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Unsaturated Groundwater Flow beneath Upper Mortandad Canyon, Los Alamos, New Mexico

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UNSATURATED GROUNDWATER FLOW BENEATH UPPER MORTANDAD CANYON, LOS ALAMOS, NEW MEXICO

by

David Carl Dander

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STATEMENT BY AUTHOR

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ABSTRACT

Mortandad Canyon is a discharge site for treated industrial effluents containing radionuclides and other chemicals at Los Alamos National Laboratory, New Mexico. This study was conducted to develop an understanding of the unsaturated hydrologic behavior below the canyon floor. The main goal of this study was to evaluate the hypothetical performance of the vadose zone above the water table. Numerical simulations of unsaturated groundwater flow at the site were conducted using the Finite Element Heat and Mass Transfer (FEHM) code. A two-dimensional cross-section along the canyon's axis was used to model flow between an alluvial groundwater system and the regional aquifer approximately 300 m below. Using recharge estimated from a water budget developed in 1967, the simulations showed waters from the perched water table reaching the regional aquifer in 13.8 years, much faster than previously thought. Additionally, simulations indicate that saturation is occurring in the Guaje pumice bed and that the Tshirege Unit 1B is near saturation. Lithologic boundaries between the eight materials play an important role in flow and solute transport within the system. Horizontal flow is shown to occur in three thin zones above capillary barriers; however, vertical flow dominates the system. Other simulations were conducted to examine the effects of changing system parameters such as varying recharge inputs, varying the distribution of recharge, and bypassing fast-path fractured basalt of uncertain extent and properties. System sensitivity was also explored by changing model parameters with respect to size and types of grids and domains, and the presence of dipping stratigraphy.

1. INTRODUCTION

1.1. INTRODUCTION

Los Alamos National Laboratory (LANL) has been in operation since 1942. Many of the research activities of the Laboratory involve the use of hazardous and radioactive materials. For many years, treated and untreated effluents resulting from these activities were released directly into the environment. Today, disposal of Laboratory effluents into the environment is heavily regulated and monitored. The Laboratory is presently required to comply with many federal and state environmental programs geared towards protecting the environment.

Groundwater flow is a likely mechanism for transporting potential contaminants beneath the laboratory. For the most part, 111 km^2 (43 mi^2) of LANL lands can be divided into two environments: mesas and canyons. The greatest likelihood for water and contaminant movement may arise from infiltration beneath canyon bottoms and is the focus area of this study. The nature and extent of unsaturated flow beneath a western portion of the canyon, otherwise known and referred to as Upper Mortandad Canyon, is examined.

Mortandad Canyon, located in north-central New Mexico, is approximately 30 km northwest of Santa Fe between the towns of Los Alamos and White Rock (Figure 1.1). The canyon originates within the boundaries of Los Alamos National Laboratory and

