The Hydrogeologic Site Characterization at Los Alamos National Laboratory

Robert M. Powell

Powell & Associates Science Services, Las Vegas, NV

Charles L. Nylander

Los Alamos National Laboratory, ESH-18

Location of Los Alamos

- Los Alamos National Laboratory and neighboring areas of Los Alamos and White Rock are predominantly in Los Alamos County, north-central New Mexico, approximately 60 mi N-NE of Albuquerque and 25 mi NW of Santa Fe

Lab Setting

- The Lab is bordered on three sides by largely undeveloped tracts of land held by the Forest Service and National Park Service.
- Four pueblos are near the Lab; San Ildefonso is directly on the eastern side.
- The towns of Los Alamos and White Rock are located along the north and east boundaries.

Regional Location of Los Alamos National Laboratory

Overview of Lab

- LANL is 1 of 28 DOE labs across the country
- LANL is managed for DOE by UC
- LANL is the largest institution and the largest employer in Northern New Mexico
  - ~ 6,800 University of California
  - ~ 2,800 contractor personnel
  - ~ $1.2 billion annual budget

Overview of Lab (cont')

- Staff breakdown:
  - approx. one-third are physicists
  - one-fourth are engineers
  - one-sixth are chemists and materials scientists
  - the remainder work in mathematics and computational science, biological science, geoscience, and other disciplines
  - 35 divisions, programs, and offices

Overview of Lab (cont')
'Science Subject Areas'

- Accelerators
- Advanced Concepts
- Astronomy
- Biology
- Chemistry
- Computing
- Defense Sciences
- Education
- Energy
- Engineering
- Environmental
- Explosives
- Geology, Geophysics
- Genomics
- Hazardous Waste
- Manufacturing Technologies
- Materials
- Mathematics
- Medicine/Health
- Modeling/Simulation
- Nonproliferation
- Nonlinear Studies
- Nuclear Materials
- Nuclear Weapons
- Physics
- Space Sciences
- Superconductivity
- Testing and Evaluation
- Theory

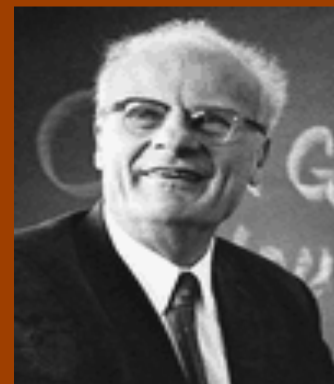
Lab History

Los Alamos was selected as the site of the laboratory that would design nuclear weapons for the Manhattan Engineer District (MED), i.e., the Manhattan Project.

Lab History

Enrico Fermi (Center)

J. Robert Oppenheimer



Hans Bethe

Niels Bohr

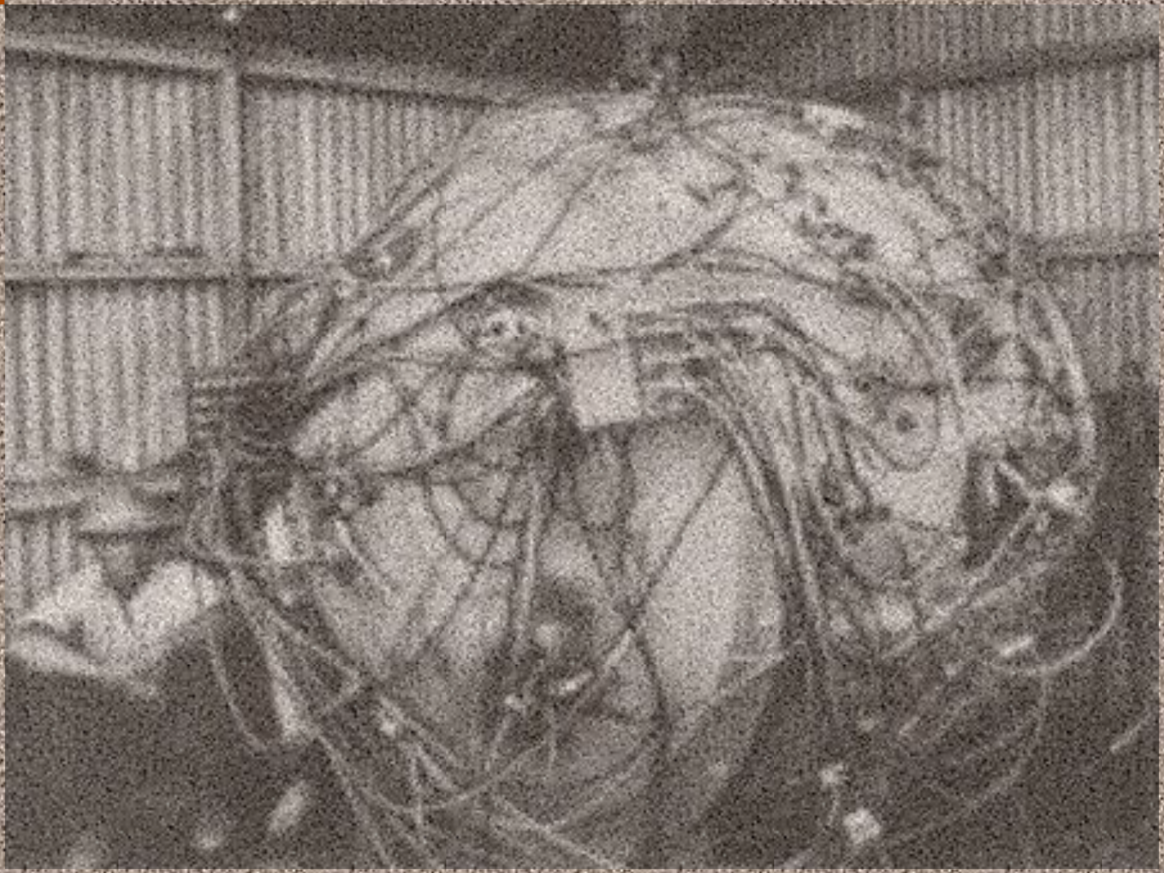
Oppenheimer & Groves

Richard Feynman (Center)

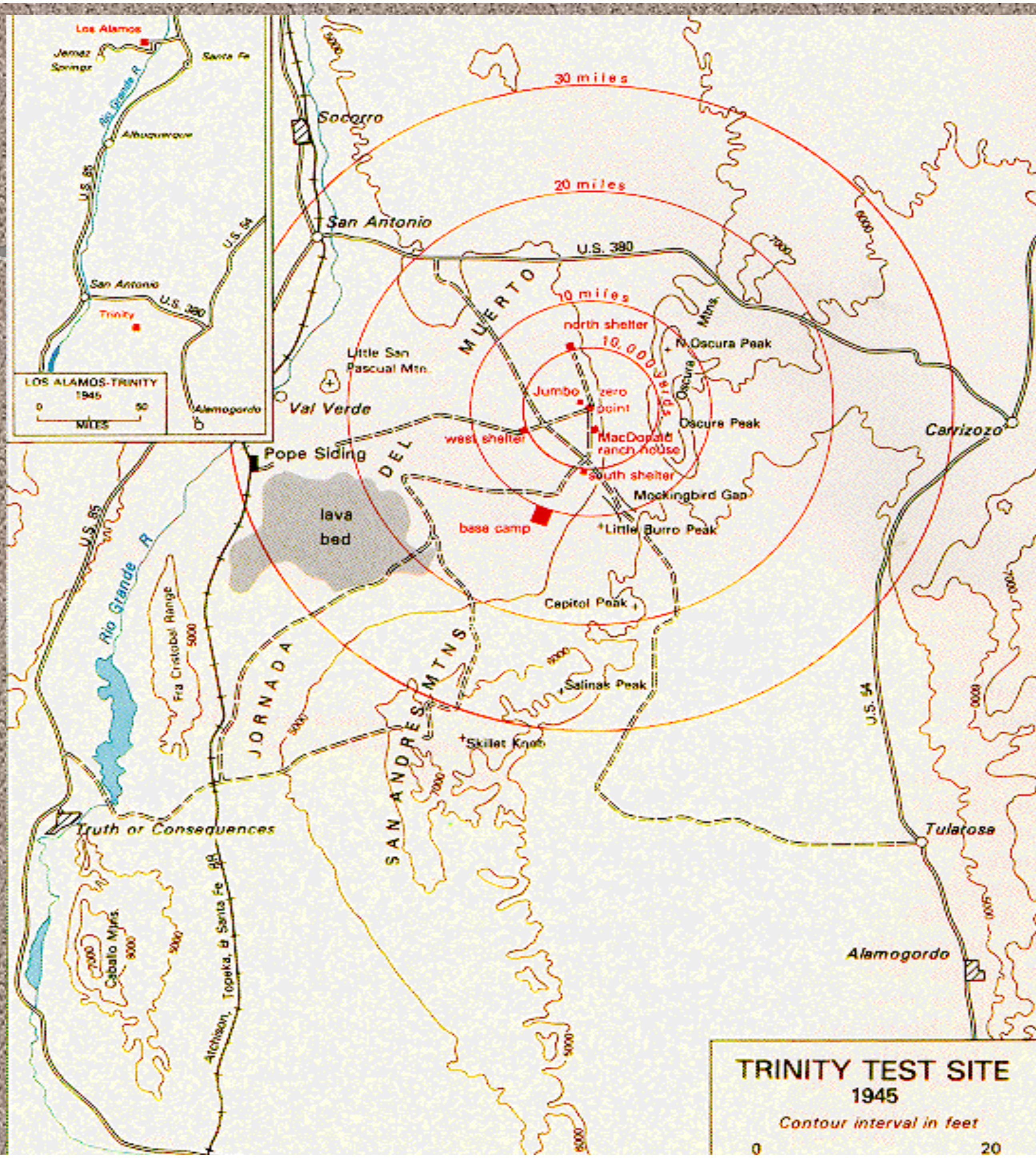
Edward Teller

John von Neumann

Lab History



"Gadget" just before the Trinity test July 16, 1945



Los Alamos
Jemez Springs
Santa Fe
Rio Grande R.
Albuquerque
U.S. 85
U.S. 54
San Antonio
U.S. 380
Trinity
Alamogordo
LOS ALAMOS-TRINITY
1945
0 50
MILES
Socorro
San Antonio
U.S. 380
30 miles
20 miles
10 miles
north shelter
10,000 yds
N. Oscura Peak
Oscura Mtns.
Little San Pascual Mtn.
Val Verde
Jumbo
zero point
west shelter
MacDonald ranch house
Oscura Peak
south shelter
Mockingbird Gap
base camp
Little Burro Peak
Carrizozo
Pope Siding
lava bed
JORNADA DEL MUERTO
Capitol Peak
Salinas Peak
SAN ANDRES MTNS
Skillet Knob
Fra Cristobal Range
Rio Grande R
U.S. 85
U.S. 54
Tularosa
Truth or Consequences
Caballo Mts.
Atchison, Topeka, & Santa Fe RR
Alamogordo
TRINITY TEST SITE
1945
Contour interval in feet
0 20

The Trinity Test

I am become Death, the Destroyer of Worlds.
Dr. J. Robert Oppenheimer, Director of Los Alamos

Now we are all sons-of-bitches.
Dr. Kenneth Bainbridge, Director of Trinity Test

July 16, 1945
5:29 a.m. Mountain War Time
Latitude: 33 40' 31'' N
Longitude: 106 28' 29'' W

Lab Mission Overview
Original Mission

- Design, develop, and test nuclear weapons

Lab Mission Overview

- Los Alamos National Laboratory's central mission is enhancing the security of nuclear weapons and nuclear materials worldwide
- Statutory responsibility is the stewardship and management of the nuclear stockpile

Lab Mission Overview
Broadened Mission

- Reduce global nuclear danger by:
  - Ensure safe, secure, reliable nuclear weapons
  - dismantlement and remanufacture of nuclear weapons
  - nuclear materials management
  - nonproliferation and counter proliferation technologies
  - environmental stewardship

Lab Mission Overview
Environmental Stewardship

- Environmental Stewardship provides for the remediation and reduction of wastes from the nuclear weapons complex
- Ensure that the environment is restored from past nuclear activities
- Ensure that the environment is minimally impacted from future activities

Program overview - Drivers

- Late 1980's and early 1990's: LANL requests waivers of GW monitoring requirements under RCRA from NMED
- NMED replied (1995) that information provided did not fulfill the groundwater monitoring standards of 40 CFR 265.

