquifer at R-15 (< 3 pCi/L) due to its short half-life (12.43 yr) and travel times through the vadose zone. Nitrate concentrations in R-15 increased from the borehole sample (<0.02 mg/L) to 2.30 mg/L in the well. It is possible that the aquifer testing which involved pumping the well (R-15) enhanced migration of a nitrate plume in the regional aquifer.

Water Quality Impacts from Drilling Fluids

Groundwater borehole and well samples are a proxy to pre-drilling groundwater conditions. The drilling process significantly affects the composition of groundwater, especially if drilling fluids are used. Oxidation-reduction reactions occur when EZ-MUD is used during well drilling for lubricity. EZ-MUD eventually biodegrades and oxidizes to inorganic carbon (alkalinity) and solutes such as sulfate, nitrate, and dissolved oxygen and oxide and hydroxide minerals containing iron(III) and manganese(III, IV) are reduced. These minerals have increased solubilities under reducing conditions where Fe(II) and Mn(II) are soluble solutes.

Examples of drilling fluids including EZ-MUD and QUIK-FOAM impacting water chemistry are presented below. When R-9 was drilled in late 1997 and early 1998, perched groundwater collected from the borehole at a depth of approximately 275 ft contained 48 μg/L dissolved uranium. Based on this analytical result and upgradient source terms containing uranium, R9I was drilled

to further characterize the two perched zones (175 and 275 ft) within the Cerros del Rio basalt. R-9I was drilled with fluids (EZ-Mud and QUIK FOAM), and concentrations of uranium in the upper and lower perched zones are 0.64 and 0.07 μg/L. The apparent decrease in uranium concentration could be the result of changes in the oxidation-reduction conditions with the introduction of drilling fluids. These reducing conditions enhance adsorption and precipitation of uranium. Another possibility is that during initial drilling, fresh mineral surfaces were exposed and uranium desorbed from mineral surfaces resulting in a temporary increase in uranium concentrations. If this process accounts for the elevated uranium, then this analyte should be observed in similar concentrations at R-12, R-15, R-19, and R-31 that penetrated the Cerros del Rio basalt. Anomalous uranium to thorium ratios (approximately 3) for clay minerals at R-9, however, suggests that additional uranium has been introduced to the system. Typical uranium to thorium ratios are approximately 0.25 or less for the Bandelier Tuff and Cerros del Rio Basalt.

EZ-MUD consists of a copolymer (polyacrylamide ($(-CH_2CHCONH_2-)_n$)-polyacrylate ($(H_2C=CH-COO^-)_n$)) containing nitrogen, carbon, and hydrogen. Analyses of groundwater collected from R-7, R-9I, R-19, R-22, R-31, and CDV-15 resulted in false positives for RDX, TNT, 2-amino-4,6-dinitrotoluene, 4-amino-2,6-dinitrotoluene, and 3-nitrotoluene due to residual EZ-MUD. These false positives are based on similar chemical structures between RDX, including $C-N-NO_2$ functional group, and the copolymers comprising EZ-MUD.

During drilling of R-7 and R-22, acetone was apparently detected at the regional water table. Presence of this organic compound may be due to oxidation of QUIK-FOAM used during drilling, which contains isopropyl alcohol. Isopropyl alcohol has the same retention time and mass units very similar to acetone. The overall oxidation-reduction reaction leading to the formation of acetone is:

$$CH_3CHOHCH_3 + 0.5O_2 = (CH_3C)_2CO + H_2O.$$

The Groundwater Focus Area suspects that the results reported for acetone from the analytical laboratory are false positives from the isopropyl alcohol, which is supported by the mass spectral data. Acetone is being misidentified because the secondary ion for isopropyl alcohol is 43, which is the primary ion for acetone. The analysis of the QUIK-FOAM confirms this suspicion.

Migration of Contaminants

With regard to interconnection between alluvial groundwater, perched zones, and the regional water table, contaminant source terms correlate reasonably well with the downgradient characterization wells. Non-adsorbing contaminants

(perchlorate, nitrate, RDX, and TNT) are the most mobile and travel the furthest distances along groundwater-flow paths.