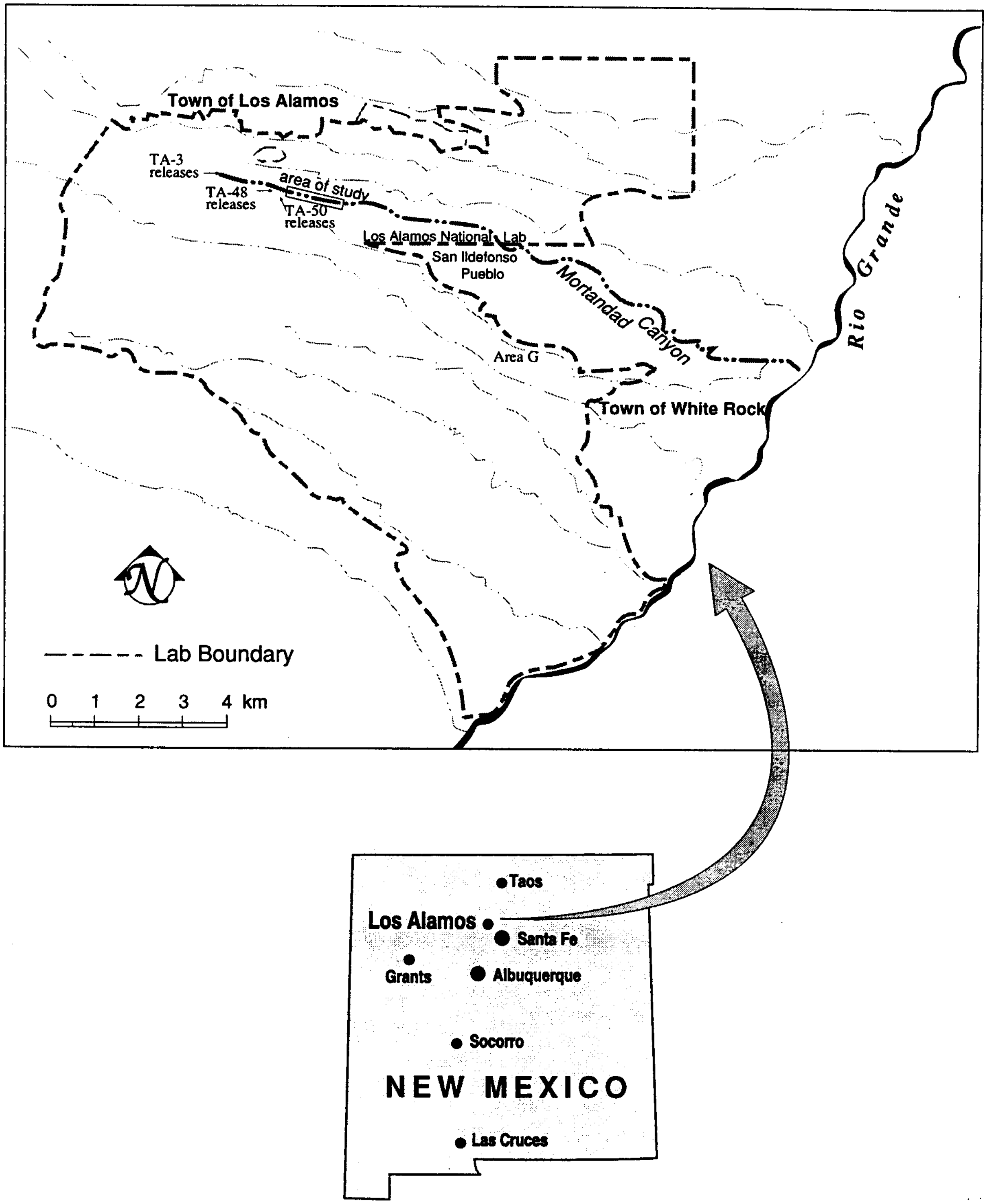

Figure 1.1 Regional location of Los Alamos National Laboratory.

extends about 16 km in an easterly direction to the Rio Grande. The upper 7 km of the canyon is on lands belonging to LANL, and the lower 9 km is on lands belonging to San Ildefonso Pueblo.

The canyon cuts into a sequence of volcanic tuffs underlain by other volcanic and sedimentary rocks on the Pajarito Plateau (Figure 1.2). The Plateau lies on the southeastern slopes of the Valles Caldera. Some aspects of the canyon's geometry and geology influence the hydrologic system within. In general, the hydrologic system consists of an intermittent stream, a shallow alluvial perched groundwater system, a thick unsaturated zone, and a deep regional aquifer. The stream flow is supplied by LANL effluents, snow melt, and storm runoff. Stream flow rarely exists below Upper Mortandad Canyon except during flood events. The shallow alluvial groundwater system extends through Upper Mortandad Canyon and another 2 km down canyon. Water in the regional aquifer flows east, about 300 m below the canyon floor. Most of the intervening rock between these two saturated systems is unsaturated (Stoker et al., 1991, Purtymun, 1995).

There are several potential sources of contamination entering the canyon; however, the source of most interest is the discharge from the Radioactive Waste Liquid Treatment Facility. Beginning in June 1963, treated effluents from this facility have been released into Upper Mortandad Canyon. Aside from ramifications of contaminants entering the system, the additional source of water has altered the natural system.