Program overview - Drivers

- NMED responses to waiver requests
  - Basic geology, hydrogeology, and pathways for contaminant transport have not been adequately addressed”
  - “a comprehensive ground-water monitoring program plan should be developed”
  - Individual zones of saturation beneath LANL have not been adequately delineated, and the "hydraulic interconnection" between these is not understood.
  - The recharge area(s) for the main and perched-intermediate aquifers have not been identified
  - The ground-water flow direction(s) of the main aquifer and perched-intermediate aquifer(s), as influenced by pumping of production wells are unknown

Program overview - Drivers

- NMED responses, cont.
  - Aquifer characteristics cannot be determined without additional monitoring wells installed within specific intervals of the various aquifers beneath the facility
  - "...a RCRA site-wide hydrogeologic Workplan should be developed and submitted to NMED and EPA for review and approval. A site-wide hydrogeologic Workplan developed under the driver of RCRA will provide a mechanism to assure a compliance schedule with specific tasks to meet the permit objectives. The Workplan should address both the HSWA hydrogeologic permit requirements and RCRA regulatory ground-water monitoring requirements."

HGWP Program Overview

- Characterize the hydrogeologic setting beneath the Laboratory
- Enhance the Laboratory's groundwater monitoring program
- The Workplan scope represents an integration of all Laboratory projects and activities that contribute to the characterization of the hydrogeologic setting beneath the Laboratory

HGWP Program Goals

(1) reduce the hydrologic setting uncertainties

(2) reduce stratigraphic and structural uncertainties

(3) detect contamination of the water supply system; and

(4) assess the nature and extent of potential contamination in groundwater

Program Participants

- Groundwater Integration Team (GIT) - provides guidance on program
- ER Project - construction manager for wells
- Other Lab groups - database, modeling
- Stakeholders - provide input on program adequacy
- External Advisory Group (EAG) - provides peer review and recommendations

GW Integration Team (GIT)

- The GIT consists of earth science specialists from LANL's major groundwater programs
  - Water Quality and Hydrology Group (ESH-18) responsible for performance and project leadership
  - track deliverables and activities
  - interpret site-specific information from a Laboratory-wide context
  - integrate data into central database
  - conceptual model revisions

Stakeholders

- NMED
- DOE
- Los Alamos County
- Four Pueblos (San Ildefonso, Cochiti, Santa Clara, Jemez)
- Northern NM Citizens Advisory Board
- Concerned Citizens for Nuclear Safety
- New Mexico Attorney General
- EPA
- Residents
- Lab employees

External Advisory Group

- The EAG
  - provides an independent review of the GIT's implementation of LANL's Hydrogeologic Workplan
  - provides a broad technical and managerial review of the Workplan activities and methods
  - meets for 3 days, twice per year, at LANL during the March Annual and October Quarterly Meetings of the GIT
  - then issues a report with recommendations
  - currently consists of six members that have diverse technical and professional backgrounds.

External Advisory Group

All members review and contribute to all aspects of our review and assessment

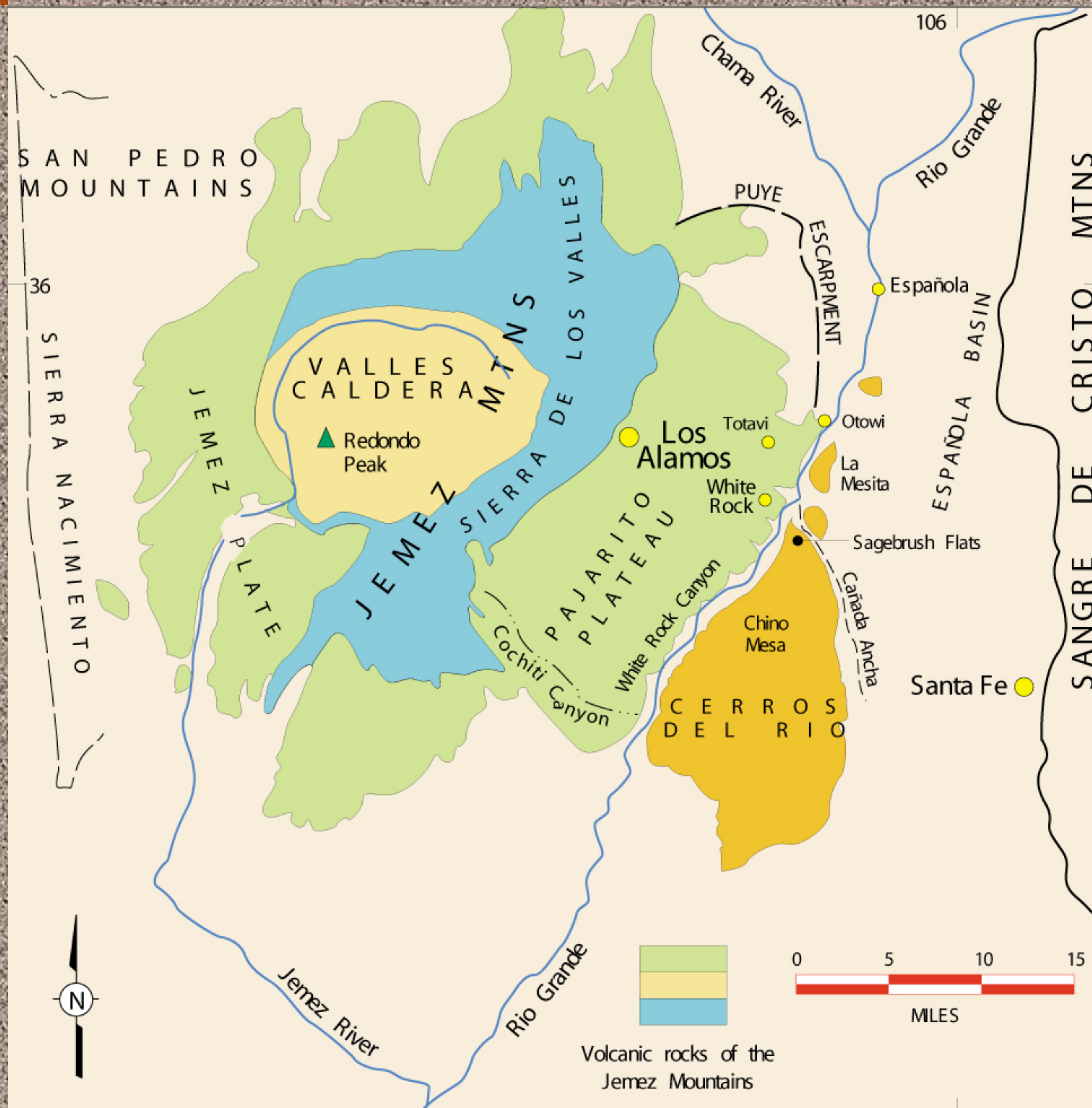
Members

- Robert Charles, Ph.D. (Chair)
  - Executive Summary, Program Mgmt, Mgmt. Stakeholder Issues, Administrative Issues
- Jack Powers, P.E.
  - Drilling, Well Completion
- Robert Powell, M.S.
  - DQOs, Data Gathering, Database, Geochemical Modeling, Groundwater Monitoring
- Elizabeth Anderson, Ph.D.
  - Risk Assessment
- David Schafer, M.S.
  - Drilling, Well Completion
- Charles McLane, Ph.D.
  - Modeling

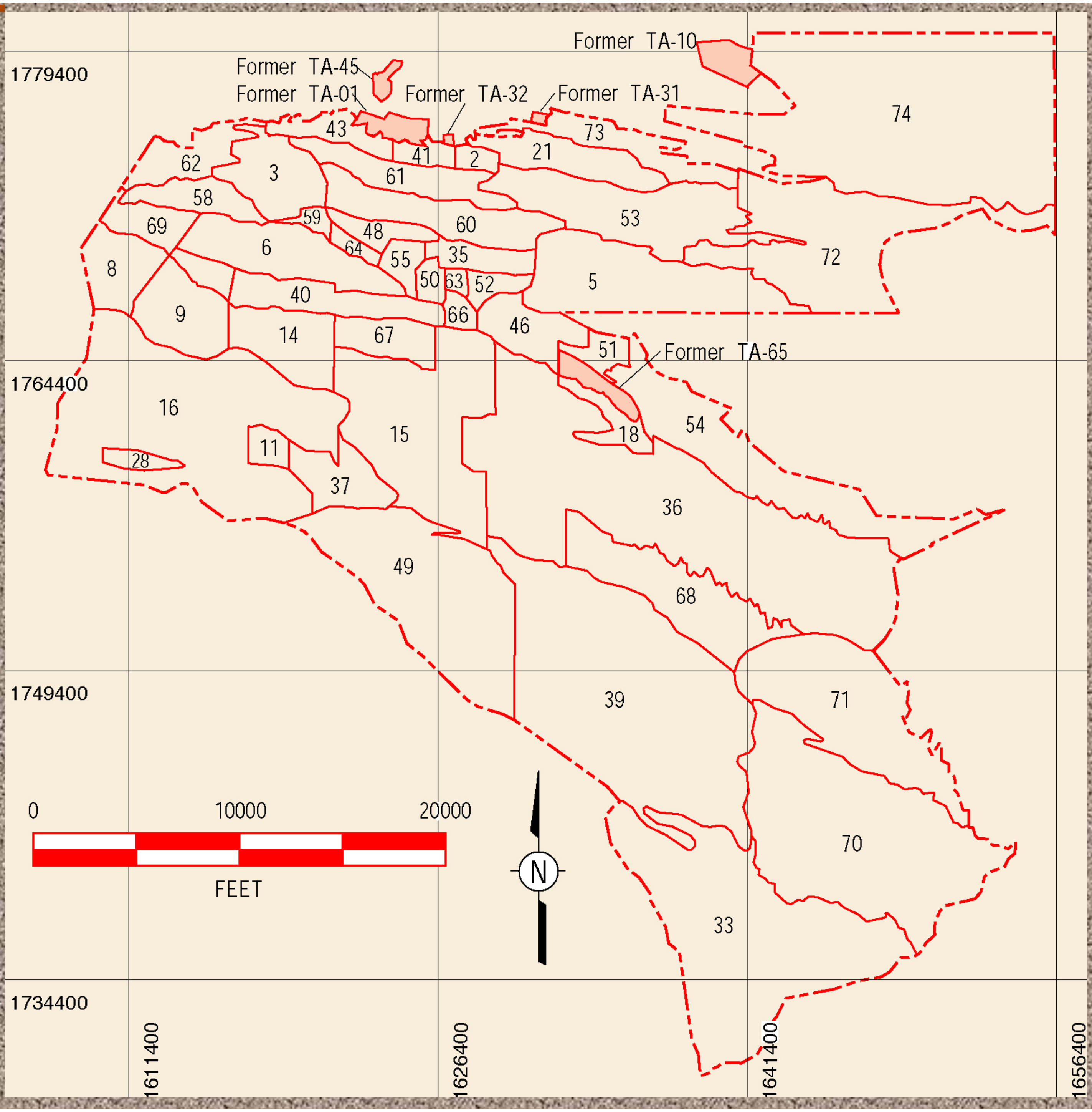
Geographical Setting

- Areal extent = 43-mi^2 (lab site and adjacent communities)
- Situated on the Pajarito Plateau
  - A series of mesas separated by deep canyons containing ephemeral and intermittent streams that run from west to east
  - Mesa top elevations from approximately 7,800 ft on the flank of the Jemez Mountains to about 6,200 ft at their eastern termination above the Rio Grande valley
  - The eastern margin of the plateau stands 300 to 900 ft above the Rio Grande
  - LANL is divided into Technical Areas (TAs) each of which has a specific research function or use