A.4 Overview of Pajarito Plateau Vadose Zone Hydrology and Modeling

Definitions:
Infiltration - water flowing into a material at its atmospheric interface
Percolation - flow through porous media
Recharge - addition of water to a saturated zone
Vadose - the geologic media between the land surface to regional aquifer, including unsaturated materials, water in capillary fringes, and perched zones.

Infiltration of surface water flow (caused by effluent discharges, spring discharge, or stormwater runoff) maintains shallow groundwater in the alluvium of some canyons. Alluvial groundwater is unconfined and is perched on underlying Bandelier Tuff, Cerros del Rio basalts, or Puye Formation. Evapotranspiration and percolation into the underlying rocks deplete alluvial groundwater as it moves down the canyons. Alluvial groundwater is a source of recharge to underlying intermediate perched zones and to the regional aquifer, usually by unsaturated flow.

Dry canyons have little surface water flow. In these canyons groundwater may occur seasonally in the alluvium. Dry canyons are generally those that head in the eastern portion of the Pajarito Plateau.

In wet canyon bottoms, infiltration of surface water maintains shallow groundwater in the alluvium. Wet canyons generally have large surface water flow, head in the Jemez Mountains, or receive effluent discharges. Groundwater levels are typically highest in the late spring due to snowmelt runoff and in mid-to-late summer due to thunderstorms. Groundwater levels and extent of saturation decrease during the winter and early summer when runoff is at a minimum.

Water quality of the alluvial groundwater reflects the composition of storm runoff, snowmelt, and effluent discharges where present. In canyons affected by effluents, the alluvial groundwater and sediments contain the majority of adsorbing contaminants (such as plutonium). Mobile solutes (such as tritium, high explosive compounds, and anions) migrate with moving groundwater, and are present in recharge.

Recharge from alluvial groundwater by unsaturated flow may account for a source of contaminants in recharge and relatively rapid rates of groundwater flow (reaching the regional aquifer in decades or less). In some cases recharge might occur by saturated flow. Faults, fractures, joints, surge beds, and higher permeability geologic units that underlie saturated alluvium (such as the Guaje Pumice Bed, Cerro Toledo Interval, Cerros del Rio basalts, and Puye Formation) could provide pathways for downward movement of water and contaminants.

Intermediate perched zones occur beneath major canyons and in the western portion of the Laboratory. Intermediate perched zones are found particularly beneath wet canyons that receive effluent discharges, have large surface water flow, or head in the Jemez Mountains. These intermediate perched zones occur in the Guaje Pumice Bed at the base of the Bandelier Tuff, the underlying Cerros del Rio basalts, and the Puye Formation. The location of intermediate perched zones is determined by presence of sufficient recharge, permeability variations of the rocks (reflecting lithologic variations), and geologic structure. Intermediate perched zones may be confined or unconfined. Discharge at springs and percolation into the underlying rocks (resulting in recharge to the underlying regional aquifer) deplete intermediate perched groundwater.

Intermediate perched zones beneath canyons do not generally extend laterally beneath the mesas. Neither are the intermediate perched zones continuous along the length of the canyon. Variations in stratigraphy and in both recharge and percolation losses along the canyon cause changes in thickness or presence of the intermediate perched zones. Lateral movement of intermediate perched groundwater away from the canyon axis may occur if the dip of the perching horizon and the canyon orientation do not coincide.

In the western portion of the Laboratory, groundwater has been observed to occur as a large (300 ft-thick in well R-25) intermediate perched zone within the lower Bandelier Tuff and the Puye Formation, approximately 700 ft below the mesa top. Most recharge for this zone originates as underflow of groundwater from the Jemez Mountains, with some contribution from recharge through mesas and canyon bottoms. Percolation losses from this intermediate perched zone result in recharge to the underlying regional aquifer.

