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NMED Hazardous Waste Bureau

Mr. James Bearzi,
Chief
Hazardous Waste Bureau
New Mexico Environment Department
2905 Rodeo Park Road East, Bldg. 1
Santa Fe, NM 87505

Dear Mr. Bearzi:

On behalf of the Department of Energy (DOE) and Sandia Corporation, DOE is submitting the Burn Site Groundwater Current Conceptual Model. This submittal is required under the Compliance Order on Consent (Consent Order) for Sandia National Laboratories, New Mexico, EPA ID No. 5890110518.

The Current Conceptual Model satisfies the requirements of Section IV.C of the Consent Order, which states that site characterization efforts at the Sandia National Laboratories/New Mexico (SNL/NM) Burn Site must be completed to the satisfaction of NMED prior to conducting a Corrective Measures Evaluation (CME). The objective of the Current Conceptual Model is to provide a basis for NMED to determine the adequacy of site characterization performed at the Burn Site Groundwater study area so that SNL/NM can proceed with a CME. Evaluation of remedial alternatives for contaminants of concern in groundwater at the Burn Site Groundwater study area relies on this current conceptual model of groundwater flow and contaminant transport.

If you have any questions regarding this submission, please contact me at (505) 845-6036, or Dan Pellegrino of my staff, at (505) 845-5398.

Sincerely,

Patty Wagner

Patty Wagner
Manager

Enclosure

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CERTIFICATION STATEMENT FOR APPROVAL AND FINAL RELEASE OF DOCUMENTS

Document title: **Burn Site Groundwater Current Conceptual Model**

Document authors: **Mike Skelly, Department 06765**

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision according to a system designed to ensure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine or imprisonment for knowing violations.

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Sandia National Laboratories/New Mexico

Current Conceptual Model of Groundwater Flow and Contaminant Transport at Sandia National Laboratories/ New Mexico Burn Site

March 2008

United States Department of Energy
Albuquerque Operations Office

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SNL 1179

Current Conceptual Model of Groundwater Flow and Contaminant Transport at Sandia National Laboratories/New Mexico Burn Site

Sandia National Laboratories
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Abstract

This document presents the current conceptual model of groundwater flow and transport at the Sandia National Laboratories/New Mexico (SNL/NM) Burn Site; it will provide the basis for a technically defensible remediation program. Information presented in this conceptual model will support a Corrective Measures Evaluation for remediation of the contaminant of concern (COC) in groundwater at the SNL/NM Burn Site. The New Mexico Environment Department (NMED) requires the CME as a deliverable specified by the Compliance Order on Consent (the Order). Nitrate has been detected in groundwater above the Environmental Protection Agency maximum contaminant level and is the only COC in Burn Site Groundwater.

The Order identified nine areas of characterization requirements. These characterization requirements consist of those geohydrologic characteristics that control the subsurface distribution and transport of contaminants. This conceptual model summarizes regional geohydrologic conditions that provide the setting for the SNL/NM Burn Site. The document also presents a summary of site-specific geohydrologic data and integrates these data into the current conceptual model of flow and contaminant transport. This summary includes characterization of the local geologic framework; characterization of hydrologic conditions at the Burn Site, including recharge and hydraulics of groundwater flow as it pertains to downgradient receptors; and characterization of contaminant transport in groundwater, including discussion about contaminant sources and distribution and transport in Burn Site Groundwater.

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Acronyms and Abbreviations

amsl	above mean sea level
bgs	below ground surface
BSG	Burn Site Groundwater
CME	Corrective Measures Evaluation
COC	contaminant of concern
DOE	U.S. Department of Energy
DRO	diesel range organic
EPA	Environmental Protection Agency
ft	foot or feet
GRO	gasoline range organic
HE	high explosives
HI	Hazard Index
HQ	Hazard Quotient
IMWP	Interim Measures Work Plan
in.	inch or inches
JP-4	jet fuel composition 4
JP-8	jet fuel composition 8
KAFB	Kirtland Air Force Base
LAARC	Light Air Transport Accident Resistant Container
m^2	meters, squared
MCL	maximum contaminant level
MDL	method diction limit
mg/L	milligrams per liter
NMED	New Mexico Environment Department
NPN	nitrate plus nitrite
Order, the	Compliance Order on Consent
Sandia	Sandia Corporation
SNL/NM	Sandia National Laboratories/New Mexico
SVOC	semi volatile organic compound
SWMU	Solid Waste Management Unit
USGS	United States Geological Survey
VOC	volatile organic compound
μg/L	micrograms per liter

1.0 INTRODUCTION

Sandia National Laboratories/New Mexico (SNL/NM) is located on Kirtland Air Force Base (KAFB), south of Albuquerque, New Mexico (Figure 1-1). SNL/NM manages the Coyote Canyon Test Area, which consists of three large canyons in the Manzanita Mountains (Madera Canyon from the north, Sol se Mete Canyon from the south, and Lurance Canyon from the east). These canyons are the headwaters of the Arroyo del Coyote. The Lurance Canyon Burn Facility, located within Lurance Canyon, is a test site in the Coyote Canyon Test Area (Figure 1-1) that has operated since 1967.

Section IV.C of the Compliance Order on Consent (The Order) between the New Mexico Environment Department (NMED), U.S. Department of Energy (DOE) for SNL/NM, and Sandia Corporation (Sandia) for SNL/NM (NMED April 2004) identified the Burn site as an area with groundwater contamination as follows:

> *In 1996, sampling results from the Burn Site Well, a non-potable water supply well, showed elevated nitrate levels at 26 mg/L (maximum contaminant level (MCL) is 10 mg/L [as nitrogen]). The Department required monitoring wells at the Burn Site; these wells have yielded groundwater samples with levels of nitrate greater than 10 mg/L. Fuel constituents below state and Environmental Protection Agency (EPA) standards have also been detected in some wells. The contamination is found in canyon alluvium and fractured bedrock aquifers that may connect to the regional aquifer in the Albuquerque Basin to the west.*

Also in Section IV.C of the Order, NMED requires a Corrective Measures Evaluation (CME) of groundwater contamination at the Burn Site. Evaluation of remedial alternatives for contaminants of concern (COCs) in Burn Site Groundwater (BSG) requires a current conceptual model of groundwater flow and contaminant transport. Therefore, a conceptual model was submitted to NMED in June 2004 (SNL/NM June 2004). Subsequent to this submittal the NMED requested additional site characterization as summarized in Section 1.1 (NMED February 2005).

Data collected as part of additional characterization are incorporated in this updated version of the conceptual model. This conceptual model will provide the basis for a technically-defensible remediation program that will be developed and documented in the CME Work Plan and CME Report. An unpublished draft of the report "*Current Conceptual Model of Groundwater Flow and Contaminant Transport at Sandia National Laboratories/New Mexico Burn Site*" was prepared by North Wind, Inc. in September, 2006 (Orr, Hall, and Witt September 2006). That draft conceptual model report formed the basis for this report. The main contribution of this edition of the report is the inclusion of recent groundwater monitoring data through the December 2007 sampling event.

1.1 Background

The Burn Site has been used since 1967 to test the effects of impact, burning, and explosion. Historical operations included open detonation of high explosives (HE). Most HE testing occurred between 1967 and 1975, and was completely phased out by the 1980s. Burn testing began in the early 1970s and has continued to the present. Early burn testing was conducted in unlined pits excavated in native soil. By 1975, portable burn pans were used for open burning using jet fuel composition 4 (JP-4). The Light Air Transport Accident Resistant Container (LAARC) Unit was constructed in 1980 and other engineered burn units were constructed by 1983. These burn units used jet fuel, gasoline, and diesel as fuels for burn tests.

Groundwater samples taken during 1996 from the Burn Site well contained elevated concentrations of nitrate. Although the Order states that sampling results from the Burn Site well showed elevated nitrate levels at 26 milligrams per liter (mg/L), the nitrate concentration from the Burn Site Well in 1996 was reported in Skelly (January 2005) to be 25 mg/L. The measured nitrate concentration was 24.3 mg/L in November 1996. In 1997, the NMED, DOE, and Sandia agreed to investigate the source of this contamination. Later in 1997, monitoring well CYN-MW1D was installed downgradient of the Burn Site well. Samples from this well contained nitrate concentrations above the maximum contaminant level (MCL). Three more wells, CYN-MW3, CYN-MW4, and CYN-MW5, were installed during 1999-2001 to continue the investigation.