Geographic Map Near Los Alamos and the Pajarito Plateau

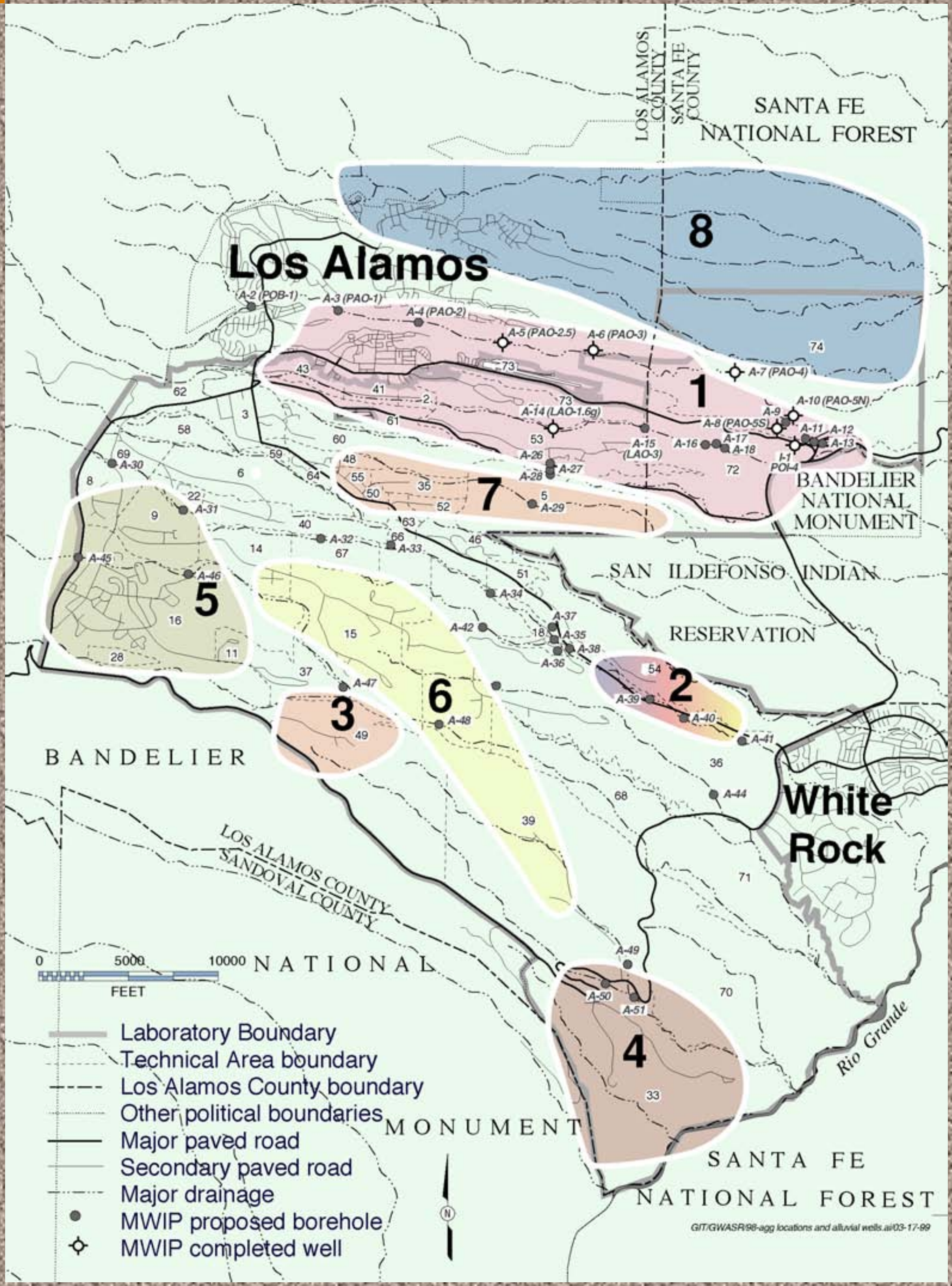


Technical Areas at LANL



Aggregates

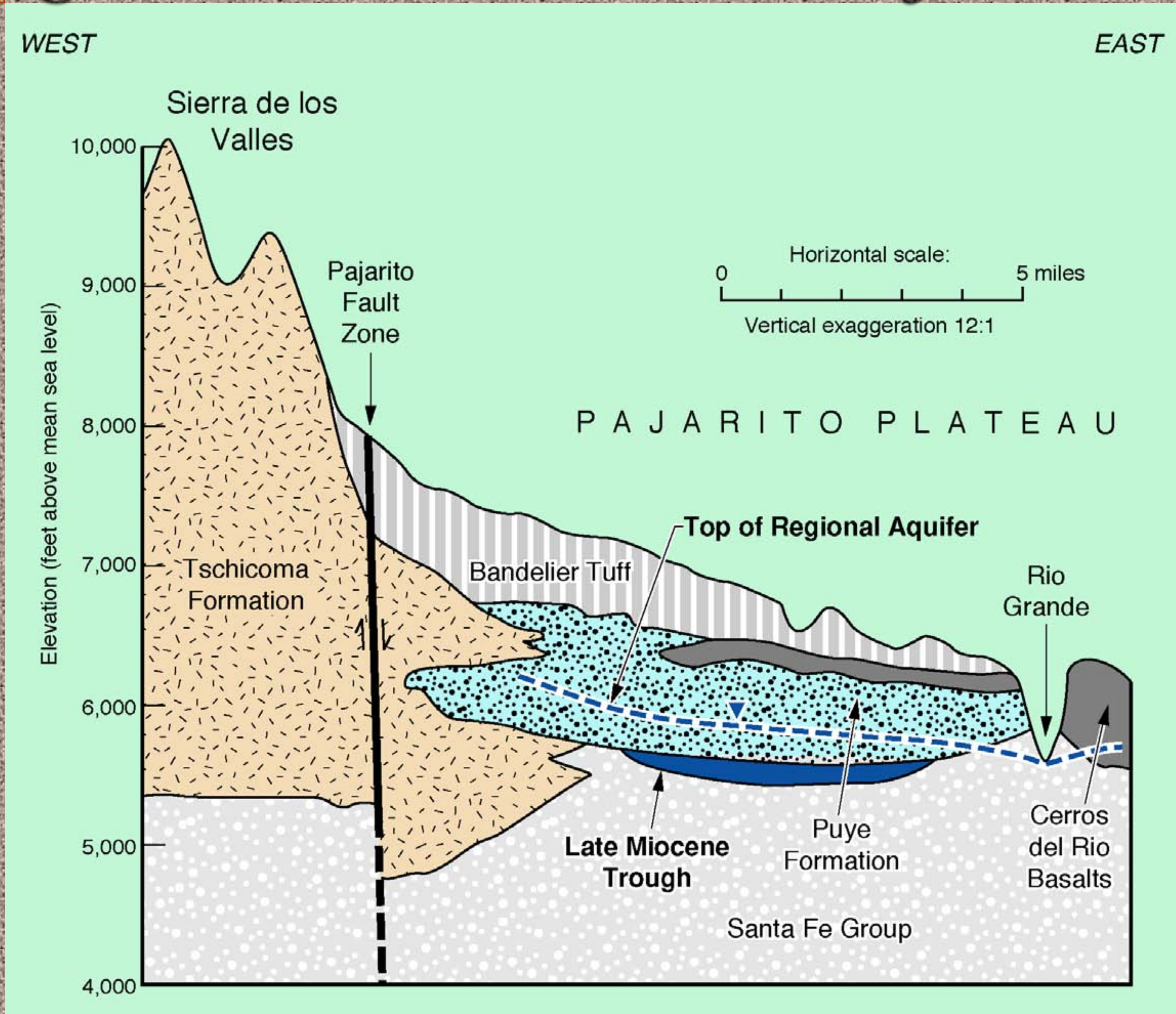
1. Pueblo, Los Alamos, Sandia Canyons, Los Alamos, DP Mesas, Mesita de Los Alamos
2. Cañada del Buey, Pajarito Canyon, Mesita del Buey
3. Frijoles Mesa
4. Ancho and Chaquehui Canyons, Un-named Mesa Top [TAs-33 and -39]
5. Cañyon de Valle, Threemile Mesa, Un-named Mesa Top [TA-16]
6. Portrillo, Fence, Water Canyons, Threemile Mesa, Lower Frijoles Mesa
7. Mortandad Canyon
8. Rendija, Guaje, Barrancas, Bayo Canyons
9. Regional (.e.g, site-wide)



Geologic Setting

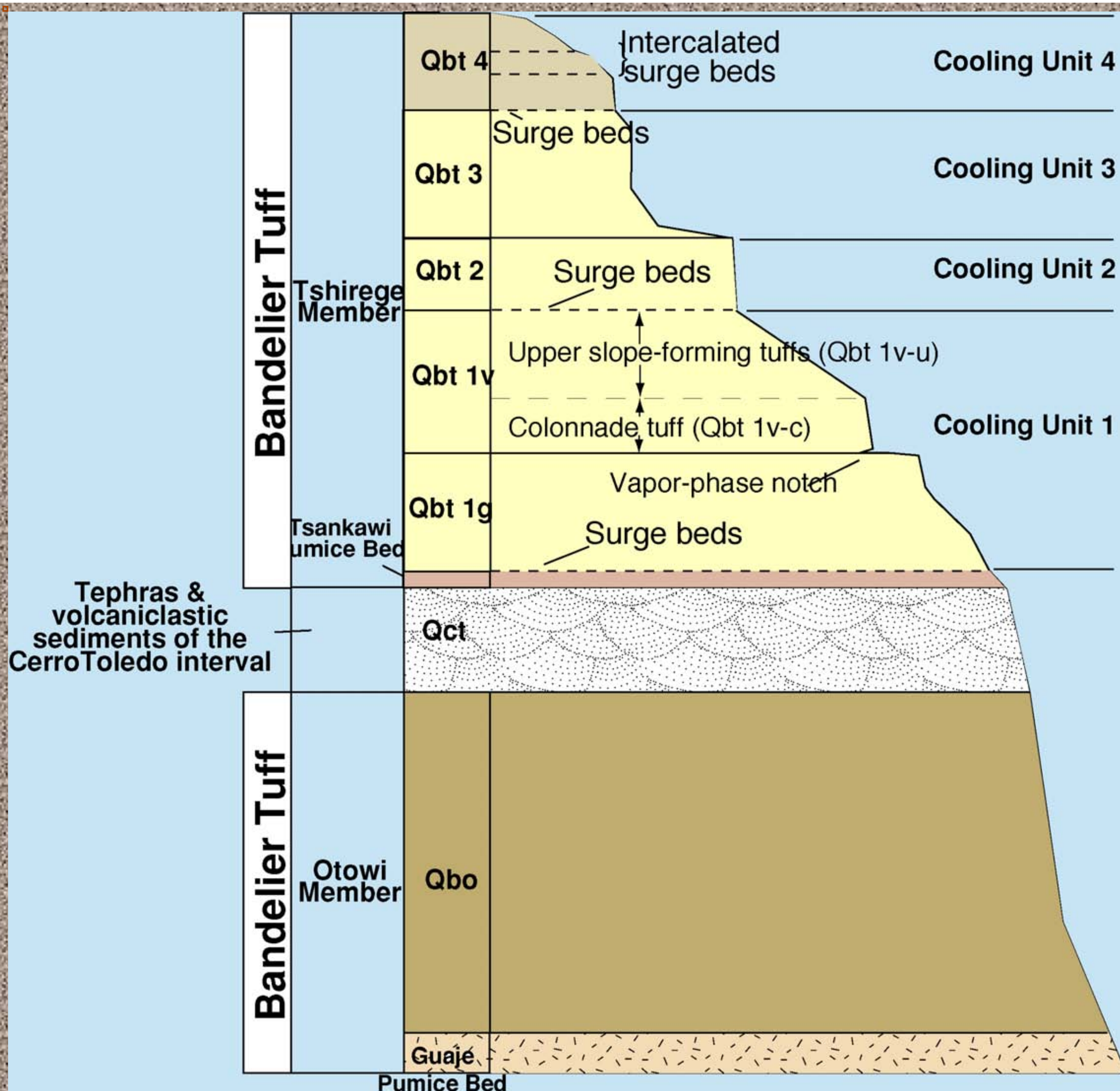
- The Pajarito Plateau lies on the east flank of the Jemez volcanic field and astride the active west margin of the Española basin of the Rio Grande rift. The principal bedrock units in this area consist of, in ascending order,
  - the Santa Fe Group (4-21 Ma)
  - the Puye Formation (1.7-4 Ma) and interstratified volcanic rocks including the Tschicoma Formation on the west (2-7 Ma) and basalts of the Cerros del Rio on the east (2-3 Ma),
  - the Otowi Member of the Bandelier Tuff (1.613 ± 0.011 Ma),
  - epiclastic sediments and tephras of the Cerro Toledo interval, and
  - the Tshirege Member of the Bandelier Tuff (1.223 ± 0.018 Ma).