If discharges from the Lab cease, the changes in vadose zone moisture content would vary on a canyon-by-canyon basis. For example, Mortandad Canyon has significant water input from the TA-50 treatment plant. Water in vadose zone moves downward due to gravity, but with a decrease in percolation rate it will move more slowly

Percolation rates are different beneath the canyons and within the mesas. Percolation rates beneath mesas are less than 1 mm/yr or less but vary across the lab due to the variability in precipitation and vegetation with elevation. Beneath canyons, percolation rates range from about 10 to 1000 mm/yr. Based on model results, uncertainty in the percolation rates beneath Los Alamos Canyon is +/- a factor of 3. A question that the GIT must consider is "Do we need to know this better?". One outcome might be that it's not cost effective or possible to know it better. However, another outcome is that is important to reduce the uncertainty. In a few units (for example, the Otowi member) the range in values of hydrologic properties is due to variability in texture. More measurements will not reduce that range of values. The range is the result of variability, not uncertainty. Moisture content measurements and water budgets can only reduce uncertainty in travel times to about one order of magnitude. Joint inversion of moisture content and contamination front data can reduce this uncertainty.

Water flow under unsaturated conditions is principally 1-dimensional and downward. There is lateral diversion beneath regions of high infiltration where low permeability barriers restrict downward percolation; examples: alluvial water, Bandelier tuff perched water, and Puye formation perched water. There has been rapid lateral transport over some distance along canyons. Examples in the alluvial groundwater include a tracer test in Mortandad Canyon and movement of tritium in Los Alamos Canyon. There has also been rapid lateral diversion to canyons from mesas, with travel times of months; examples: within mesa at TA-16; tracer tests and geochemical monitoring (Newman).

Velocity and direction of flow in intermediate zones is uncertain. Velocity in perched zones can be conceptualized with a bathtub model as a trough with water piled up inside and slow percolation out, resulting in a delay in flow time. Another conceptual model is of lateral diversion and flow through porous media. Modeling done so far has been based on the lateral diversion porous flow and it does reproduce the perched zones. Even if you could map a perched zone, it would be difficult to know what it means for transport to the regional aquifer. A third conceptual model of flow in the perched zones is lateral diversion model with fast-path flow. It is difficult to distinguish between the two lateral diversion models. Flow direction is controlled by the dip of the unit on which perching occurs and/or the dip of local permeability features not represented in the geologic model.

Although current modeling (such as for Los Alamos Canyon) uses perched intermediate zones, it is difficult to have enough data to fully map, define flow paths, and predict transport velocity. For example, the Los Alamos Canyon weir

wells are close enough to begin looking at the perched zones, but we still have not figured them out. Three wells in Mortandad Canyon drilled a short distance apart to the perched zones found very different stratigraphy and saturation. If the aerial geophysics are successful in locating intermediate perched zones, there are still questions of saturated thickness, flow direction, and velocity. Is it realistic to try to map out pathways from the perched zones? Should resources be put into continued investigations in the perched zones?

In summary, what we've found so far is that the intermediate perched zones (except for the one under TA-16) are very thin and discontinuous. They seem not to hold a large volume of water or to have very large extent. Because of their small size and discontinuity, it is likely that the intermediate perched zones' role in contaminant transport isn't that great in terms of water volume. Also because of their small size and discontinuity, it is difficult to obtain sufficient detailed information (in a cost effective fashion) to adequately portray these intermediate perched zones in a model. Small variations in geology such as the presence or thickness of a soil zone or an ash layer within a basalt sequence will cause a local perched zone to form, but these stratigraphic variations cannot be reasonably predicted in the subsurface. The characterization effort should pursue relatively inexpensive methods such as the geophysical techniques to "image" the intermediate groundwater without making false promises about our ability to figure out the details. The reason for the geophysics, combined with ground truth from the well drilling program, is to make a best effort at characterizing the perched water, while at the same time pursuing the bounding analyses are proposed. This would provide confidence that we made a good faith attempt to figure out the intermediate groundwater (and in fact learned something about them, though not everything there is to know) but also honestly acknowledged the inherent limitations and came up with a rational alternative to a rigorous characterization of this groundwater.

Water quality within intermediate perched zones reflects that of the recharge water including precipitation and runoff, effluent discharges, and native groundwater. Flow within intermediate perched zones could transport contaminants some distance away from their surface source.