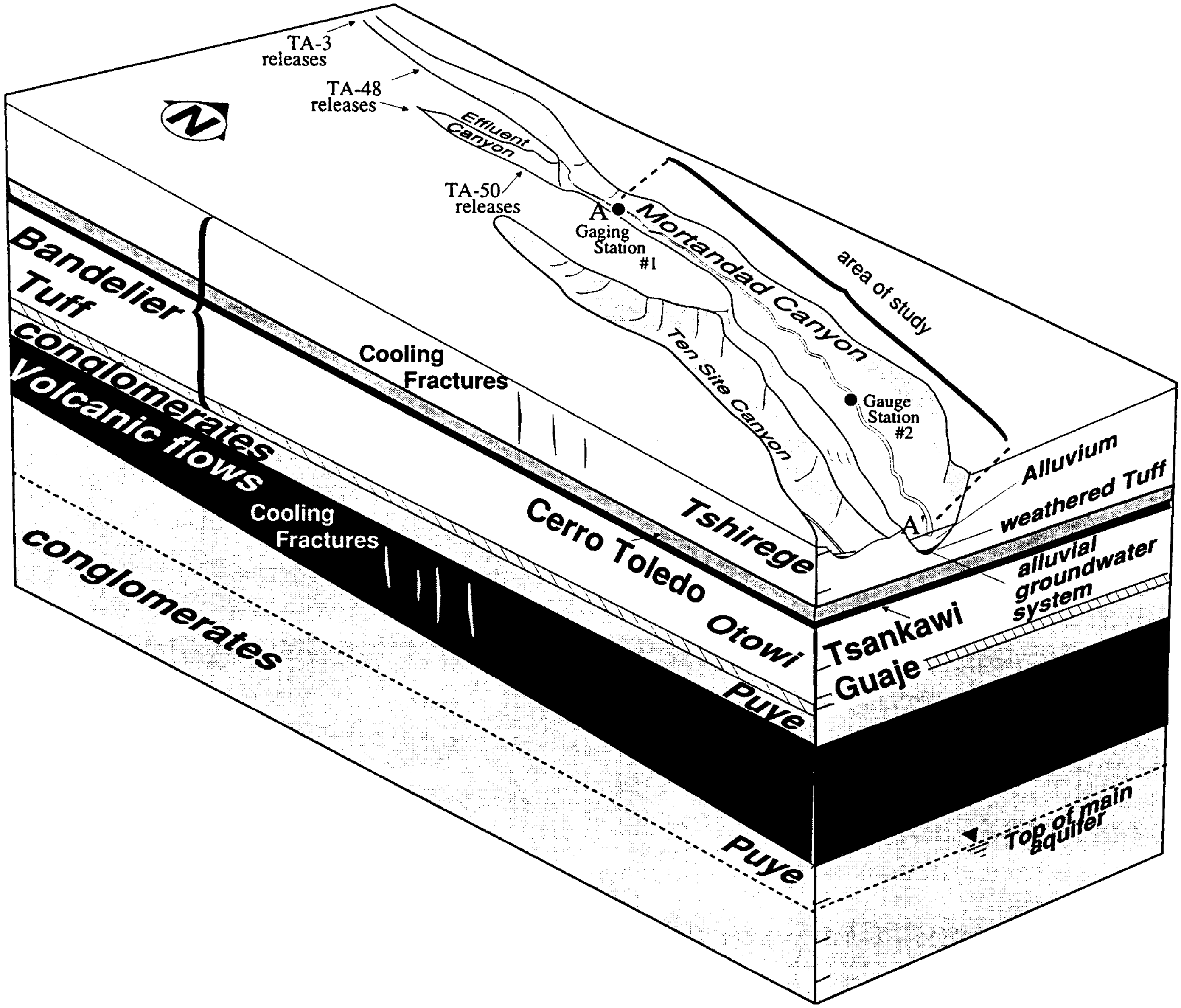

Figure 1.2 Block diagram of Mortandad Canyon.