Geologic Cross Section across Pajarito Plateau

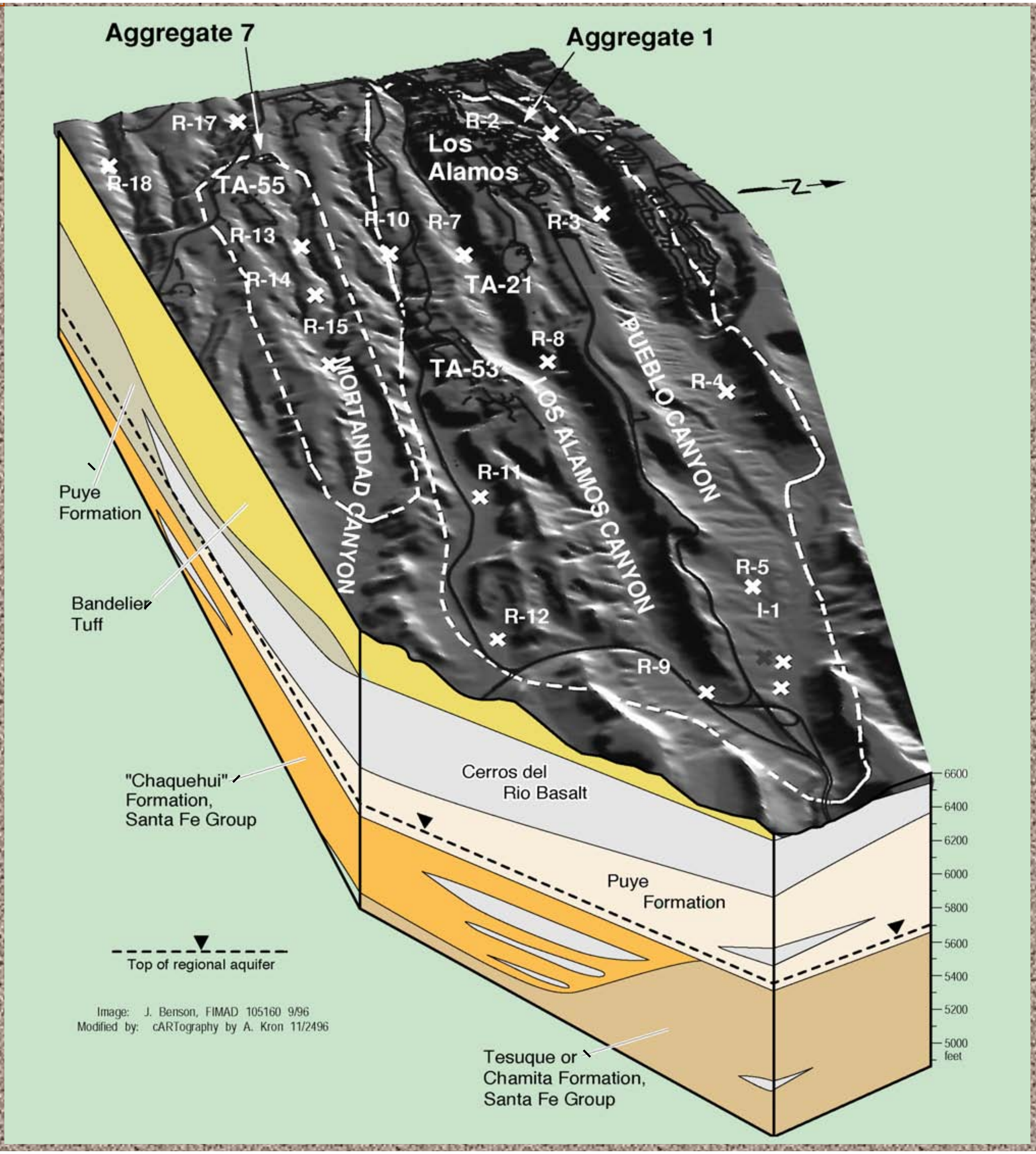


Stratigraphic Nomenclature for Bandelier Tuff

(from Broxton & Reneau, 1995)



Terrain and Bedrock Geology for Aggregates 1 and 7



Hydrologic Setting

- The hydrologic setting of the Pajarito Plateau includes surface water, alluvial groundwater, intermediate perched zone groundwater and the regional aquifer.
- All surface water drainage and groundwater discharge from the plateau ultimately arrive at the Rio Grande.

Drainage in Los Alamos Area

Key to spring locations

Map ref. no.	Spring ID
1	Sacred Spring
2	Indian Spring
3	La Mesita Spring
4	Spring 1
5	Spring 2
6	Sandia Spring
7	Spring 3
8	Spring 3A
9	Spring 3AA
10	Spring 3B
11	Spring 4
12	Spring 4A
13	Spring 5
14	Spring 5A
15	Spring 5AA
16	Ancho Spring
17	Spring 6
18	Spring 6A
19	Spring 8A
20	Spring 7
21	Spring 8
22	Spring 9
23	Spring 9A
24	Doe Spring
25	Spring 10
26	Spring 8B
27	Spring 5B
28	Spring 2A
29	Spring 9B
30	Otowi Spr.
31	Los Alamos Spr.
32	LA-5.19 Spr.
33	DP Spr.
34	Hamilton Bend Spr.
35	TS-1.42 Spr.
36	TW-1.72 Spr.
37	LA-11.2 Spr.
38	SM-30A Spr.
39	SM-30 Spr.
40	Hanlon Spr.
41	Anderson Spr.
42	Bulldog Spr.
43	Keiling Spr.
44	Josie Spr.
45	Bryan Spr.
46	Starmer's Spr.
47	Garvey Spr.
48	Perkin's Spr.
49	Upper Starmer's Spr.
50	Charlie's Spr.
51	Peter Spr.
52	SWSC Spr.
53	Burning Ground Spr.
54	Martin Spr.
55	Fish Ladder Spr.
56	Hollow Spr.
57	WC-6.25 Spr.
58	Threemile Spr.
59	Spring 4AA
60	Spring 4B
61	Spring 4C
62	Spring 9D

Hydrologic Setting
Alluvium

- Intermittent and ephemeral streamflows in the canyons of the Pajarito Plateau have deposited alluvium that is as much as 100 ft. thick.
- Saturated hydraulic conductivity of the alluvium typically ranges from 10^{-2} cm/s for a sand to 10^{-4} cm/s for a silty sand (Abeele et al. 1981)
- The chemical quality of alluvial groundwaters is variable, depending on the location and history of effluent discharges

Hydrologic Setting
Perched Zones

- Localized bodies of perched groundwater occur beneath several canyons in the eastern portion of the Laboratory
- The extent of the perched zones and migration potential to the regional aquifer are not yet fully understood
- The chemistry of alluvial GW varies with location and history of effluent discharges
  - In Mortandad Canyon, Pu concentrations fluctuate with variations in treatment plant effluent and storm runoff
  - Tritium concentrations have fluctuated almost directly with the average annual effluent concentration from LANL's Radioactive Liquid Waste Treatment Facility (RLWTF) at TA-50, with a lag time of about 1 year (Environmental Protection Group 1992).

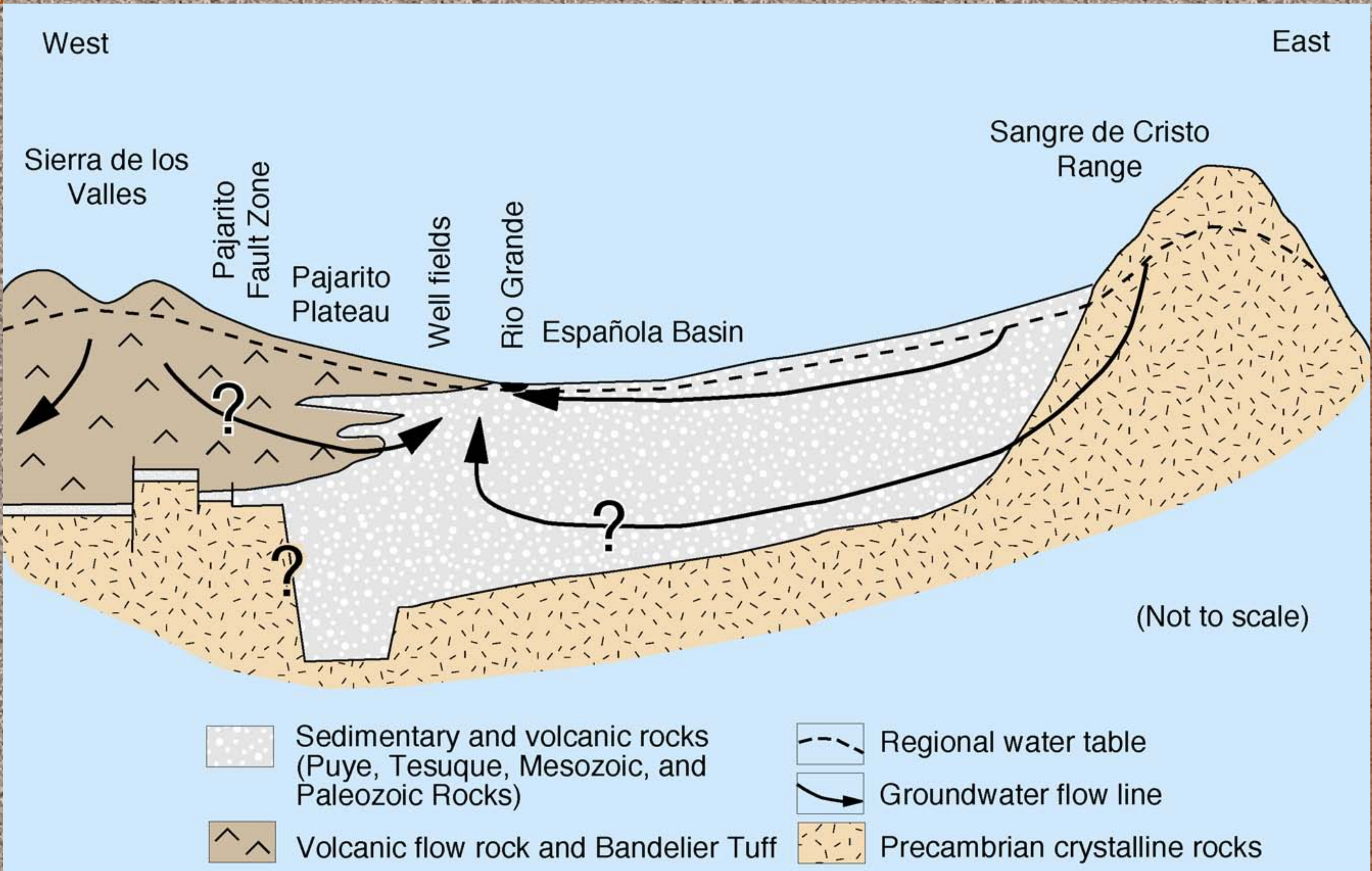
Hydrologic Setting
Regional Aquifer

- The regional aquifer of the Los Alamos area is the only aquifer capable of large-scale municipal water supply (Purtymun 1984)
- RA is separated from the alluvial GW and intermediate perched zone GW by 350 to 620 ft of tuff, basalt, and sediments (Environmental Protection Group 1993)
- Hydraulic gradient ≈ 60 to 80 ft/mi in Puye Formation, 80 to 100 ft/mi along the plateau's eastern edge in the less permeable sediments of the Santa Fe Group.