The Order specified the Burn Site as an area of groundwater contamination (NMED April 2004). In response to the Order, DOE/Sandia submitted the "Current Conceptual Model of Groundwater Flow and Contaminant Transport at Sandia National Laboratories Burn Site" and the "Corrective Measures Evaluation Work Plan Burn Site Groundwater" to the NMED in June 2004 (SNL/NM June 2004). On March 1, 2005, the DOE/Sandia received a letter from NMED (NMED February 2005) with the following requirements/statements:

- DOE/Sandia must prepare and submit an Interim Measures Work Plan (IMWP) within 90 days from the receipt of the letter (by May 30, 2005).
- NMED requires additional characterization of the nitrate-contaminated groundwater near the Burn Site. Specifically, the downgradient extent of groundwater with nitrate concentrations greater than 10 mg/L shall be determined.
- NMED does not accept the CME Work Plan because they are not satisfied with the existing characterization of nitrate-contaminated groundwater near the Burn Site.

- NMED also requires the installation of one additional monitoring well "*adjacent to Solid Waste Management Unit (SWMU)-94F in order to establish groundwater conditions in this petroleum-contamination source area.*"

In response, DOE/Sandia submitted the Burn Site IMWP (SNL/NM May 2005) on May 30, 2005. DOE/Sandia received a Request for Supplemental Information from the NMED (NMED July 2005), and responded to the request with proposed changes to the IMWP in August 2005 (SNL/NM August 2005). DOE/Sandia never received approval from NMED on the proposed changes to the IMWP. However, the proposed modifications to the Burn Site IMWP were implemented consistent with the regulatory direction to further characterize the groundwater near the Burn Site. This plan also included implementation of institutional controls.

As detailed in the May 2005 IMWP, three new monitoring wells (CYN-MW6, CYN-MW7, and CYN-MW8) were installed near the Burn Site from December 2005 to January 2006 at locations shown on Figure 1-2. Quarterly sampling for eight quarters began for the three new monitoring wells in March 2006 and was completed in December 2007. Samples from the newly installed wells downgradient of CYN-MW1D (CYN-MW7, and CYN-MW8) were sampled and analyzed for nitrate. Samples from the newly installed well adjacent to SWMU-94F (CYN-MW6) were analyzed for gasoline and diesel range organics, nitrate, and other parameters. Groundwater-monitoring programs continued as outlined in the IMWP (SNL/NM May 2005).

1.2 Objectives

According to Section IV.C of the Order (NMED April 2004), site characterization efforts at SNL/NM Burn Site must be completed to the satisfaction of the NMED prior to conducting a CME. The objective of this report is to provide the basis for a remediation program. This current conceptual model of groundwater flow and contaminant transport is based on data from all investigations to date, as summarized in Appendix A of this report.

This document summarizes geohydrologic data collected at the Burn Site and presents a current conceptual model of contaminant release and subsequent subsurface transport that characterizes contaminant source terms, the geohydrologic framework, and the distribution of contaminants in the subsurface at the Burn Site. The conceptual model includes a compilation of all data, observations, and discussions with technical experts concerning Burn Site Groundwater to date.

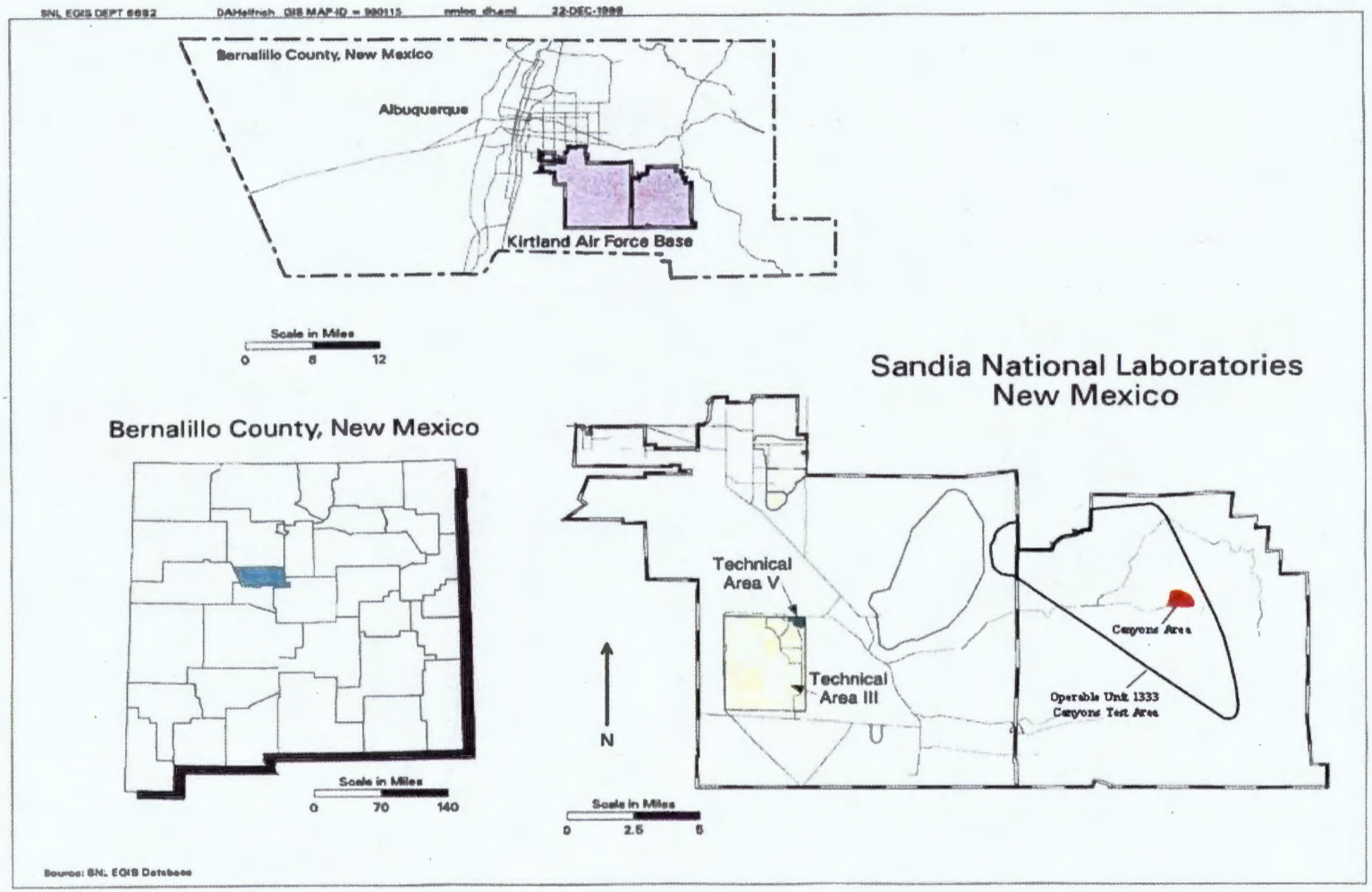


Figure 1-1. Location of the Burn Site, other SNL/NM facilities, and KAFB.

1.3 Organization

This document, presenting the current conceptual model of groundwater flow and contaminant transport at the Burn Site, is organized into the following sections:

- Section 1—provides the introduction, background, objectives, and organization of this report.
- Section 2—summarizes regional geohydrologic conditions.
- Section 3—presents a summary of geohydrologic data and integrates these data into the current conceptual model of groundwater flow and contaminant transport for the Burn Site. The conceptual model discussion includes:
  - Characterization of the local geologic framework, including structural and stratigraphic features that are important to flow and transport.
  - Characterization of hydrologic conditions at the Burn Site, including groundwater recharge and hydraulics of groundwater flow as it pertains to downgradient receptors.
  - Characterization of contaminant transport in the subsurface, including discussions of contaminant sources and contaminant distribution and transport in groundwater.
- Section 4—summarizes key elements of the conceptual model of contaminant release and transport in the Burn Site.

Nine requirements were identified in the Order that needed to be met to satisfactorily characterize contaminant transport in the subsurface (NMED April 2004). Those nine requirements and their correlation to specific sections of this document are presented in Table 1-1.

Table 1-1. Characterization requirements established in the Order (NMED April 2004) and correlation of these requirements to sections within the Site Conceptual Model document.