Los Alamos National Laboratory
Hydrogeologic Characterization Program
Proposed Hydrogeologic Workplan Scope
Appendix A
October, 2001

Summary of Available Information on Vadose Zone Hydrology & Modeling

Sources/ Pathways	Aggregate 1: Los Alamos/ Pueblo	Aggregate 2: Cañada del Buey/ Pajarito	Aggregate 3: TA-49	Aggregate 4: Ancho/ Indio/ Chaquehui	Aggregate 5: Cañon de Valle	Aggregate 6: Water/ Potrillo/ Fence	Aggregate 7: Mortandad	Aggregate 8: Guaje/ Bayo/ Rendija
Sources	Liquid waste discharges, MDAs, reactors	MDA G, L	Underground testing debris	Firing sites, tritium production, landfills	Liquid waste discharges (HE)	Firing sites	Liquid waste discharges	Firing sites, liquid discharges
Pathways/ transport modes	Percolation of alluvial groundwater Vadose zone percolation (MDAs)	Vadose zone percolation	Vadose zone percolation	Percolation of alluvial groundwater?	Percolation of alluvial groundwater, underflow from Jemez Mtns.	Percolation of alluvial groundwater	Percolation of alluvial groundwater	Vadose zone percolation?
Data Needs								
Presence of intermediate perched groundwater	Limited extent and continuity beneath canyons?	No perched/ limited extent beneath Pajarito Canyon?	No perched?	No perched?	Extensive thick zone recharged from Jemez Mtns.?	No perched?	Limited extent and continuity beneath canyons?	No perched?
Subsurface contaminant distribution	Perchlorate beneath Pueblo, tritium, strontium-90	Organic solvents, radionuclides ?			Extent of HE and solvents in perched zone		Extent of radionuclides, nitrate, and perchlorate in vadose zone	
Geologic Information		Structure of basalt controls vapor movement, regional aquifer and		Geology of near-Rio Grande faults, basalts could control regional aquifer and			Structure of basalt controls perched zone flow?	

Sources/ Pathways	Aggregate 1: Los Alamos/ Pueblo	Aggregate 2: Cañada del Buey/ Pajarito	Aggregate 3: TA-49	Aggregate 4: Ancho/ Indio/ Chaquehui	Aggregate 5: Cañon de Valle	Aggregate 6: Water/ Potrillo/ Fence	Aggregate 7: Mortandad	Aggregate 8: Guaje/ Bayo/ Rendija
		vadose zone flow?		perched flow systems				
Recharge distribution	Percolation of alluvial groundwater				Percolation of alluvial groundwater, perched zone recharge		Percolation of alluvial groundwater	
Percolation processes		Percolation beneath dry mesa?						
Hydrologic data					Extent of perched zone			

A question that isn't being adequately addressed is the distribution and rates of percolation. A way to collect this type of data is to drill a few shallow wells in a canyon to look at moisture and contaminant distribution. The deeper wells shouldn't be used for this purpose because they need to be focused on presence of water at greater depths. The shallow wells would be used for estimating percolation rates and travel times. R-well drilling program may be over-emphasizing intermediate groundwater investigation at the expense of less data from the regional aquifer. Bounding approaches for handling the intermediate groundwater are needed.

A Path Forward:

The issue of how to treat intermediate perched zones hinges on several considerations: how do the perched zones affect contaminant pathways and travel times?

Pathways - incorporate perched water representation into vadose zone models, capturing the extremes of behavior - bathtub versus lateral flow fast path. Perform site-wide analysis of potential flow path directions based on geologic model and simple conceptual models of lateral diversion. Test against available data. Determine whether uncertainties in lateral transport significantly affect the prediction of the location of contaminant arrival at the water table. Bracket travel times to the water table by:

- 1-D travel times and directions, from surface to regional aquifer (longest time)
- 1-D travel time to perched zone only, short circuit to water table after that (shortest time)

Travel time - Using a back-of-an-envelope calculation it is clear we need to know the wet canyon travel times better. Hydrostratigraphy of vadose zone is important. Estimates of uncertainty of thickness in units such as Bandelier tuff. Infiltration indices for canyon drainages from 1 (driest) to 5 (wettest) net infiltration.