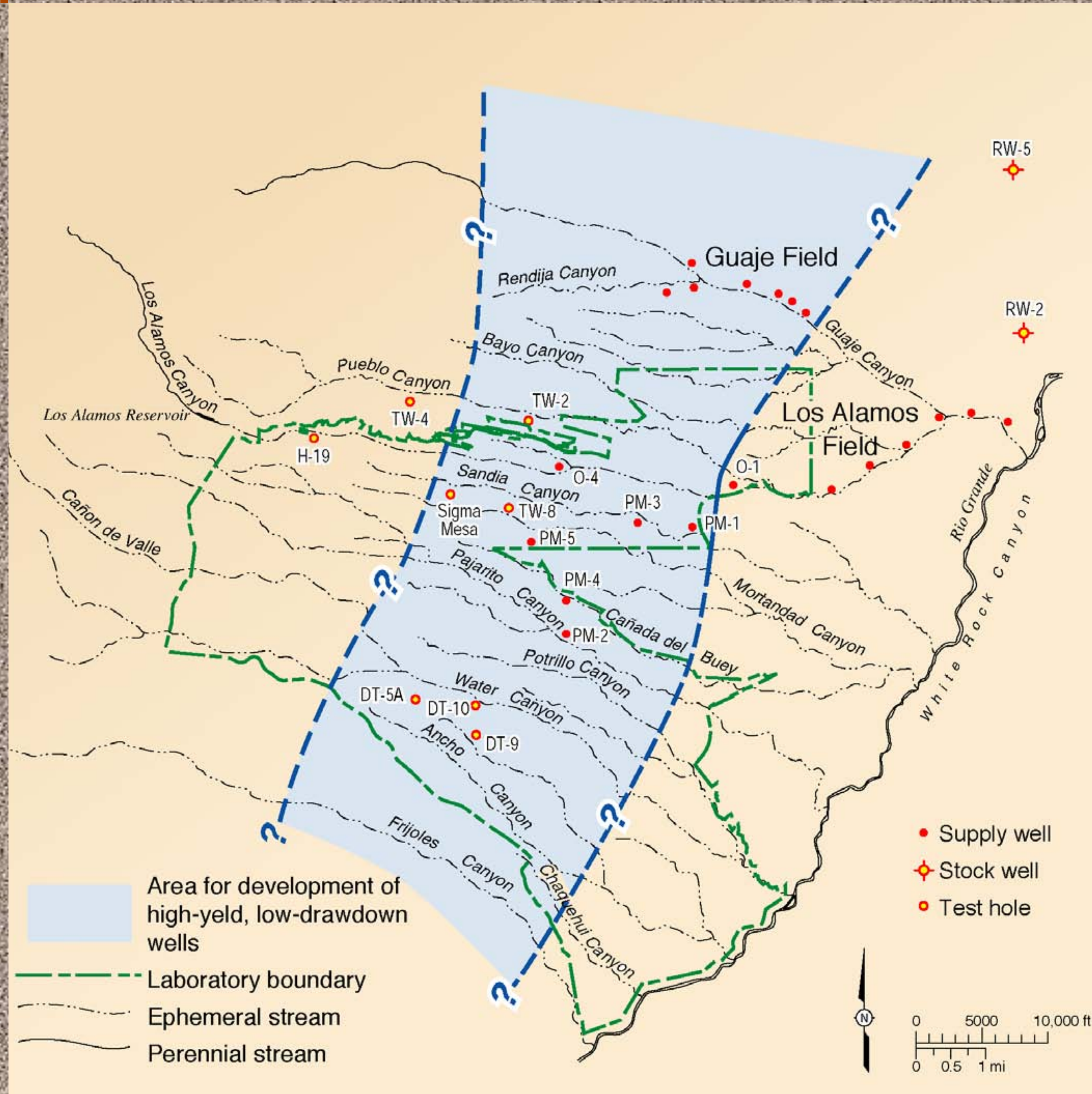
Hydrologic Setting
Regional Aquifer

- Aquifer tests yield rate of GW flow from 20 ft/yr in the Tesuque Formation to 345 ft/yr in the more permeable Puye Formation (Purtymun 1984)
- The exact source of recharge to the regional aquifer is unknown
- Declining water table: municipal withdrawal > recharge
- ^{14}C analyses give the minimum age of water in the regional aquifer from about 1,000 years (western portion of the Pajarito Plateau), increasing as it moves eastward, to about 30,000 years near the Rio Grande (Rogers et al. 1996b)
- 5 locations in RA with extremely low tritium indicate some recharge within last 40 yrs - 30 others, no recent influence

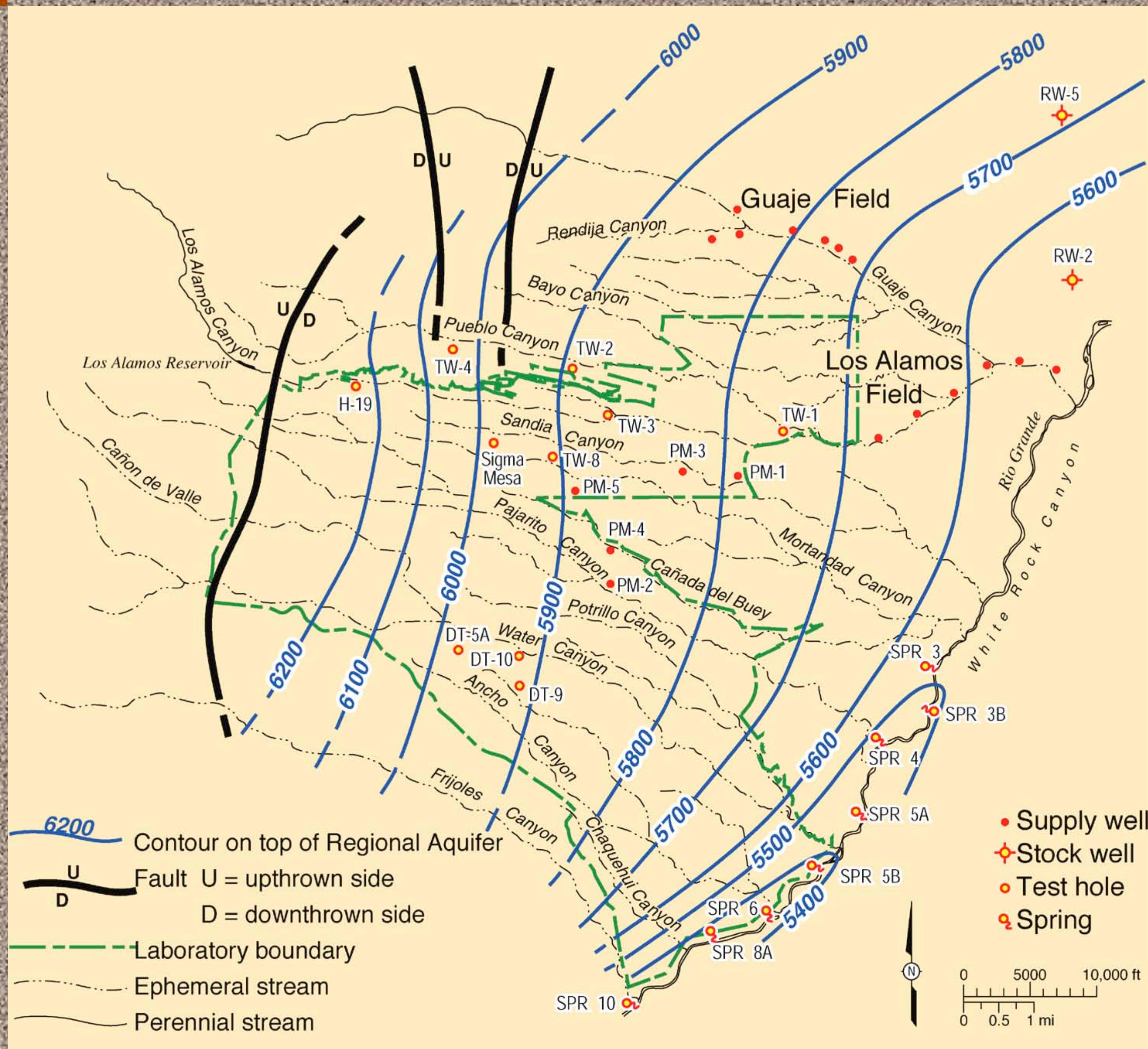
GW Flow Paths in the Española Portion of the Northern Rio Grande Basin



Area of inferred Late Miocene trough within upper Santa Fe Group



Generalized Water-Level Contours on Top of the Regional Aquifer



Workplan Components

- DQO-Based Planning
- Regional Wells: 32 R-wells
- Monitoring
- Database
- Modeling
- Risk Assessment

Data Quality Objectives Process

- State the problem to be resolved
- Identify the decision to be made
- Identify inputs to the decision
- Define the boundaries of the study
- Develop a decision rule
- Specify limits on uncertainty
- Optimize Design for Obtaining Data

Data Quality Objectives Process

- LANL will continue the DQO Process throughout Workplan implementation.
- As each activity is performed or well installed, the new data will be incorporated into a central database and input into modeling activities.
- New data will be used in an iterative manner in reassessing DQOs for the Workplan

Data Quality Objectives Process

- The DQO Process prospectively identified 84 wells for installation
  - 51 alluvial wells;
  - one intermediate perched zone well; and
  - 32 regional aquifer wells, with the boreholes for these used to characterize any intermediate perched zones encountered during borehole advancement.

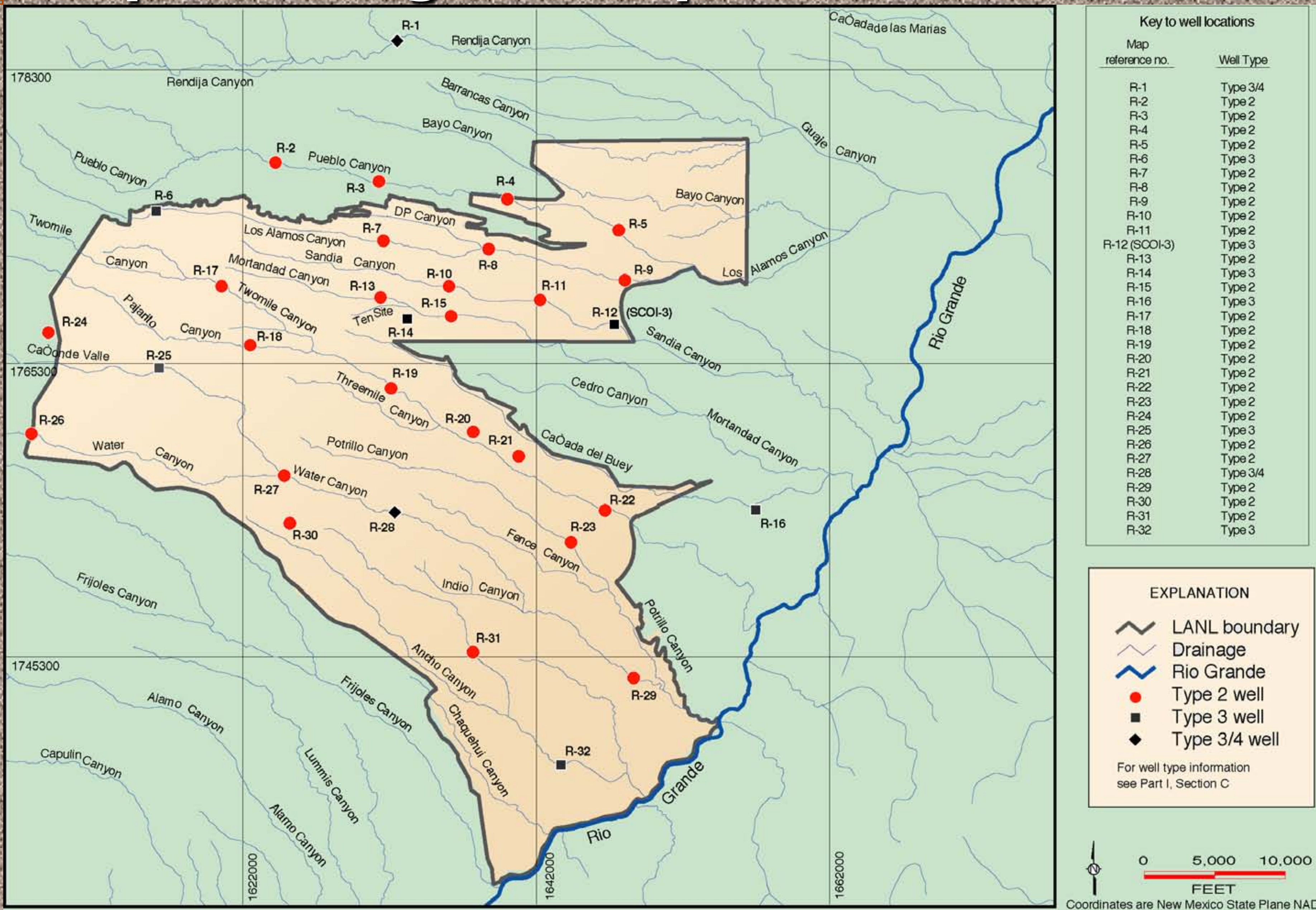
Deep Regional Monitoring (R) Wells

- Very deep, difficult drilling, very expensive
- Prioritization
  - Initial basis
  - Changes due to: discovery, watershed emphasis, drilling delays & funding
- Drilling Methods - Issues
- Development - Issues
- Completions - Single completions and Westbay