Characterization Requirements	Site Conceptual Model Sections
1. Nature, rate of transport, and extent of contamination	3.3 Distribution of Contaminants in the Subsurface at the Burn Site
2. Regional and perched aquifer boundaries	2.2 Regional Hydrologic Conditions
3. Depth to water, water levels, water table, potentiometric surface, and any seasonal variations	3.2 Hydrologic Conditions at the Burn Site
4. Flow directions and velocities	3.2.2 Groundwater Flow at the Burn Site
5. Geologic, hydrostratigraphic, and structural relationships	3.1 Geologic Features of the Burn Site
6. Water supply well pumping influences, seasonal pumping rates, and annual amounts of water withdrawn	3.2.2 Groundwater Flow at the Burn Site
7. Saturated hydraulic conductivity, porosity, effective porosity, permeability, transmissivity, particle size, storage coefficients, and estimated fracture/secondary porosity	3.2 Hydrologic Conditions at the Burn Site
8. Contaminant concentrations in soil, rock, sediment, vapor, and water (as appropriate)	3.3 Distribution of Contaminants in the Subsurface at the Burn Site
9. General water chemistry	3.3.3 General Chemistry of Burn Site Groundwater

Figure 1-2. Location of wells, piezometers, and springs at and near the Burn Site

2.0 REGIONAL GEOHYDROLOGIC CONDITIONS

The Burn Site is located in Lurance Canyon, within the Manzanita Mountains east of the Albuquerque Basin of the Rio Grande Rift in north-central New Mexico. The geologic and hydrologic conditions of the Manzanita Mountains form the regional context of local groundwater flow and contaminant migration at the Burn Site.

2.1 Regional Geologic Conditions

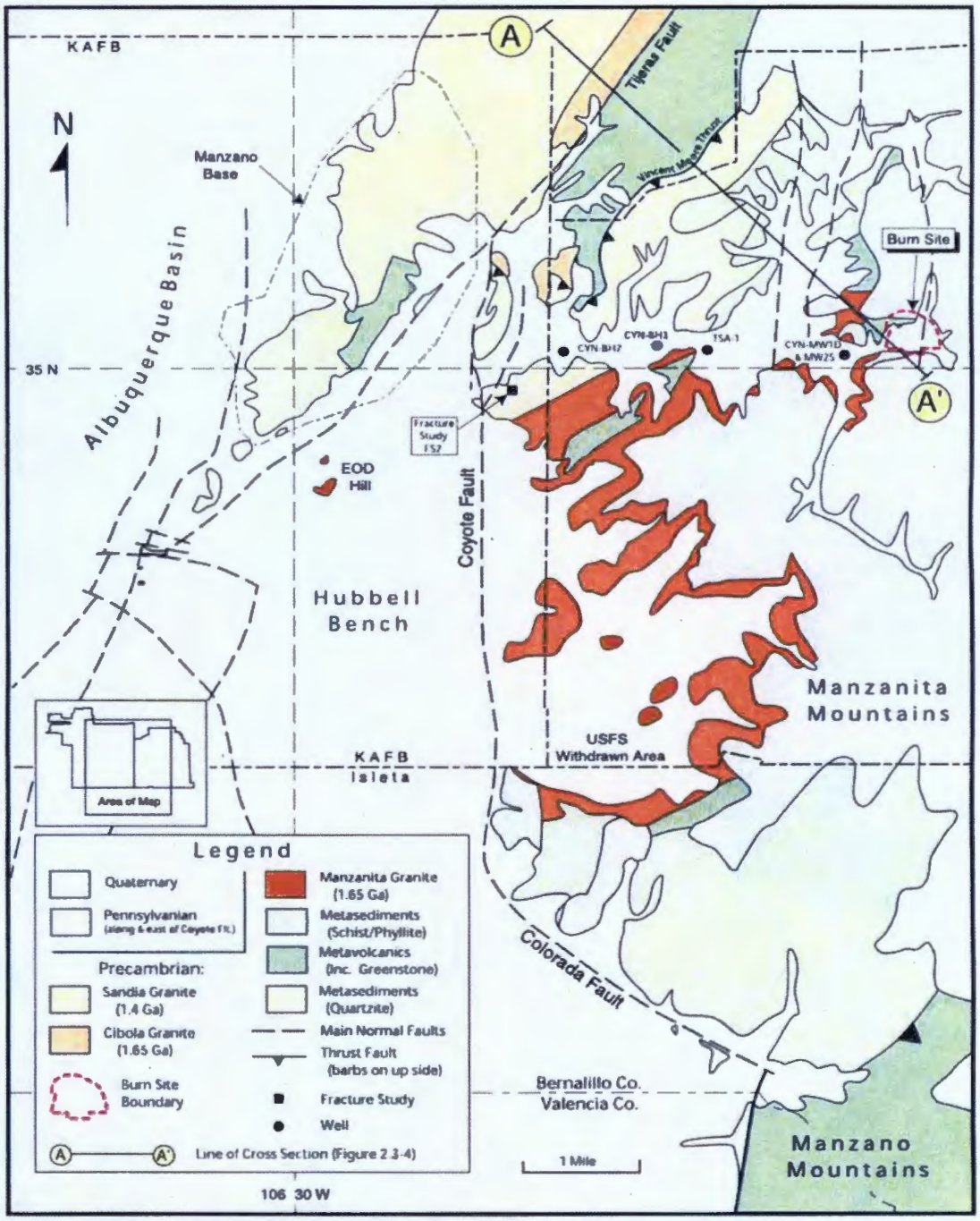
The Manzanita Mountains include a complex sequence of uplifted Precambrian metamorphic and granitic rocks (Figure 2-1) that were subjected to significant deformation throughout geologic history. These rocks are capped by Paleozoic sandstones, shales, and limestones of the Sandia Formation and Madera Group. The following discussion of the geologic history of the Manzanita Mountains is derived from the description presented in the "Groundwater Investigation Canyons Test Area, Operable Unit 1333 Burn Site, Lurance Canyon" (SNL/NM November 2001) and utilizes the model presented by Brown et al. (1999).

A sequence of sedimentary and volcanic rocks was deposited approximately 1.7 billion years ago in the region around what is now north-central New Mexico. These rocks subsequently were deformed through northwest compression and overthrust. This compression was followed by continued deformation and regional metamorphism.

The Manzanita Pluton was intruded 1.65 billion years ago. This magmatic intrusion was accompanied by continuing deformation. Approximately 1.4 billion years ago, a renewal of the northwest thrust resulted in activation of shear zones and emplacement of the Sandia granitic pluton to the north. Deformation from compression and intrusion fractured the metamorphic rocks and developed sets of north-trending normal faults subsidiary to thrust and shear zones. Subsequent uplift and erosion over the next billion years resulted in a beveled surface of low elevation.

Approximately 300 million years ago, regional subsidence resulted in transgression of Pennsylvanian seas and deposition of a sedimentary sequence of sandstones, shales, and limestones. The region was uplifted approximately 40 million years ago during the northeast-directed Laramide compressive event.

Approximately 26 million years ago, east-west continental tensional forces initiated opening of the Rio Grande Rift across New Mexico. The rift was delineated by a series of basins, including the Albuquerque Basin. Continued basinal development was accompanied by deposition of a thick sequence of unconsolidated alluvial deposits. Continental tensional forces also lowered the erosional base for flanking uplands, permitting cliff retreat to the east across the Hubbell Bench resulting in the present-day architecture of the Manzanita Mountains.



From SNL/NM November 2001; modified from Karlstrom et al. (1994), and Myers and McKay (1970).