Shallow groundwater flow within LANL in Mortandad Canyon has been modeled in several studies. However, these models did not include much of the deeper materials below the saturated-unsaturated interface at the base of the alluvium. Two studies that included modeling of saturated-unsaturated contaminant migration in the perched aquifer were conducted by Vollick (1992) and Mostafa (1993). Their models included a no flow lower boundary condition between 2 m to 15 m below the alluvium-tuff interface, thus neglecting leakage (or recharge) to the lower units. A study by Koenig and McLin (1992) used a lumped parameter model to examine the behavior of the perched groundwater system throughout the canyon. Their study examines and incorporates monthly water budget calculations at several locations by Purtymun (1967). They conclude that most (>75%) of the water in the system leaves as seepage into the tuff (Koenig and McLin, 1992). Another study by Stone (1995) included modeling of pre-1960 (before effluents) saturated groundwater flow using a no flow lower boundary at the base of the alluvium. The model was designed to help estimate recharge from surplus water in the domain; however results are preliminary. Preliminary modeling by Geddis (1992) examines flow in the upper unsaturated zone, below the perched groundwater system. Whereas other studies modeled the canyon along its axis, he conducted simulations of a cross-section perpendicular to the canyon about 2 km downstream from the Radioactive Waste Liquid Treatment Facility discharge point. He uses specified head and specified flux for a small part of the upper boundary, and a no flow conditions for the remaining boundaries. His work illustrates the importance of many simulation differences incorporated in this study, major differences include: Code selection, depth modeled, grid orientation, representing dipping stratigraphy, boundary conditions, variable recharge scenarios, and proximity of simulation domain to primary recharge source. These differences are described in the following section.

Unsaturated flow behavior at other sites, similar in geology and hydrology to Mortandad Canyon, has been modeled and is well-documented. Studies and modeling at Yucca Mountain by Montazer and Wilson (1984) and elsewhere at LANL by Birdsell et al. (1997) describe important aspects of geohydrology that influence flow and need to be explored and documented for this site.

> "The presence of certain hydrogeologic features affects flow in the unsaturated zone. These features include the presence of fractured porous media, layered units with contrasting physical properties, dipping units, and a deep water table resulting in a very thick unsaturated zone. The combination of these features provides a hydrogeologic framework that probably results in certain flow phenomena, namely infiltration and flow through fractured rocks, retardation of flow by capillary barriers, lateral flow, and vapor flow." (Montazer and Wilson, 1984)

Understanding these concepts and the unsaturated flow beneath the canyon is important in determining how contaminants may be transported within this and possibly other systems at LANL. This understanding is useful for monitoring and planning purposes related to other LANL programs such as the hydrogeologic workplan.

1.2 Objectives and Scope of Work

The surface water and alluvial groundwater systems in Mortandad and surrounding canyons are fairly well characterized; however, knowledge of this unsaturated system is limited.

The main goal of this study is to evaluate the nature and extent of the unsaturated system beneath Upper Mortandad Canyon. The following questions are addressed:

- What role might recharge play in the distribution and movement of the water?
- At what rate and directions might water be moving within this unsaturated zone?
- How might the water within this unsaturated zone be distributed?

This modeling study uses a numerical model, FEHM (Finite Element Heat and Mass Transfer) by Zyvoloski et al. (1994b), to simulate unsaturated flow. It addresses limitations of other studies at this site, mainly those of Geddis' (1992) work. He used another numerical model, UNSAT2, by Davis and Neuman (1983), to simulate unsaturated flow in the upper unsaturated system (450 ft in depth). His work calls for further study of the system down to the regional aquifer, approximately 1000 ft below, which this study accomplishes. Geddis oriented a two-dimensional grid perpendicular to the canyon axis for simulations and concluded that unsaturated flow perpendicular to the canyon axis under the mesas was minimal. This study orients a two-dimensional grid down the axis of the canyon to incorporate the dip in stratigraphy and assess lateral flow behavior in that direction. An assumption of no dip in the stratigraphy perpendicular to the canyon axis is common in both studies. When setting up the grid in this study the proximity of the Radioactive Waste Liquid Treatment Facility discharge point was taken into consideration as well. Boundary conditions used by Geddis restricted his simulations to time dependent solutions, while the simulations in this study could reach steady state conditions with various recharge scenarios. He modeled a small portion of his upper boundary with both a specified flux and constant head boundary condition; his remaining boundaries were no flow. Although this study uses a specified flux (recharge) along the upper boundary close to that used by Geddis, it also examines recharge at various magnitudes distributed evenly and variably with respect to location. Simulations presented here incorporate the remaining upper boundary with several specified flux conditions; the lower boundary with a specified saturation condition to represent the water table at the regional aquifer; and side boundaries with no flow conditions.