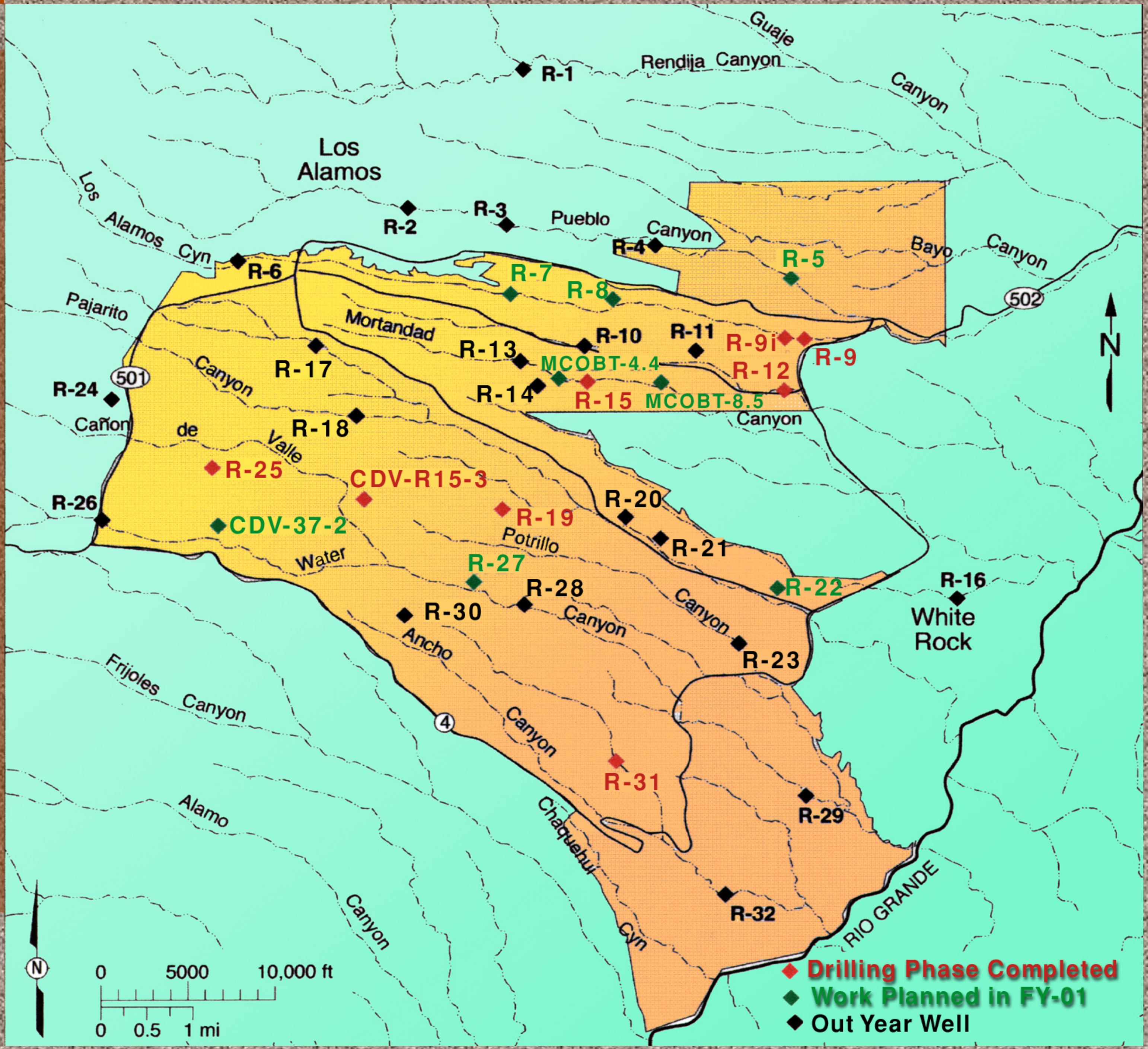
Criteria & Scores for Locating Wells

1. Reduce hydrologic Setting uncertainty [5pt max]
2. Reduce stratigraphic and structural uncertainty [4pt max]
3. Contaminant detection for water supply system [4pt max]
4. Assessment of nature and extent of potential contamination in GW [4pt max]
5. Future water supply [3pt max]
6. Control of timing and construction of other wells [2 pt max]
7. Budget and programmatic constraints [2 pt max]
8. Operational efficiency [1 pt max]

Proposed Regional Aquifer Well Locations



Drilling status for regional aquifer wells being installed as part of the Hydrogeologic Workplan



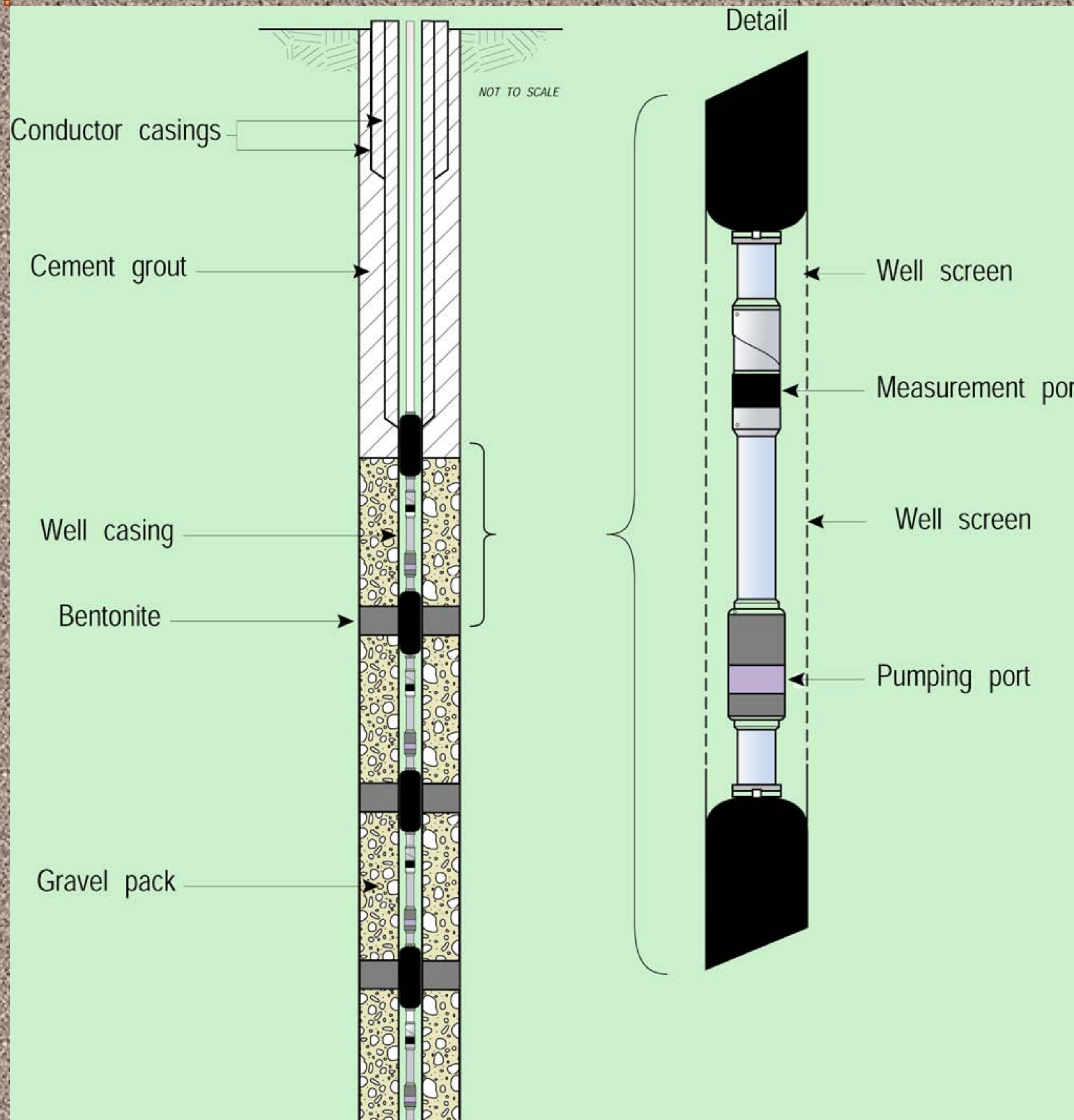
Hydrologic Data Collection

- Core sample collection and testing
- Borehole geophysics (gamma, etc.)
- Borehole video (observe fractures)
- Transducers for water level
- Spinner logs/Pump tests/Slug tests
- Testing depends on drilling methods

Monitoring

- Approaches are under discussion. Currently ER sampling SOPs are being used.
- Low-flow purging & sampling being encouraged.
- NMED does not yet have formal low-flow protocols or guidelines in place.

Westbay-type Design for Multi-Level Monitoring



Contaminants Detected

	R-9	R-12	R-15	R-19	R-25	R-31
Perched	U, NO_3^-, Oxalate Tritium	U, NO_3^-, Tritium	ClO_4^-, Tritium	HE?	HE, RDX, deg. Prod.	Clean
Regional	NO_3^-, Tritium	NO_3^-, Tritium (N isotope, sewage)	Clean	Clean	HE?	Clean

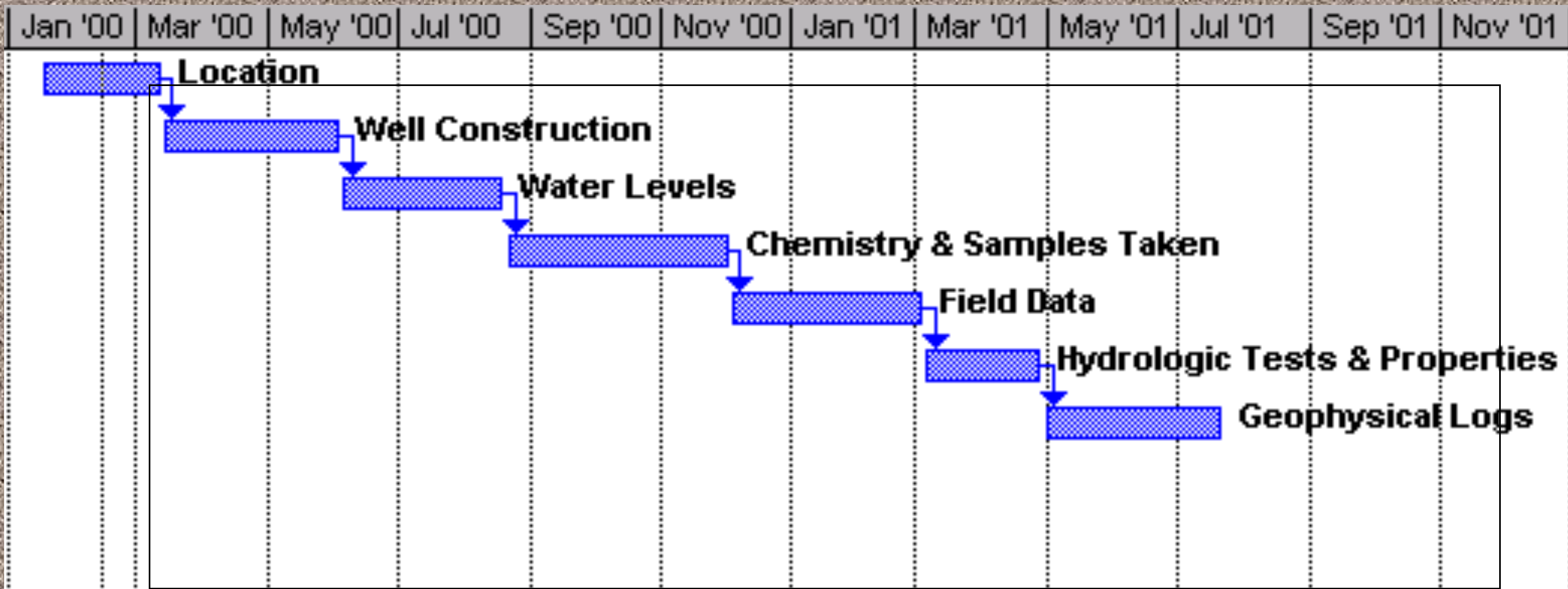
Water Quality Database

- A single database development effort to provide an institutional repository for water data that includes groundwater data.
- Cooperative design effort between ER and GIT information management system project teams.
- Goal is a database structure that simplifies data sharing

Water Quality Database

- The end product will support water data management activities for ESH-18, the GIT and will be accessible to the greater Laboratory and public stakeholder communities.
- The WQDB is implemented as an Oracle relational database.