Reduce uncertainty -

- geologic model needs to estimate uncertainties (e.g. in unit thicknesses) but focus on uncertainties that matter to travel time and continue to update geologic model with new data
- migration rate using water budget studies, infiltration monitoring sites, shallow boreholes to measure water contents and migration fronts of contaminants, e.g. nitrate profile in R-15

A.5 Overview of Regional Aquifer Hydrology and Modeling

This summary attempts to provide an overview of our current knowledge and determine outstanding data needs regarding 1) groundwater flow directions and velocities, and 2) contaminant transport in the regional aquifer; however, we emphasizes data needs regarding (1). This emphasis is reasonable since it addresses basic characterization requirements and also gives us the necessary information to predict migration of highly mobile contaminants which could pose the greatest threat to water quality. Characterization of aquifer properties that control retardation of contaminant migration (essential to (2), for some contaminants) is best addressed on a site- and contaminant-specific basis and is outside the scope of this document.

Flow Directions

Flow directions in the regional aquifer are determined by hydraulic gradients and permeability variations within the aquifer. Variations in both gradients and permeability are expected to be scale-dependent. Characterizing large-scale flow directions (at the scale of the LANL site: kilometers to tens-of-kilometers) is the highest priority; followed by medium-scale flow (hundreds to thousands of meters). The importance of quantifying small-scale variations (tens to hundreds of meters) should be evaluated on a case-by-case basis according to site-specific monitoring and/or environmental restoration issues.

Permeability characterization

The regional aquifer beneath the Pajarito Plateau occurs in rocks of the Puye Formation, the Cerros del Rio basalts, the Tschicoma Formation, and the Santa Fe Group. The hydraulic conductivity of aquifer rocks is heterogeneous and averages approximately 140 m/yr. The aquifer is unconfined in the west and confined or partially confined in some locations near the Rio Grande.

<u>Large-scale permeability variations</u>

The best indicators of large-scale permeability variations (over 100's to 1000's of meters) are water level responses to long-term pumping, spatial variation in water levels across the plateau, and multi-hole pump tests. No multi-hole pump tests have been conducted to date.

If the total flux of water through the aquifer is reasonably well-known, water level data can be analyzed using a numerical flow model to estimate large-scale permeability of hydrostratigraphic units within the aquifer. Analysis of historical streamflow data along the Rio Grande has provided both an estimate of mean

flux and associated uncertainty. Combining this flux information and water level data (both present and historical) with our flow model for the aquifer, we have estimated large-scale permeability of the major aquifer units. For the sedimentary rocks, there are relatively small differences between units (less than one order of magnitude). There are insufficient water level data available to estimate permeability of other units (basalts, dacite flows) using this method.

Unit	Estimated permeability (m^2)	95% Confidence Limits
Santa Fe Group (lower)	-13.33	+/- 0.25
Santa Fe Group ("Los Alamos aquifer")	-12.99	+/- 0.30
Puye Formation	-12.74	+/- 0.46

Medium-scale permeability variations

Our estimates of medium-scale permeability are derived from single-hole pump tests in water supply wells screened over ~2000'. These estimates are representative of the rock within within tens of meters to a few hundreds of meters of the boreholes. Estimates are only available for the Santa Fe Group (both lower and "Los Alamos Aquifer" facies). Other units such as basalts and Puye were present in many of these boreholes; the effect of these units on test results is unknown.

Unit	Mean permeability (m^2)	Max/Min	Number of te
Santa Fe Group (lower)	-12.5	-12.26/ -12.84	12
Santa Fe Group ("Los Alamos aquifer")	-11.2	-11.94/ -11.67	3

These estimates are noticeably higher than the large-scale estimates (described above). Possible reasons for this discrepancy are 1) large-scale features that single-well pump tests cannot detect, such as low-permeability faults (trending N-S), 2) the fact that pump test data are entirely derived from water supply wells, which may have been purposely sited in relatively high-permeability zones within the Santa Fe Group, and flow model errors such as 3) underestimation of total flux through the aquifer, and/or 4) overestimation of the total thickness of the aquifer. We are using sensitivity analyses to evaluate the plausibility of (3) and (4); preliminary results indicate that neither of these factors can explain the discrepancy. Additional pump test data, particularly 2 or 3-hole pump tests, are needed to evaluate (1) and (2).

These data clearly suggest that there are relatively high-permeability zones within the Santa Fe Group. At present, we do not have a geologically-based conceptual model of the structure of these high-permeability zones.

Small-scale permeability variations

Hydraulic test data from wells screened over relatively short intervals (e.g. R-wells) demonstrates variability over 4 orders of magnitude exists within the Puye Formation and the basalt flows. Although no such data exist for the Santa Fe group, it is reasonable to assume that similar variability exists within these rocks.