This modeling study addresses these limitations among others, and simulation results are used to specifically:

- Provide estimates of the distribution of pressures, saturations, and liquid flux
- Assess potential pathways taken through the system
- Estimate travel times through the system
- Assess the effects of certain recharge scenarios

2. SITE DESCRIPTION

2.1. LOCATION AND PHYSIOGRAPHY

Los Alamos National Laboratory (LANL) is located in north-central New Mexico, USA, approximately 30 km northwest of Santa Fe between the towns of Los Alamos and White Rock (Figure 1.1).

"The laboratory site is situated on the Pajarito Plateau, which consists of a series of finger-like mesas separated by deep east-to-west oriented canyons cut by intermittent streams. Mesa tops range in elevation from approximately 2,400 m (7,800 ft) on the flanks of the Jamez Mountains to about 1,900 m (6,200-ft) at the eastern termination above the Rio Grande Canyon."

"Most Laboratory and community developments are confined to mesa tops. The surrounding land is largely undeveloped, with large tracks of land north, west, and south of the laboratory site being held by the Santa Fe National Forest, Bureau of Land Management, Bandelier National Monument, and Los Alamos County. The Pueblo of San Ildefonso borders the Laboratory to the east."

"The laboratory is divided into Technical areas (TA's) that are used for building sites, experimental areas, waste disposal locations, roads, and utility right-of-ways. However, these uses account for only a small part of the total land area. Most land provides buffer areas for security and safety and is held in reserve for future use.

"The Department of Energy controls the area within LANL and has the option to completely restrict access. The public is allowed limited access to certain areas of the laboratory." (Environmental Protection Group, 1994)

Mortandad Canyon, the focus of this study, originates within the boundaries of LANL and extends about 16 km in an easterly direction to the Rio Grande Canyon. The first 7 km of the canyon is on lands belonging to LANL, and the final 9 km is on lands belonging to San Ildefonso Pueblo. The elevation change, along the 1829 m (6000 ft) length of channel in the area of study, is approximately 58 m (283 ft), with the elevation of the western end being 2154 m (7066 ft) and the eastern end being 2096 m (6877 ft).

2.2. CLIMATE

The local climate is described as a "temperate mountain climate" with an average annual precipitation of 47.6 cm that varies greatly with elevation. Summers at LANL tend to begin warm and arid and end with typical daily thunder showers during the later part. Average monthly lows range between 51-55°F, and highs between 77-80°F. Autumns are generally calm, arid, and much cooler. Average monthly lows range between 27-47°F, and highs between 48-71°F. Winter temperatures fluctuate greatly, and snow storms are frequent enough to keep a snow base for a couple of months with average monthly lows ranging between 19-21°F, and highs between 39-43°F. Spring temperatures fluctuate greatly as well and are usually windy and dry. Average monthly lows range between 26-42°F, and highs between 49-67°F.

2.3. VEGETATION

Vegetation within Mortandad Canyon varies by elevation. Upper Mortandad Canyon is densely vegetated with shrubs, pine, fur, Box-Elder, Gambel oak, and

Chokecherry providing the dominant overstory, while the understory consists of forbs and grasses mainly of Bluegrass, Clematis, and Bedstraw (Miera et al., 1977).

2.4. Land Use

Beginning in June 1963, liquid radioactive waste from the Laboratory was diverted to a new treatment facility located above Mortandad Canyon at Technical Area (TA)-50. Since that time, treated effluents from that facility have been released into the stream bed of Upper Mortandad Canyon. Other LANL sites, such as TA-3's Sigma building and former TA-48 outfalls, release waters to the canyon as well. However, the quality is better and the quantity is smaller than those from TA-50's Radioactive Waste Liquid Treatment Facility. The choice of Upper Mortandad Canyon for an effluent release site was based on several conditions considered favorable which included the following (Purtymun, 1964):

- No perennial streamflow
- The watershed is fairly small
- The depth to the regional aquifer is approximately 300 m
- The volume of the canyon's alluvial sediment on LANL's land is large
- No surface or groundwater flows down canyon past the LANL boundary
- High evapotranspiration rates
- The centralized LANL location
- The remoteness of the location