Figure 2-1. Geology of the Canyons Test Area

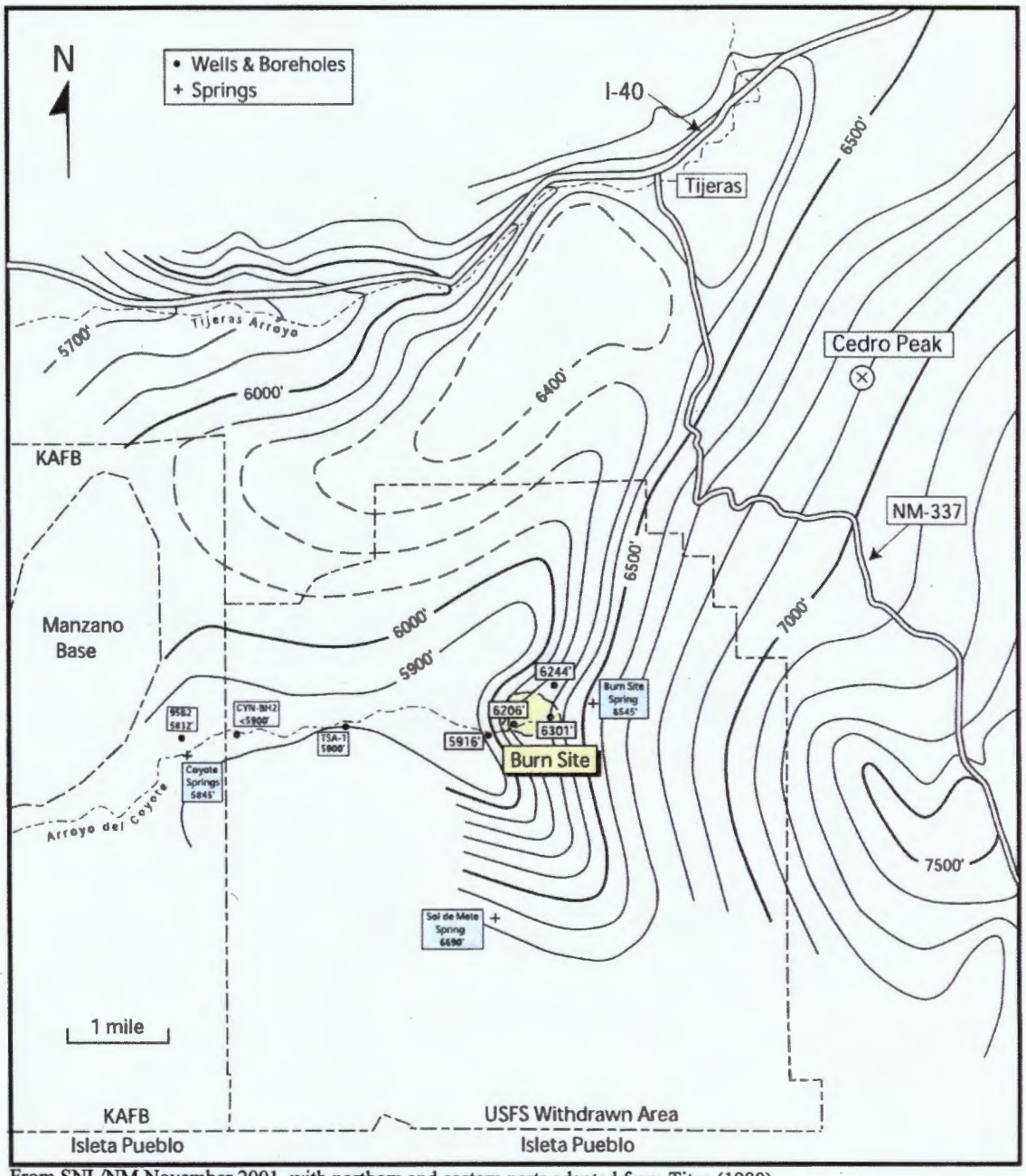
2.2 Regional Hydrologic Conditions

Groundwater in the western Manzanita Mountains largely occurs in the fractured Precambrian metamorphic and intrusive rocks and in the Pennsylvanian sedimentary rocks. Precambrian rocks include metavolcanics, quartzite, metasediments, and the Manzanita Granite. Pennsylvanian sedimentary rocks consist of the Sandia Formation and Madera Group. Groundwater in these rocks moves primarily as flow through fractures. The permeability of these fractured rocks characteristically is low and well yields are small.

The fractured rocks of the Manzanita Mountains are recharged by infiltration of precipitation, largely occurring in summer thundershowers and, to a lesser degree, from limited winter snowfall on the higher elevations. Recharge is restricted by high evapotranspiration rates (losses to the atmosphere by evaporation and plant transpiration) and low permeability of the metamorphic rocks.

Groundwater in the western Manzanita Mountains moves generally to the west (Figure 2-2) from a groundwater flow divide located east of the Burn Site (SNL/NM November 2001). On the eastern side of that divide, water likely moves to the east. Westward groundwater flow across the Lurance Canyon Test Facility discharges primarily as direct underflow to the unconsolidated basin-fill deposits of the Albuquerque Basin. Based on field observations, some discharge occurs at springs along the mountain front. Much of the flow that discharges from these springs probably is lost to the atmosphere through evapotranspiration. Some flow from the springs probably infiltrates alluvial deposits.

The regional potentiometric surface map (Figure 2-2) indicates that the generally westward flow direction locally may be modified by topographic features. Deeply incised canyons may provide local points of discharge through fault zones where the potentiometric surface intersects the canyon floor.



From SNL/NM November 2001, with northern and eastern parts adapted from Titus (1980).

Figure 2-2. Generalized potentiometric surface for the Burn Site and surrounding area.

3.0 CURRENT CONCEPTUAL MODEL FOR THE BURN SITE

Groundwater flow and contaminant transport at the SNL/NM Burn Site are controlled by the local geologic features and hydrologic conditions. The current understanding of these features and conditions, including discussion of contaminant distribution and transport, is presented in the following sections.

3.1 Geologic Features of the Burn Site

The Burn Site is within Lurance Canyon, located in the Manzanita Mountains east of the Albuquerque Basin. The terrain is characterized by large topographic relief (exceeding 500 feet [ft]). Lurance Canyon, deeply incised into Paleozoic and Precambrian rocks, provides local westward drainage of surface flows to Arroyo del Coyote. Groundwater flow at the Burn Site is controlled by the local geologic framework and structural features.

3.1.1 Consolidated Bedrock

The Burn Site is underlain by a structurally complex sequence of Precambrian metamorphic and Paleozoic sedimentary rocks (Figures 3-1 and 3-2). Surface exposures to the east consist of limestones and clastic rocks of the Sandia Formation and Madera Group. Exposures at the Burn Site consist of Precambrian metasediments and mafic metavolcanics. Exposures to the west consist of granites of the Manzanita intrusion.

The Precambrian metamorphic rocks typically are fractured as a result of the long and complex history of regional deformation. Core data and exposures indicate that fractures are filled with chemical precipitates in the upper portions of these rocks. These fracture fillings likely occurred when the water table was elevated prior to the development of the Rio Grande. As chemical precipitates filled fractures, permeability was effectively reduced, creating a semi-confining unit above underlying rocks with open fractures.

3.1.2 Alluvial-Fill Deposits

The canyon floor at the Burn Site consists of unconsolidated alluvial fill deposits over bedrock. These deposits typically are sand and gravel derived from erosion of the upstream drainage basin. These alluvial deposits range in thickness from 21 to 55 ft in borings conducted at the Burn Site.

3.1.3 Structural Features

The Burn Site is cut by a north-trending system of faults, consisting locally of several high-angle normal fault zones that are downfaulted to the east. Faults

(where exposed) are characterized by zones of crushing and brecciation. The Burn Site fault extends north in the vicinity of the Burn Site well and well CYN-MW4. The estimated displacement of this fault locally is as much as 160 ft based on exposed contacts.

Excavation of an unlined wastewater disposal pit at the LAARC Unit revealed a zone of brecciated rock that may be a fault zone or a splay of the Burn Site fault. A sequence of north-trending normal faults has been mapped to the west of the Burn Site (Figure 3-1). These faults generally are downfaulted to the east. Other faults may exist in the area but, if so, are covered with alluvium. The occurrence of limestone near the top of the recently drilled CYN-MW7 borehole (Figure 3-2) may be attributed to a fault bringing Paleozoic rocks into fault contact with underlying Precambrian granitic rocks.

Figure 3-2 illustrates the subsurface geology of the Burn Site based on borehole lithology (SNL/NM November 2001). As illustrated, the geology of this system is heterogeneous and wells at the Burn Site are completed in several different geologic formations (Orr, Hall, and Witt, September 2006).

3.2 Hydrologic Conditions at the Burn Site

Hydrologic conditions at the Burn Site are controlled by the amount of water available for recharge and the capability of the rocks to store and transmit water. Subsequent sections describe aquifer recharge and flow within the fractured rocks beneath the Burn Site.

3.2.1 Recharge

Water available for recharge of groundwater flow systems in the Manzanita Mountains is derived from precipitation. Recharge may occur when precipitation falls directly on surface exposures of brecciated fault zones. Recharge also may occur when stormwater runoff infiltrates canyon-floor sediments and moves across fault zones that subcrop beneath the sediments.