Conclusions

At large-scales, our estimates of the permeability of sedimentary units are very well constrained. However, there are small and medium-scale variations within these units that we do not understand. There are two important aspects to addressing this problem. First, we need larger-scale hydraulic tests (multi-hole tests) that can help us understand the discrepancy between permeability estimates derived from water level data and those derived from single hole tests. Second, we need to continue our efforts to develop a conceptual model and eventually a numerical model of permeability variation within sedimentary rocks. This model will be critical to our ability to accurately simulate water level gradients in the aquifer and to our ability to accurately determine flow directions at medium and local scales. Although more medium and small-scale permeability data may be helpful in this regard, we recommend emphasizing more detailed analysis of *existing* data (water level, geophysical and geologic logs, mineralogy data, hydraulic testing data) to develop a conceptual model relating our geologic understanding to permeability variation at small and medium scales. This analysis is critical to ensure that we are collecting the appropriate types of data in the remaining R-wells.

Permeability data for the basalt units clearly shows a very large variability, presumably due to various lithologies lumped into the "basalt" category such as fractured and unfractured lava, inter-flow breccia, and inter-flow paleosols. It is unclear how important it will be to gather more detailed knowledge of the spatial distribution of these various lithologies.

Hydraulic gradients

At the western edge of the plateau the water table is located approximately 300 to 400 m below ground surface. The hydraulic gradient in the western portion of the aquifer is generally downwards. The flow of groundwater is east/southeast,

towards the Rio Grande. The hydraulic gradient in the eastern portion of the aquifer near the Rio Grande is generally upwards.

In plan view, the spatial distribution of wells on the plateau is sufficient to determine that flow is generally east (although a slight southerly component is present in some areas) in the uppermost portion of the aquifer. Although deeper head data are more sparse and (in some wells) ambiguous (e.g. some heads are composite measurements over long screened-intervals and some heads are heavily influenced by nearby pumping), deeper head data also suggest easterly flow. This result is consistent with regional hydraulic gradient data, which suggest that flow is generally east-west, towards the Rio Grande, despite the well-documented fact that considerable geologic complexity exists within aquifer rocks.

The radiocarbon ages of water from deep wells beneath the Pajarito Plateau increase from west to east, supporting this conceptual model of easterly flow indicated by water level data.

Although all the available data suggest easterly flow, departures from this trend may occur at scales smaller than typical well spacing. There is no reason to expect this, however, unless either 1) new water level data are collected that demonstrate departures from regional gradients, or 2) geologic features are identified *with measured influence on permeability* that would cause either local perturbations in hydraulic gradients and/or cause flow directions to be oblique to water level iso-potentials.

Groundwater velocity

Simple calculations of flow velocity using measured head gradients and assumed porosities suggest velocities are tens of meters per year. We are currently using flow and transport modeling, in combination with radiocarbon age dates, to provide a more rigorous analysis of velocities. Unfortunately, contaminants that have been detected in the regional aquifer, such as ^{3}H, Sr90, HE, cannot be used to calculate velocities because we do not know whether they have been transported from the source primarily in alluvial, vadose zone (including perched aquifers) or primarily in the regional aquifer. Either cross-hole tracer tests or single-hole "huff-puff" tests could provide valuable information about groundwater velocity.

Recharge/discharge

The Rio Grande is the main discharge area for the regional aquifer. Estimates of discharge are based on springflow data (although it is unclear whether springs in

White Rock Canyon discharge perched aquifer(s) or the regional system) and streamflow gain along the Rio Grande. These data suggest that the regional system discharges approximately 15 cfs between Otowi Bridge and Cochiti Reservoir. Statistical analysis of streamflow data suggest that this estimate is associated with a standard error of 4.3 cfs.