Water Quality Database



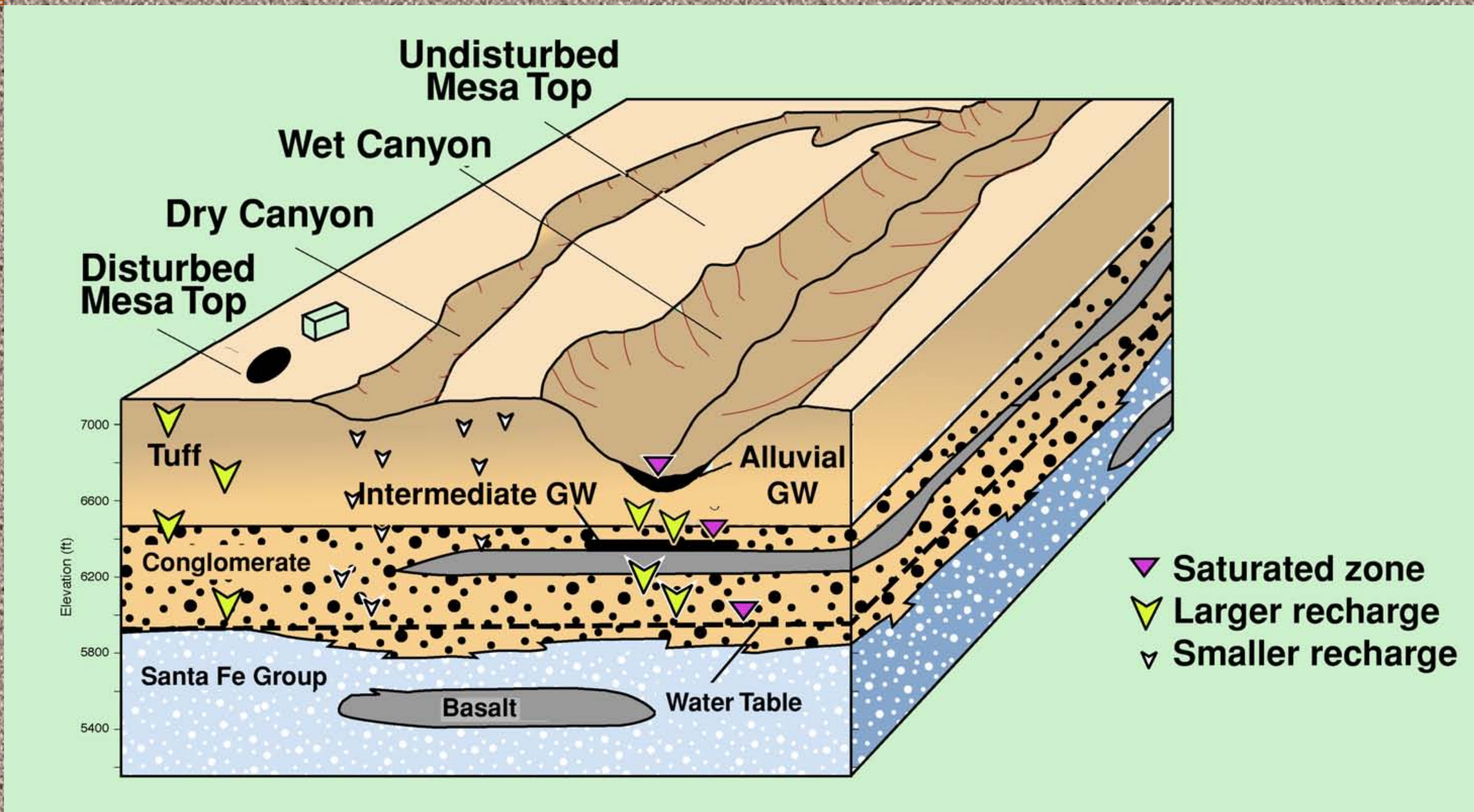
Modeling

- Conceptual
- GW Flow
- Geochemical
- Contaminant Transport

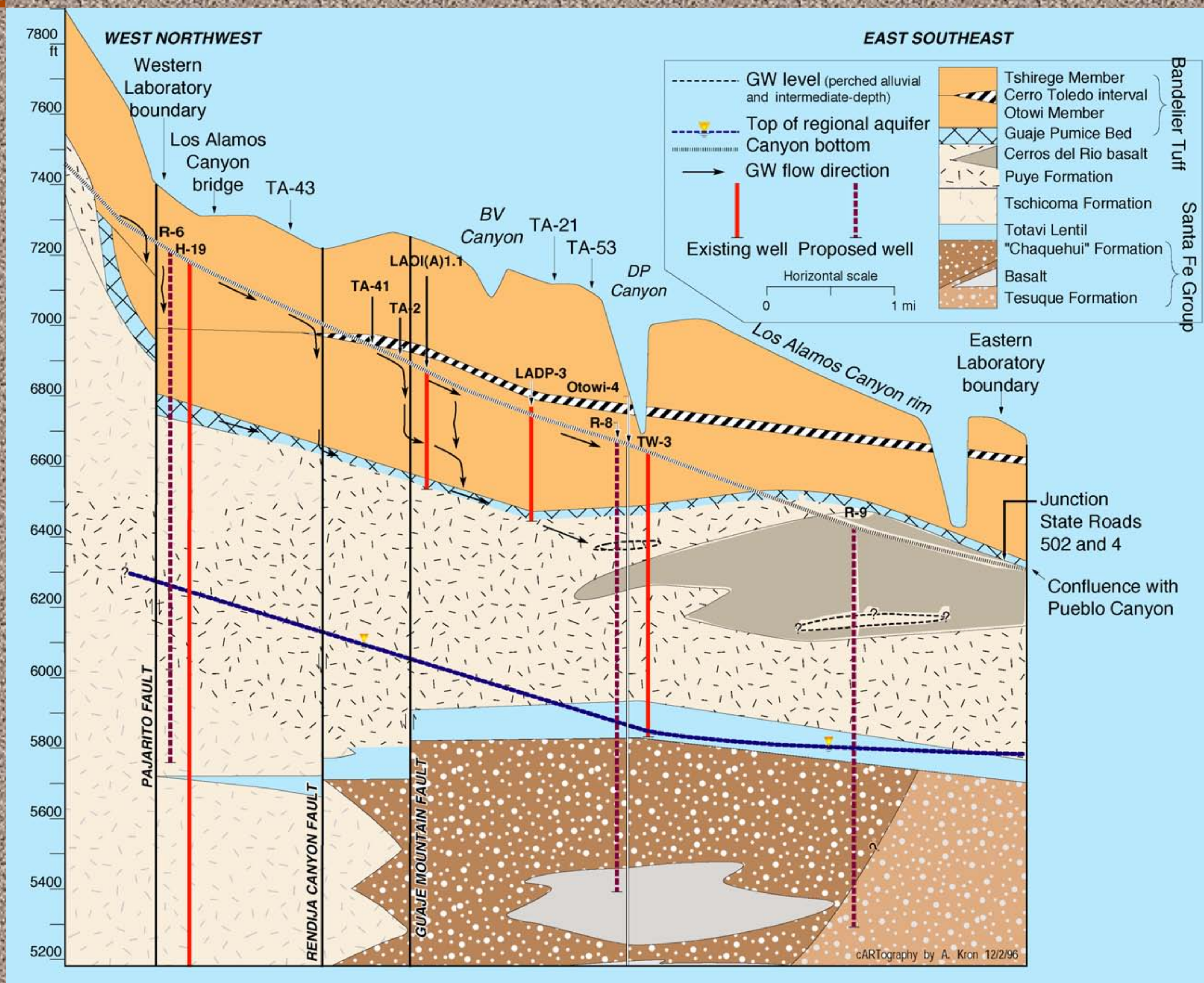
Conceptual Models

- Plateau & canyon
- Hydrologic
- Geochemical

Hydrogeologic Model for Mesas/Canyons



Conceptual Model and proposed RA wells for upper LA Canyon



Conceptual Model and proposed wells for upper LA Canyon

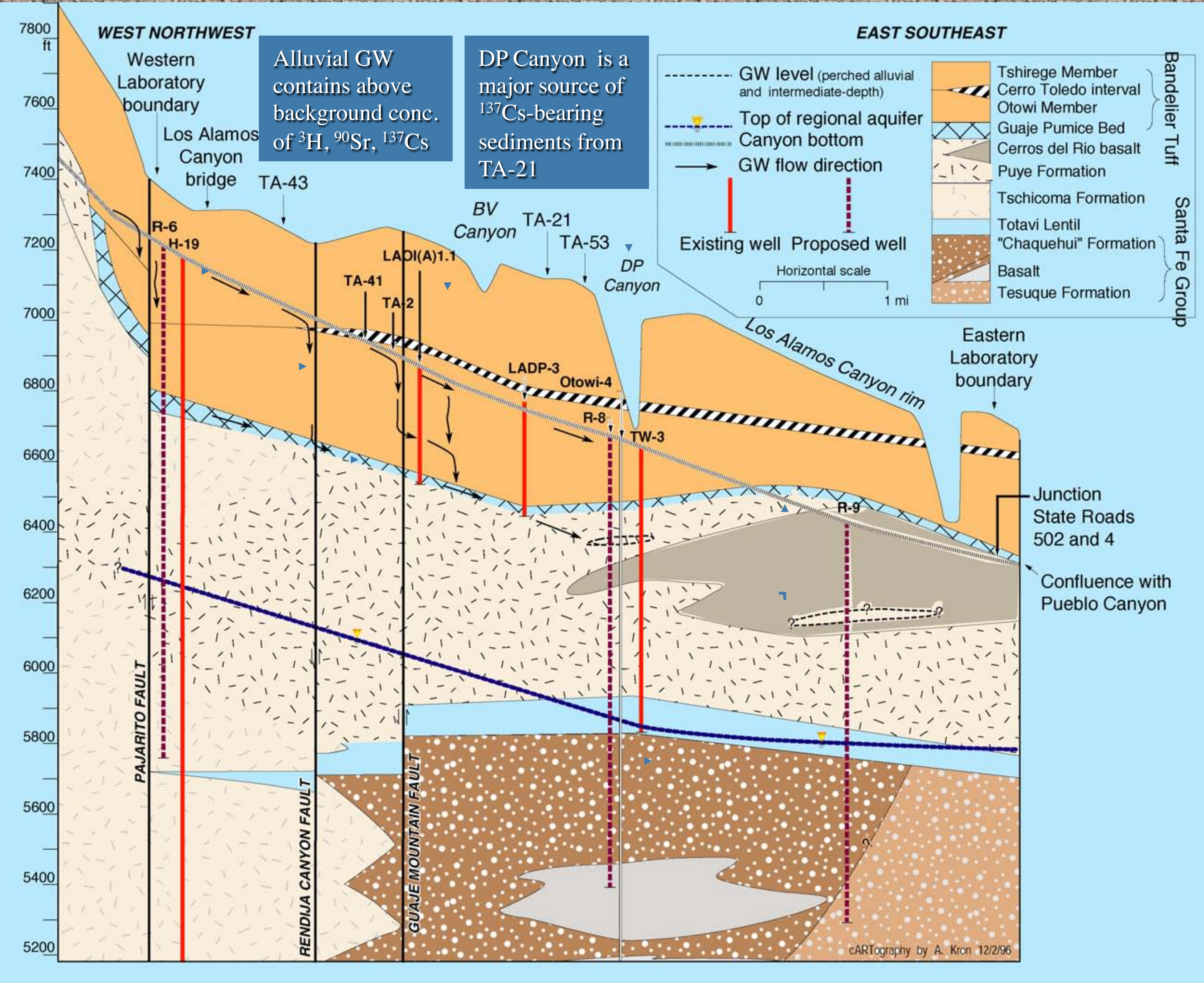
Lateral flow in stream & perched alluvial zone

Potential for water from canyon leaking along faults and fractures

^3H-bearing perched GW w/in Guaje Pumice Bed

Alluvium is saturated from mountains in west to this point

Above background ^3H & ^{90}Sr in regional aquifer in TW-3



Flow Models

- Steady-state regional-scale hydrologic flow model
- Includes embedded high-resolution grid for the Pajarito Plateau within the coarser regional-scale hydrologic flow model
- Uses the Finite Element Heat and Mass Transfer (FEHM) code