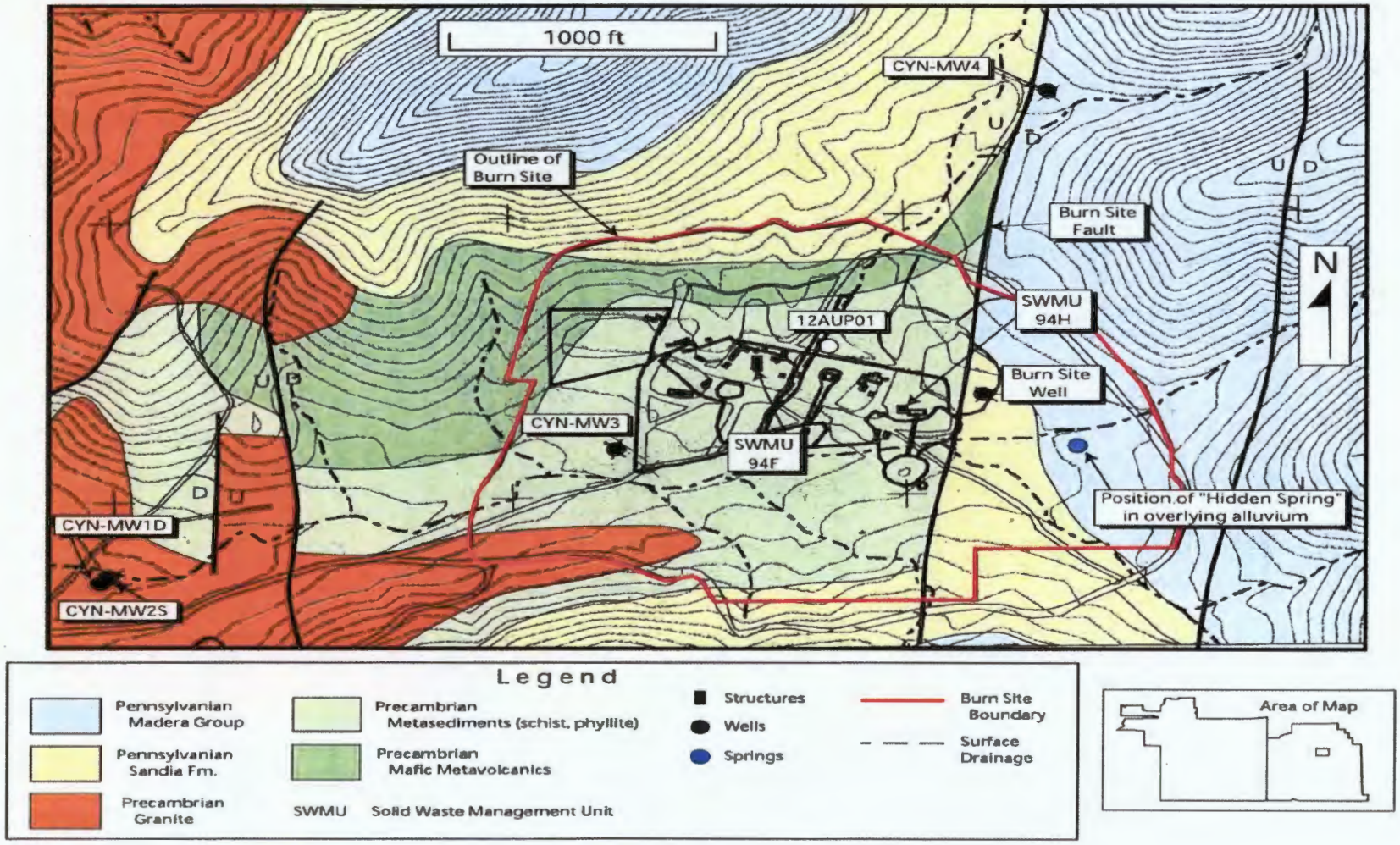
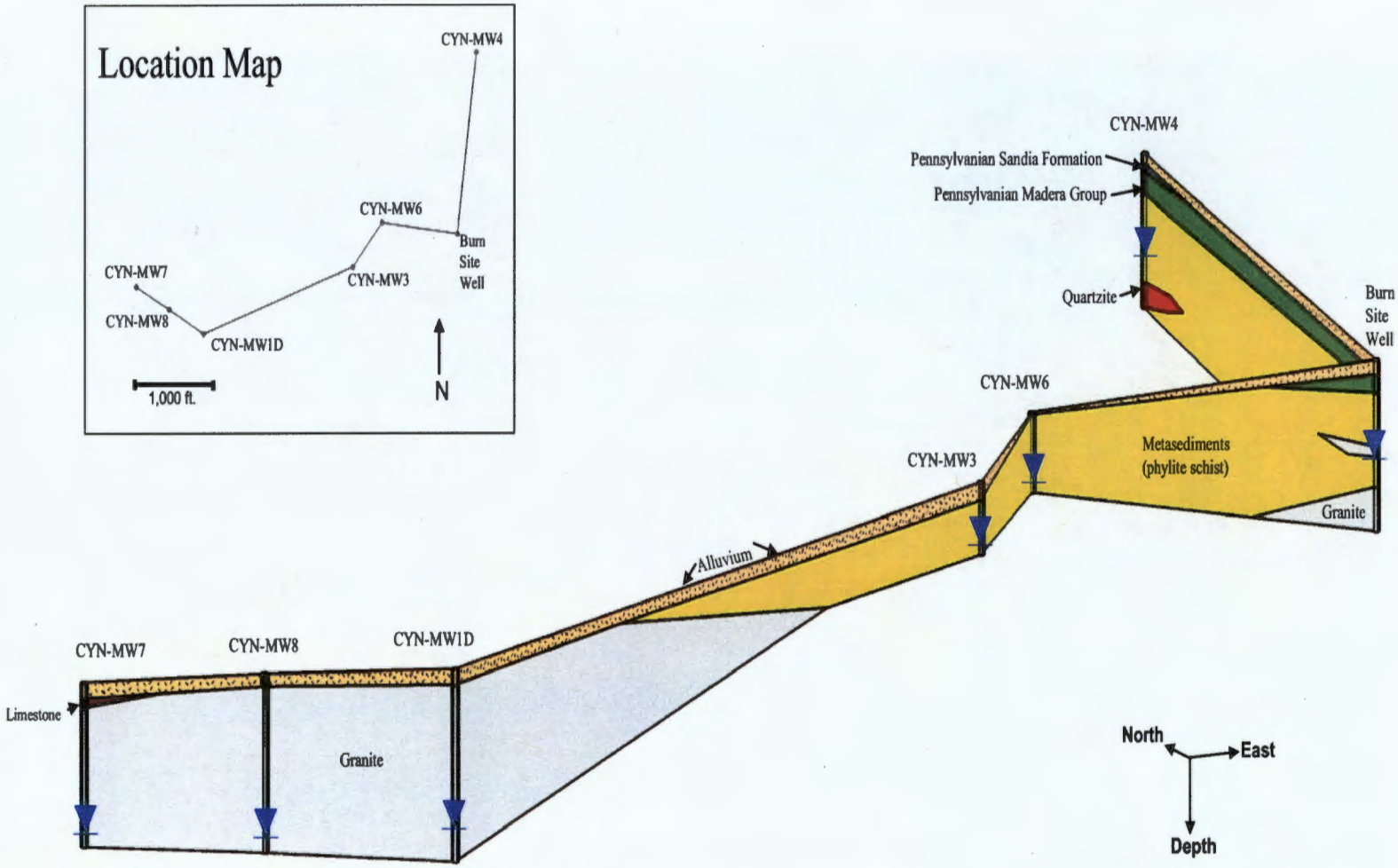


Figure 3-1. Bedrock geology of the Burn Site.



From Orr, Hall, and Witt, J.L. September 2006

Figure 3-2. Generalized geologic fence diagram of the Burn Site (Stratigraphic contacts from SNL/NM November 2001).

3.2.1.1 Direct Infiltration of Precipitation

Annual precipitation in the Manzanita Mountains is in the form of rainfall and minor snowfall. July and August are typically the wettest months; 45 to 62% of annual precipitation falls in summer thunderstorms from July-October (National Weather Service, 2002). Because thunderstorms typically are localized and short-lived, precipitation is extremely variable from year to year and from place to place. Annual precipitation varies with elevation in the region surrounding the Burn Site. Average annual precipitation ranges from 8.7 in. at the Albuquerque Airport (elevation 5,310 ft above mean sea level [amsl]) to 23.0 in. at Sandia Crest (elevation 10,680 ft). The ground-surface elevation of the Lurance Canyon drainage basin varies from 6,200 to 7,600 ft amsl. The average annual precipitation in this drainage basin is estimated to range between 12 and 16 in. depending on elevation and assuming a linear correlation between elevation and precipitation (Figure 3-3).

Precipitation data are collected from a meteorological station (Arroyo del Coyote) located approximately three miles west of the Burn Site. Annual precipitation at this station ranged from 7.63 in. (2003) to 19.25 in. (1997); the average for the 11-year period of record (1995 through 2005) was 10.96 in. Monthly precipitation was typically highest during the summer. The largest monthly precipitation (5.14 in.) occurred in July 1997 (Figure 3-4).