The largest component of recharge occurs as underflow of groundwater from the Sierra de los Valles, to the west of the Pajarito Plateau. Recharge also occurs by leakage from mesas and from alluvial groundwater in canyon bottoms on the Pajarito Plateau. While it may be insignificant volumetrically, local recharge on the Pajarito Plateau is important because it provides pathways for contaminants that originate from effluent discharges. The exact volume of recharge occurring on the plateau is *impossible* to measure; however, using the regional aquifer discharge estimate (described above) to place bounds on the total amount of recharge that can possibly occur on the plateau we use sensitivity analyses and flow and transport modeling to evaluate the effect of various plausible recharge scenarios. For example, to predict a "worst-case" scenario, we can simulate aquifer quality assuming all recharge occurs within those canyons that are most contaminated. Water budget, chloride-mass balance estimates, and vadose-zone flow model calibration can also be used to place bounds on recharge rates.

A.6 Data Needs Compiled from Comprehensive Evaluation Presentations

Data Needed	Recommendations: Field Data	Recommendations: Analysis
Head Data -Vertical Gradients	• **Spinner logs in water supply wells.** Water supply wells are much deeper than R wells. If contamination enters the aquifer in areas with strong downward gradients (such as the vicinity of R25), shallow R wells downgradient may not intercept contamination. Conducting spinner log tests in existing water supply wells would help identify locations where this could be a problem. • **Multiple screen well(s) in northwestern portion of LANL, transducers in all in existing wells.** No data is available east of R-22; lack of vertical gradient information to the east will affect our ability to predict potential impacts to wells on San Ildefonso land.	
Head Data - Horizontal Gradients	▪ Current spatial distribution is adequate to determine large-scale flow directions; **closer well spacing may be necessary to determine local variations in flow.** ▪ **Well(s)s west of the Pajarito Fault zone** will be necessary to evaluate the impact of the fault zone on flow.	
Range of measured permeability - large scale	▪ **Multi-hole pump test(s)** to determine medium-to-large scale permeability & to reconcile model parameters with test data ▪ **Pump tests across fault zones**.	• Geometry of basalt flows, which are potential fast pathways, is uncertain. We should develop and consider **multiple alternative geologic models**. • Do large-scale facies with distinct hydraulic properties exist? Conceptual models need to be incorporated into geologic model and tested (with flow model) against water level data.

Range of measured permeability - small scale	▪ **Evaluate existing methods** and (if necessary) develop new methods for hydraulic testing to ensure that we're testing the formation and not simply the filter pack	▪ For sedimentary rocks, we need a conceptual model relating depositional or textural facies to permeability variations ▪ **Further analysis of existing geologic, geophysical, and hydrologic data** may provide additional information
Permeability - Geologic influences	▪	▪ Review logs to see if anything is in logs related to permeability. Develop a method of logging to provide a correlation between textural deposits or depositional facies and permeability estimates. ▪ Incorporate hypothesis concerning fault zones, facies within sedimentary rocks, alternative realizations about structure of basalt flows, etc. quickly into 3-D geologic model so that they can be tested against water level data using flow modeling.
Effective porosity on a field scale.	▪ No site-specific data from saturated zones. This will help with travel times in regional aquifer. ▪ Existing tracer data is inadequate to estimate travel times.	
Bracket porosity using some contaminants	Could use 1) single-well injection-withdrawal tracer tests, 2) age dating, or 3) cross-hole forced-gradient tracer tests.	
Presence of intermediate perched groundwater	▪ Aggregates 1 & 7: Limited extent and continuity beneath canyons? ▪ No perched/ limited extent beneath Pajarito Canyon? Need an intermediate well(s) in Pajarito Canyon east of TA-18, based on R-22 analytical results. ▪ Aggregates 3, 4, 6, 8: No perched? West of R-31, however, there are source terms of depleted U and Be. Possibly **delete R-32 based on R-31.** ▪ Aggregate 5: Extensive thick zone recharged from Jemez Mtns.?	▪ Incorporate perched water representation into vadose zone models, capturing the extremes of behavior - bathtub versus lateral flow fast path. ▪ Perform site-wide analysis of potential flow path directions based on geologic model and simple conceptual models of lateral diversion. ▪ Test against available data. ▪ Determine whether uncertainties in lateral transport significantly affect the prediction of the location of contaminant arrival at the water table.