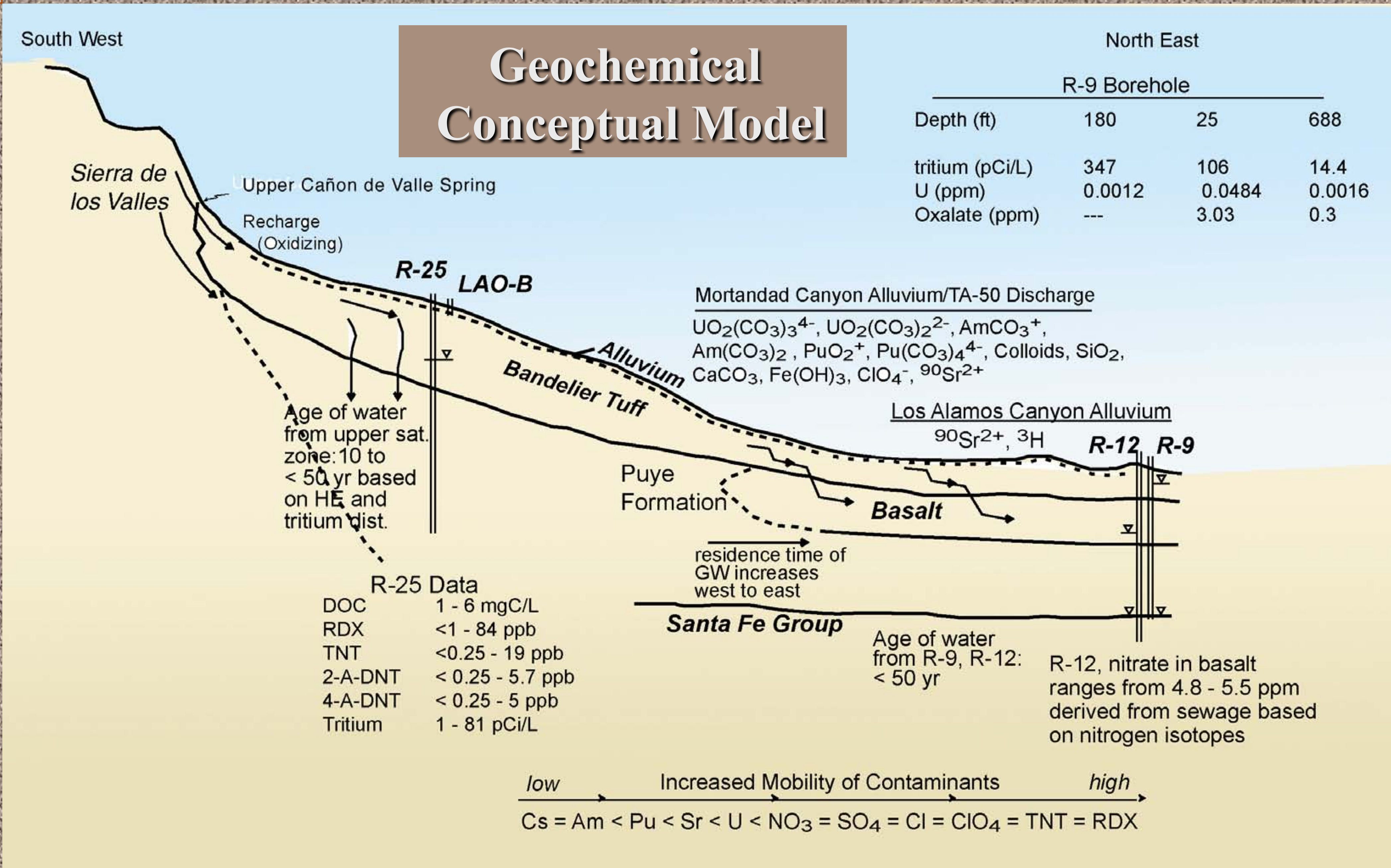
Flow Models

- Regional-scale hydrologic flow model has been improved
  - model was calibrated using water level responses over a 50-year period from the plateau and the Española basin
- Preliminary water budget calculations for the plateau have been prepared
- Canyon-scale and MDA-scale flow and transport models have been developed and calibrated using the FEHM code

Geochemical Models

- Use of PHREEQC and MINTEQA2 geochemical codes
- A geochemical conceptual model was developed of plateau-wide water, rock and contaminant interactions
- Allowed inclusion of geochemical model elements into the FY99 Hydrogeologic Conceptual Model

Geochemical Conceptual Model



Risk Assessment

- RA based in the ER division at LANL
- Risk assessment is the "ultimate DQO"
- Approach is borrowed from EPA
- Focus attention and resources on greatest risks
  - Must understand the system for decision-making
  - Provide greatest real risk reduction per dollar invested

Timeline to completion

- Began 1997/1998, well installation concludes in 2005.
- Year-by-year iterative process of data collection, review and re-assessment

Program cost

- Total program cost = \$50,000,000
- Cost since FY97/98 ≈ \$22,600,000
- Funding comes from Defense Programs (DP), Environmental Restoration Program (ER) and Environmental Safety and Health (ESH) Programs

Cerro Grande Fire: Watershed Damage

Issue: Cerro Grand Fire

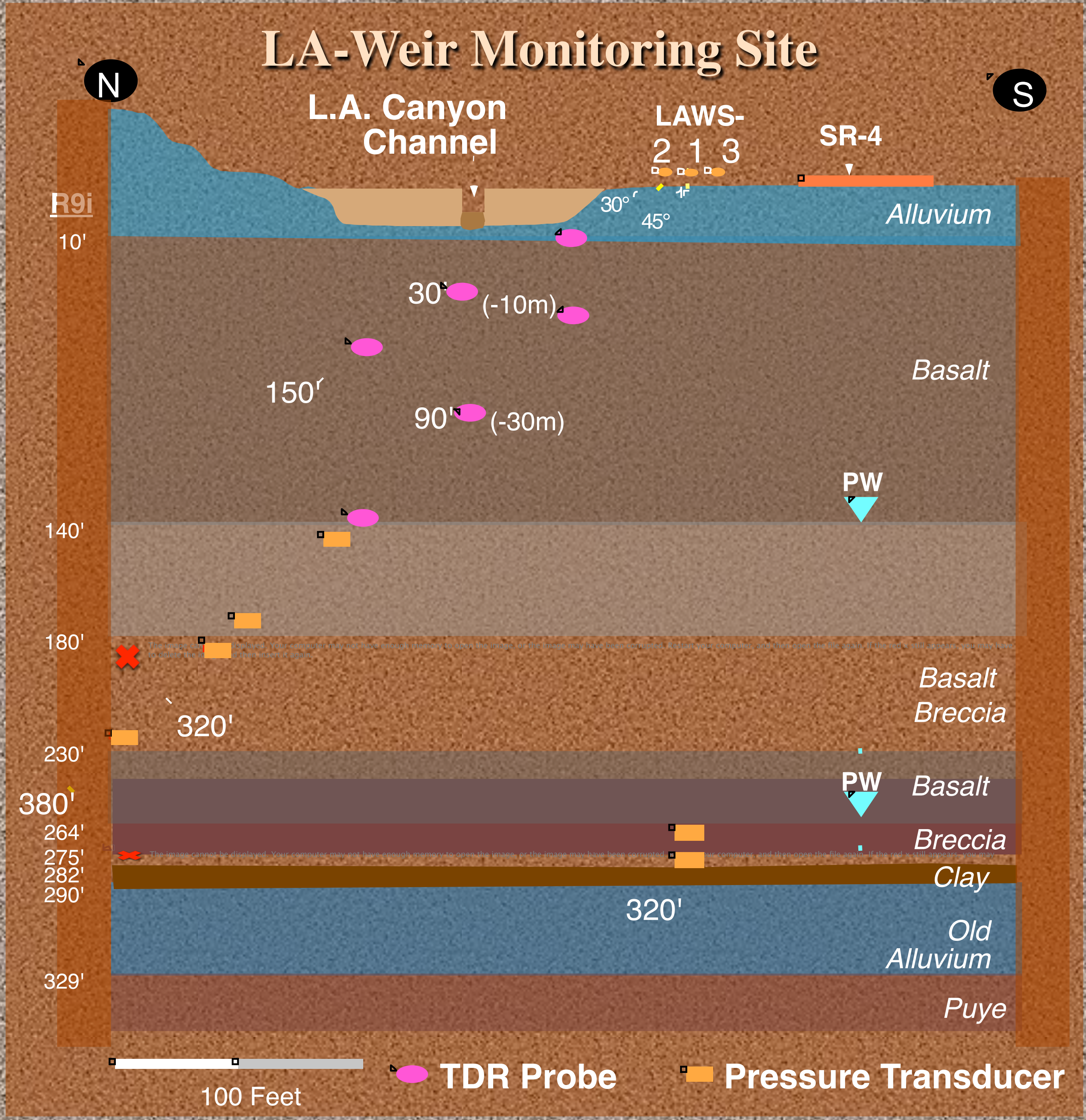
- Cerro Grand fire started May 7 and closed the Lab for 2 weeks; field operations finally resumed June 1
- Work in canyons can not be scheduled during rainy season (Jul-Sep)
- Chemical changes in runoff may affect GW
- Engineered flood control structures may affect hydrogeologic system

Cerro Grande Fire Issue Resolution

- Re-schedule wells in canyons for non-rainy season (Exchanged R-22 for R-7 in FY00)
- Modeling used to assess potential effects of changes in runoff chemistry
- Installed well head flood protection structures
- 1000 personnel working on rehabilitation
- $600,000,000 for fire rehabilitation efforts

Construction of LA Canyon Weir June-July 2000

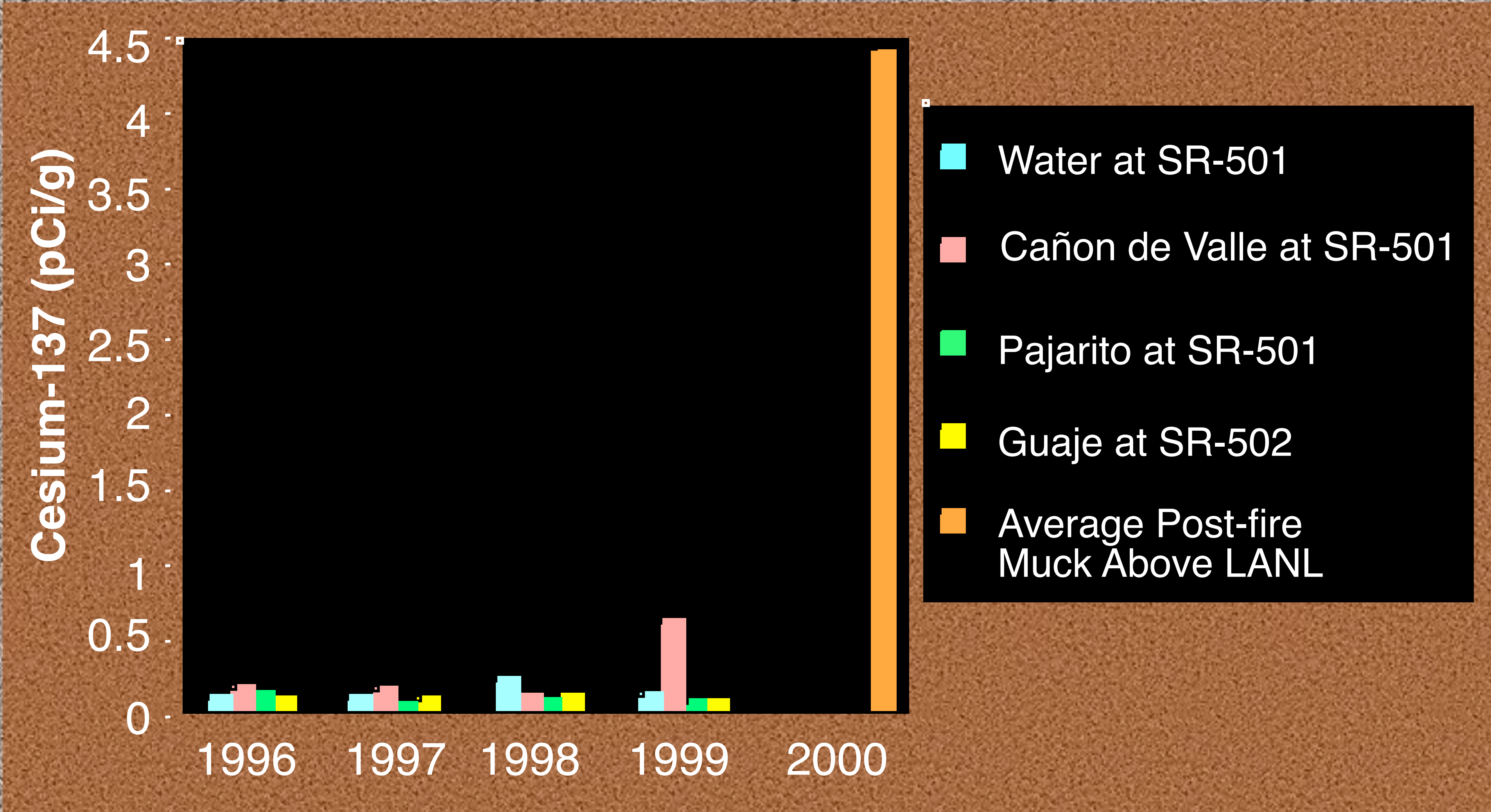
LA-Weir Conceptual Design



Key Trends Seen Through mid-August

- Not detected so far in runoff
  - High explosives, mercury, dioxins and furans, benzo(a)pyrene, hexachlorobenzene, PCBs
- Few organic chemicals
- Metals and minerals elevated
- Radioactivity dissolved in water comparable to pre-fire
- Radioactivity in sediments elevated
- Cyanide detected

Cesium-137 in Stream Sediments Above LANL



Risk Evaluation

- All data will be reviewed by multi-agency Flood Risk Assessment Team
  - NM Environment Dept. NM Dept. of Health, LANL with help from pueblos and other agencies
- NM Environment Dept. DOE Oversight Bureau
  - Has hired outside contractor

Los Alamos National Laboratory Hydrogeology