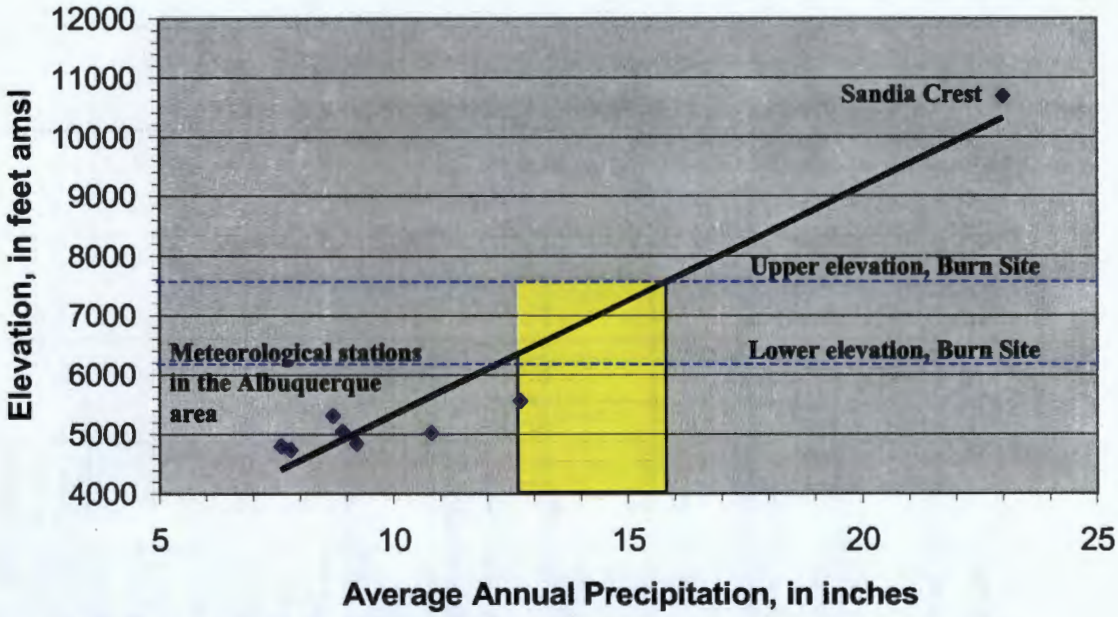


Figure 3-3. Precipitation variations with elevation in the Albuquerque area.

Annual potential evapotranspiration in the Albuquerque area greatly exceeds annual precipitation. Because much of the rainfall in the Lurance Canyon drainage occurs during the hot summer months, losses to evapotranspiration are

high. A small percentage may infiltrate into the exposed bedrock or into alluvial deposits in the canyon.

The north-trending brecciated fault zones crossing the Burn Site and the Lurance Canyon drainage are considered to provide a permeable conduit between the land surface and the fractured water-bearing rocks at depth. These fault zones encompass a very small percentage of the drainage basin. Consequently, the amount of precipitation that falls directly on these fault zones is insignificant.

3.2.1.2 Infiltration from Streamflow

Streamflow occurs episodically in the Arroyo del Coyote channel in response to precipitation in the drainage basin. A United States Geological Survey (USGS) stream gaging station was operated during 1990-95 on Arroyo del Coyote approximately seven miles downstream from the Burn Site (http://waterdata.usgs.gov/nwis/inventory?search_site_no=08330565) (USGS 2008). This station monitored streamflow from a drainage area of about 35 square miles (mi^2), including the 2.8 mi^2 drainage area above the Burn Site. A total discharge of 137 acre-ft of water occurred during July-September 1991, and 12 acre-ft of water occurred during May-September 1994. With the exception of several other short flows, the remainder of the period of record was characterized by no flow. No discharge records are available for Arroyo del Coyote after 1995.

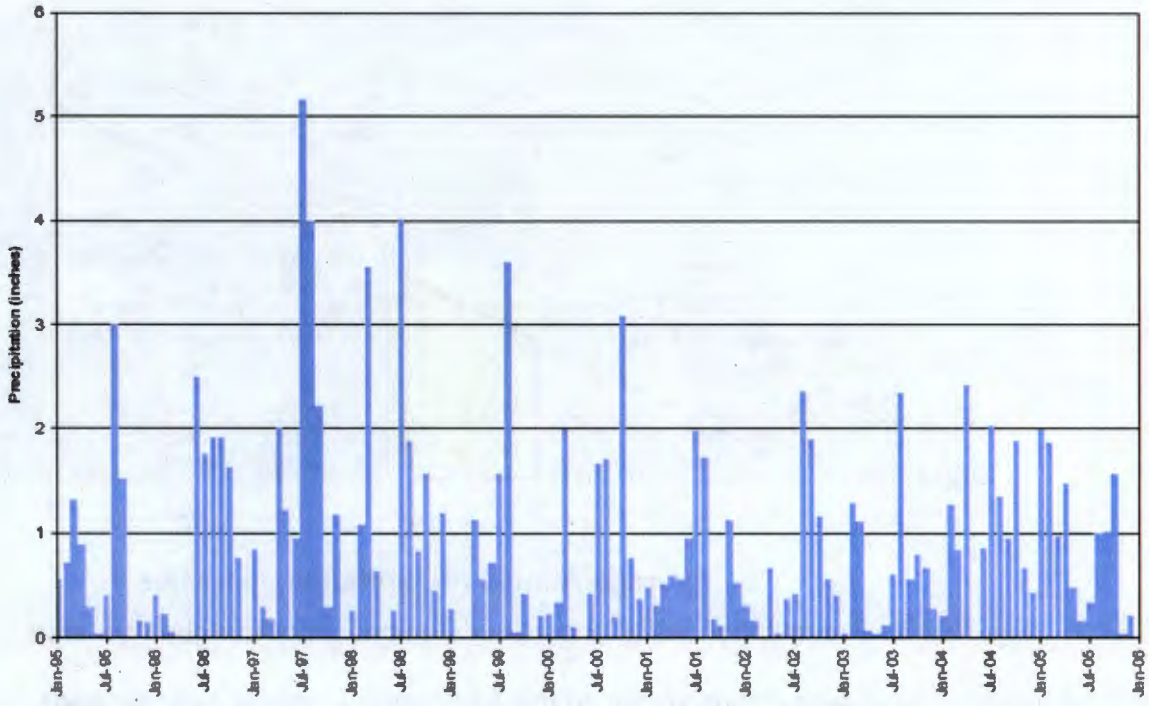


Figure 3-4. Monthly precipitation totals for the Meteorological Monitoring Station SC1 (Arroyo del Coyote)

Based on the 6-year period of streamflow record on Arroyo del Coyote and on the distribution of rainfall at Meteorological Monitoring Station SC1 located in Arroyo del Coyote during 1995-2005 (Figure 3-4), runoff at the Burn Site is sporadic and is associated with summer thundershowers. Periodic recharge to the alluvial sediments in Lurance Canyon is dependent on precipitation patterns in the 2.8 mi^2 drainage upstream from the Burn Site.

Two piezometers (Figure 1-2) were constructed in Lurance Canyon to monitor moisture within the channel deposits at the contact with underlying Precambrian bedrock. Piezometer 12AUP-01 is located approximately 750 ft west-northwest of the Burn Site production well and was installed in November 1996. It penetrates 55 ft of alluvium and 2.5 ft of the underlying Precambrian metamorphosed sedimentary rocks. The lower 5 ft of piezometer is screened. The second piezometer, CYN-MW2S, is located approximately 23 ft west-southwest of the CYN-MW1D well and was drilled into bedrock in December of 1997. It penetrates 27.6 ft of alluvium and 7.4 ft of Precambrian granite. This piezometer is screened from 23.6 to 28.6 ft across the contact between the alluvium and underlying Precambrian rocks.

No water was detected in either piezometer until September 2, 2004. After a series of rain events, between 1 and 2 inches of water was measured in 12AUP-01. The water level remained fairly constant through September 2004. However, more recent water level measurements show no measurable water in 12AUP-01. It is likely that moisture is present in the vadose zone only after a series of significant rain events. Episodic accumulation of precipitation, as evidenced by the occurrence of water in the piezometer, may provide a mechanism for recharge through brecciated fault zones and uncemented fractures in the underlying bedrock.

Based on the limited streamflow information and Burn Site piezometer data, streamflow at the Burn Site sufficient to saturate alluvium and provide a source of recharge to brecciated fault zones is sporadic and infrequent. Also, those recharge events may saturate only the deepest parts of the alluvium and may not be observed elsewhere where alluvium is thinner. Infiltrating water from these streamflows temporarily saturates alluvial sediments adjacent to the arroyo. Much of the water retained as bank and channel bottom storage is probably returned to the atmosphere through evapotranspiration. If infiltrating water from a flow event or sequence of events is adequate to exceed evapotranspiration losses, water may move downward through the canyon alluvium and be available to enter brecciated fault zones in underlying bedrock.