		Bracket travel times to the water table by: ▪ 1-D travel times and directions, from surface to regional aquifer (longest time) ▪ 1-D travel time to perched zone only, short circuit to water table after that (shortest time)
Subsurface contaminant distribution	▪ Perchlorate beneath Pueblo, tritium, strontium-90. Still need R-4 and R-8 to be drilled. ▪ Aggregate 2: Organic solvents, radionuclides? ▪ Aggregate 5: Extent of HE and solvents in perched zone ▪ Aggregate 7: Extent of radionuclides, nitrate, and perchlorate in vadose zone	
Geologic Controls on contaminant transport	▪ Aggregate 2: Structure of basalt controls vapor movement, regional aquifer and vadose zone flow? ▪ Aggregate 4: Geology of near-Rio Grande faults, basalts could control regional aquifer and perched flow systems; R-17 should be relocated east of TA-18 based on complex hydrogeologic conditions. ▪ **Focus on upper saturated zone, recharge from mountain front, and line source of recharge for locating CDV-37 and additional wells.** ▪ Aggregate 7: Structure of basalt controls perched zone flow?	
Distribution and rates of percolation.	Drill a few shallow wells in a canyon to look at moisture and contaminant distribution. The shallow wells would be used for estimating percolation rates and travel times.	
Vadose Zone Reduce travel time uncertainty	migration rate using water budget studies, infiltration monitoring sites, shallow boreholes to measure water contents and migration fronts of contaminants, e.g. nitrate profile in R-15	▪ geologic model needs to estimate uncertainties (e.g. in unit thicknesses) but focus on uncertainties that matter to travel time and continue to update geologic model with new data ▪ Infiltration indices for canyon drainages from 1 (driest) to 5 (wettest) net infiltration
Pathway Analysis		Form a specialized team that focuses on pathway analysis, consisting of hydrology, modeling, geology,

		and geochemistry. Integrate better with computational efforts.
Groundwater Geochemistry	Single screen wells help to minimize redox reactions produced by drilling fluids and false positives with HE compounds and solvents. R-4, R-8, R-10, R-11, R-13, R-14, and R-17 are in contaminated canyons and should be single completion wells, based on geochemical DQOs.	
Characterization of Reactive Minerals	Mineral distributions are needed for input to adsorption-transport modeling, quantifying natural attenuation, and validating geochemical modeling. Perform this work activity during geologic characterization. Perform simple leaching procedures to determine iron and manganese distributions (major adsorbents).	
Kds for Sr, U, Pu, and other chemicals	Adsorption data are needed for Cerros del Rio basalt and Puye Formation, because they have different chemistries from the Bandelier Tuff.	
C-14, $\delta^{13}C$	Determine age and groundwater travel times in regional aquifer (R wells). Perform this work activity during sampling of R wells. Need to obtain representative calcite samples from core collected at R wells and outcrops to correct $\delta^{13}C$ for recalculating C-14 dates.	
LANL Baseline Groundwater Geochemistry		Finalize publication and make database available.
Information on bentonite annular fill materials	Associated salts, redox properties, K_d	
Flow within perched zones	Can contaminants cross between canyons?	
Mappable perched zones	Alluvium, Guaje/Puye, Cerros del Rio	
	Connect well test data with lithology	
What is (are) the Los Alamos aquifers		
The eastern margin:		

facies and structure		
Western edge	Recharge, geologic unknowns, complex micrograbens and breathing fractures. Drill R-1, R-2, R-6, R-17, R-14, R-18, R-24, R-26	
Water Canyon (near R27/R28)	Axis of major topographic low in Bandelier time and in the Purtymun trough. Perhaps a change in flow within perched zones to the south.	
Potrillo Canyon (near R-23)	Difference between R-31 and R-22 is great; need to know what is going on there.	
Lower Mortandad Canyon	Could look at surface geology along the river.	
Pajarito Canyon (near R-21)		
Rio Grande	Surface exposures that could provide significant geologic control.	
Pathways	Focus on canyon reaches (e.g. MCOBT, R-15 data sets); canyon to canyon pathways? (*e.g.* dip within perched zones); eastern margin (ancestral Rio Grande paleochannels, eastern faults and changes in basin facies; how does flow get to springs and the present Rio Grande); influence of Puye and Santa Fe clay zones (clay, zeolites, and complex Mn-oxides)	
The sorption problem	Take advantage of contamination: Unlike uncontaminated sites, the dispersion of contaminants at LANL can be used to assess in situ processes, including contaminant tracking.	Literature data will be important, particularly for "conservative" contaminants.