3.2.2 Groundwater Flow at the Burn Site

Groundwater is present in the fractured rocks beneath the Burn Site. Hydrologic data are available from eight wells, two piezometers, and several springs (Figure

1-2). Subsequent sections describe the field of groundwater flow and hydraulic properties of these rocks.

3.2.2.1 Field of Flow

This section describes the subregional and local direction of groundwater flow and the hydraulic gradient. The section also discusses horizontal and vertical flow velocities, and temporal changes in water levels.

Subregional direction of flow – Based on regional potentiometric contours, groundwater flows west through fractured rocks of the western Manzanita Mountains from recharge areas in the mountain highlands to the east (Figure 2-2). Local flow direction may be modified by large-scale topographic and structural features. These features include deeply incised canyons (i.e., Arroyo del Coyote) and north-trending fault systems. Groundwater beneath the Burn Site eventually discharges to basin-fill deposits of the Albuquerque basin to the west.

Local direction of flow – Table 3-1 presents the most current measured water-level elevation for each of the Burn Site monitoring network wells (January 2008). Figure 3-5 presents the potentiometric surface in the vicinity of monitoring wells as constructed from these water levels. The general direction of groundwater flow beneath the Burn Site is to the west as indicated by the potentiometric surface.

Table 3-1. Water Level Elevation in Burn Site wells (January 2008).

Monitoring Well	Measuring Point Elevation (ft amsl)	Water Level Elevation (ft amsl)
CYN-MW1D	6,236.92	5,913.84
CYN-MW3	6,310.91	6,192.88
CYN-MW4	6,452.81	6,237.61
CYN-MW5	5,981.56	5,875.66
CYN-MW6	6,340.99	6,202.97
CYN-MW7	6,213.68	5,915.56
CYN-MW8	6,227.44	5,913.68

ft amsl = feet above mean sea level.

Supply Well Pumping Influences – No water supply wells are located near the Burn Site, except for the Burn Site well that is used only occasionally. Groundwater levels in the Paleozoic rocks near the Burn Site are not influenced by regional water supply well pumping from the basin-fill deposits of the Albuquerque basin.

Hydraulic gradient – The apparent horizontal hydraulic gradient based on Burn Site wells, piezometers, and springs varies from approximately 0.004 to 0.14. Changes in gradient over distances are evident in Figure 3-5. Based on January 2008 water-level measurements, the water-level elevation in well CYN-MW3 is approximately 279 ft higher than that of well CYN-MW1D. The distance between the two wells is approximately 2,000 ft. The apparent gradient between these two wells is approximately 0.14. The hydraulic gradient west of the Burn Site flattens greatly. The water-level elevation in well CYN-MW1D is approximately 39 ft higher than that of well CYN-MW5. The distance between the two wells is approximately 11,000 ft. The gradient between CYN-MW1D and CYN-MW5 is approximately 0.004.

The wide range of hydraulic gradients in Lurance Canyon indicate that local groundwater systems associated with brecciated fault zones in the low-permeability fractured rock at the Burn Site are poorly connected. Therefore, at the scale of the Burn Site, brecciated fault zones are compartmentalized.

Horizontal flow velocity – Limited flow velocity information includes contaminant first-arrival estimates. The unlined disposal pit (SWMU 94F) was constructed in 1980. Well CYN-MW1D is located approximately 2,800 ft west of the unlined disposal pit. Contaminants in water from this well were first detected when the well was first sampled in 1998. If those contaminants were derived from the disposal pit, then the maximum elapsed time of migration between the disposal pit and well CYN-MW1D would be 18 years. The minimum apparent velocity of the contaminants, based on this maximum travel time, is estimated to be approximately 160 ft/year. This apparent velocity is reasonable in a system where limited volumes of water move primarily through fractures.

Vertical flow velocity – No information is available about vertical flow velocity within the fractured rocks at the Burn Site. However, vertical movement of water to the water table within the brecciated fault zones probably occurs as rapid, partially saturated to saturated flow. Filled fractures within the upper portion of metamorphic rock probably act as a semi-confining unit restricting vertical flow.

Water-level fluctuations – Water levels have been routinely monitored in Burn Site wells since 1999. Figure 3-6 shows water-level fluctuations in all Burn Site wells from when they were first installed (as early as July 1999) to January 2008. No substantial seasonal variation in water levels is evident in these wells.

Overall, the water level in well CYN-MW3 declined over 9 ft from an elevation of 6,202.46 to 6,192.88 ft amsl between July 1999 and January 2008. During the same period, the water level in well CYN-MW1D, located 2,000 ft downgradient, decreased over 1.6 ft (5,915.50 to 5,913.84 amsl). The water level in well CYN-MW4, located northeast of CYN-MW3 and away from the Burn Site channel, decreased 4.7 ft during the same period (6,242.34 to 6,237.61 amsl). Water-level

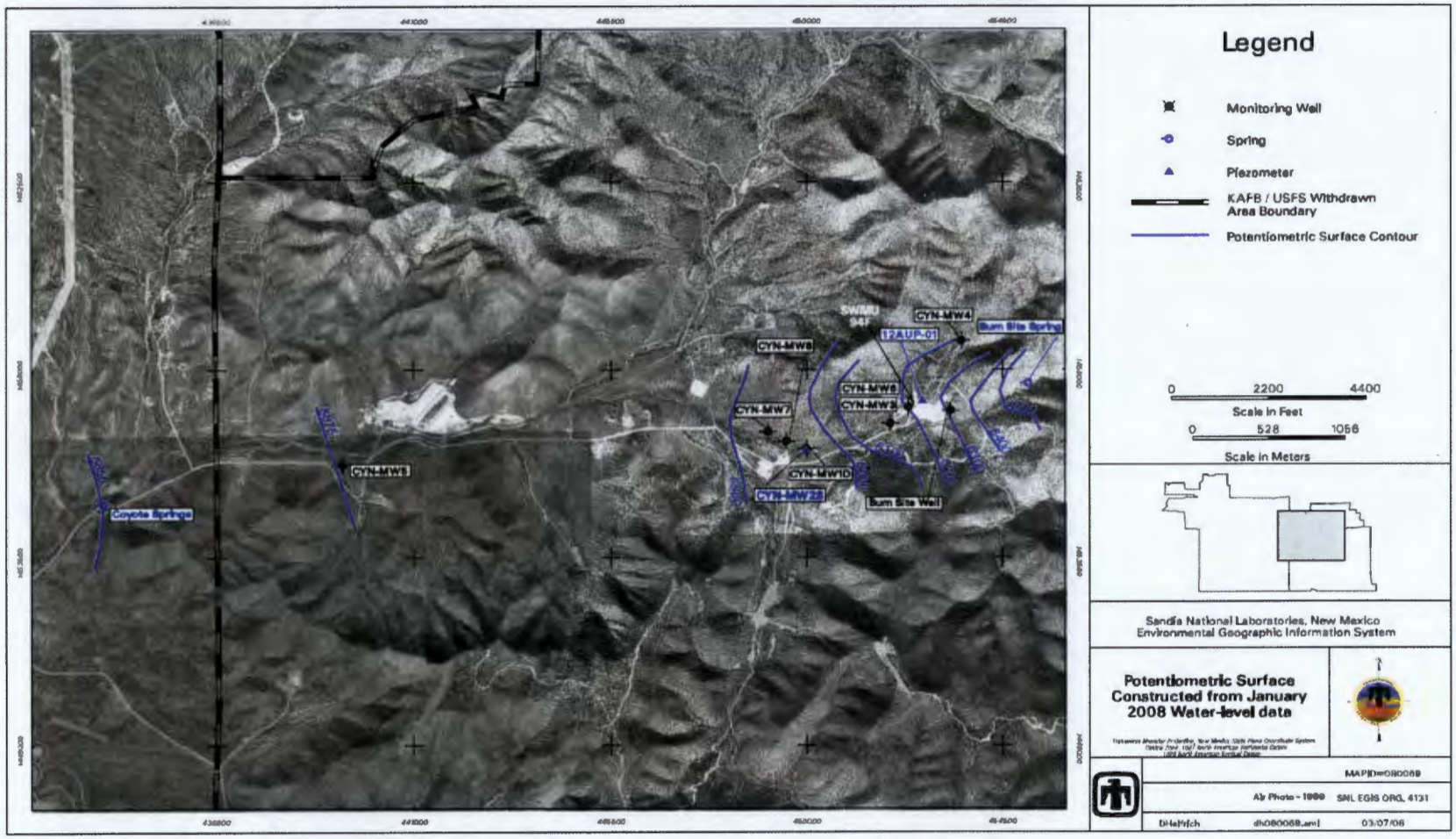


Figure 3-5. Approximate potentiometric surface constructed from January 2008 water levels in monitoring wells and piezometers, and from spring elevations.

declines in these wells likely are attributed to regional drought conditions during the period of record, although it is unclear why some wells responded more drastically than others.

The water levels in well CYN-MW5 have been the most consistent over time. Initially, the three newest wells (CYN-MW6, CYN-M W7, and CYN-MW8) have shown slight to moderate water level increases over their original water levels with a maximum of 3.5 ft in CYN-MW6. Since April 2007 through October 2007, the trend in the water levels in these three wells is down toward their original water levels.

The wide range of hydraulic gradients in Lurance Canyon and the lack of correlation between water-level fluctuations in these three wells support the assessment that the low-permeability fractured groundwater system at the Burn Site is poorly connected. Water-level fluctuations may be a result of local heterogeneities in hydraulic properties related to the fractured system.

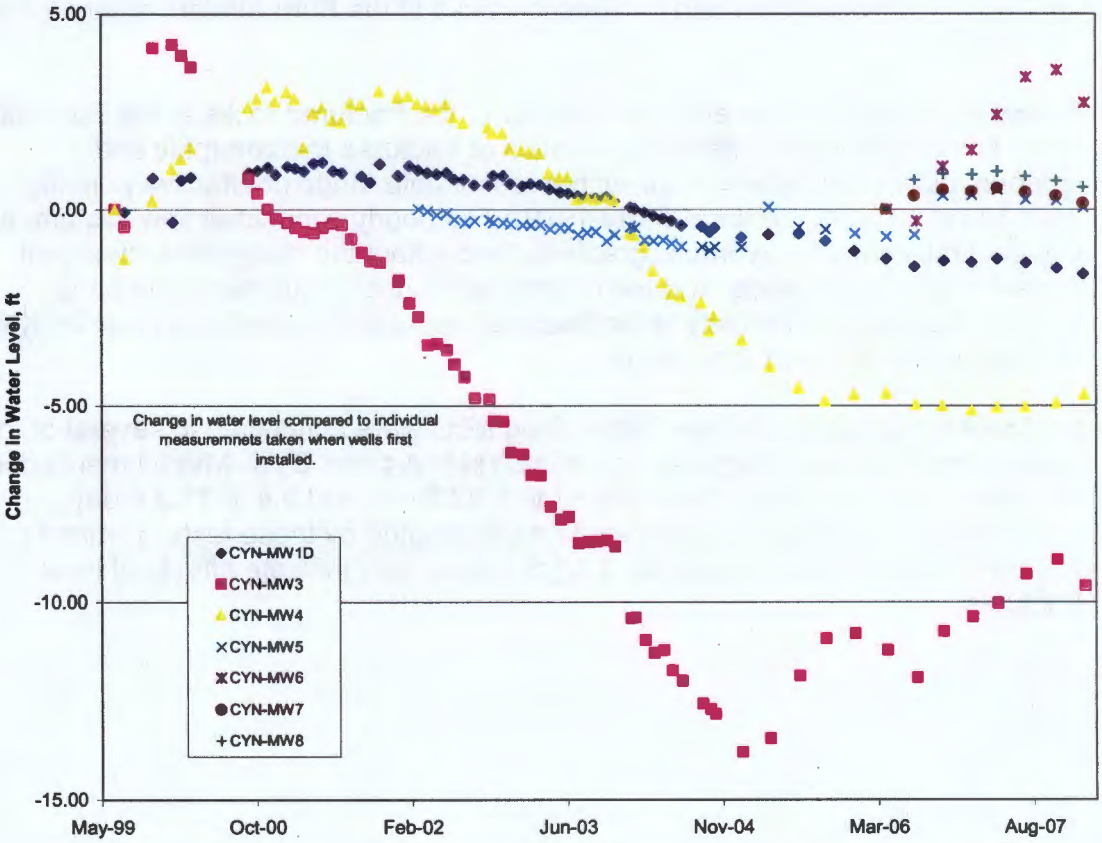


Figure 3-6. Water-level changes in Burn Site monitoring wells over the life of individual wells.

3.2.2.2 Distribution of Hydraulic Properties

Groundwater at the Burn Site predominantly moves through a semi-confined low-permeability fracture system. Semi-confined flow conditions are indicated from drilling data demonstrating that the potentiometric surface is higher than the top of saturated rocks. These conditions are attributed to cementation of fractures in overlying rocks. Cementation probably occurred prior to development of the through-flowing Rio Grande when calcium-enriched water was moving in a regionally elevated water table. Filled fractures within these upper units confine the underlying fracture-flow system.

The fracture-flow system poorly connects a series of predominantly north-trending brecciated fault zones that cross the Burn Site. These brecciated zones probably are characterized by increased horizontal hydraulic conductivity to the north and south along the orientation of the faults.

The capability of the fractured and faulted rocks underlying the Burn Site to store water is described by the total and effective porosity. The capacity of these rocks to transmit water is described by the horizontal and vertical hydraulic conductivity. Hydraulic property values for rocks at the Burn Site are summarized in Table 3-2.

Effective porosity – The effective porosity of the fractured rocks at the Burn Site is not known. However, effective porosities of fractured metamorphic and igneous rocks typically are small, with a reasonable range of effective porosity from 10^{-5} to 10^{-2} (Freeze and Cherry 1979). The poorly connected flow system, as evidenced by variable hydraulic gradients throughout the study area, divergent water-level trends in wells, and the minimal amount of groundwater recharge indicate that the bulk porosity of the fractured rocks at the Burn Site most likely is toward the lower end of that range.

Horizontal hydraulic conductivity – Slug tests were conducted in several of the wells in the Burn Site. Slug tests in wells CYN-MW4 and CYN–MW1D resulted in ranges of hydraulic conductivity of 0.91 to 1.92 ft/day and 3.4 to 12.3 ft/day, respectively. The volume of saturated rock evaluated by these tests is limited to the immediate vicinity of the wells. Larger values may indicate effects of local fractures.

Table 3-2. Summary of the hydraulic properties of the fractured rocks at the Burn Site.

Property	Value/Range	Source
Effective porosity (n_f) (dimensionless)	10^{-5} to 10^{-2}	Values from literature for fractured rock (Freeze and Cherry 1979).
Horizontal hydraulic gradient (ft/ft) (dimensionless)	0.004 to 0.14	Maximum gradient calculated from water levels in wells CYN-MW3 and CYN-MW1D. The gradient flattens to the west as observed in water levels measured in CYN-MW1D and CYN-MW5.
Horizontal flow velocity (ft/yr)	160 ft/yr	Estimated using maximum travel time estimate between DRO source (SWMU 94F) and well CYN-MW1D.
Horizontal hydraulic conductivity (K) (ft/day)	10^{-2} to 12.3	Lower end of bulk value derived from estimates of gradient, effective porosity, and velocity. Upper value obtained from analysis of slug-test data from CYN-MW1D.
Vertical hydraulic conductivity (K) (ft/day)	No estimate	None
Vertical flow velocities (ft/min)	No estimate	None

ft = feet or foot.
min = minutes.
yr = year(s)

No other quantitative data about the horizontal hydraulic conductivity of the rocks in the Burn Site are available. However, based on the range of apparent hydraulic gradient and velocity estimates for groundwater at the Burn Site, the magnitude of bulk horizontal hydraulic conductivity for the fractured and faulted rocks is estimated to be 10^{-2} ft/day. This estimated bulk hydraulic conductivity is based on the following equation:

$$K \geq \bar{v} n_f \frac{dl}{dh}$$

where

$\bar{v}$	=	minimum average velocity (estimated to be 160 ft/year)
K	=	bulk hydraulic conductivity, in ft/day (unknown)
n_f	=	effective porosity of fractured rock (dimensionless, 10^{-5})
$\frac{dl}{dh}$	=	inverse of the hydraulic gradient (dimensionless, 0.14).

Vertical hydraulic conductivity – No information is available regarding the capability of the fractured rocks at the Burn Site to vertically transmit water. Increased hydraulic conductivity of the brecciated fault zones most likely permits vertical flow of water to groundwater flow systems locally from recharge sites along the canyon floor. Cemented fractures in the upper sections of rocks at the Burn Site restrict vertical flow to the aquifer elsewhere. As previously noted, water levels in wells rise above the interval where saturated rock was first observed during drilling.

3.3 Distribution of Contaminants in the Subsurface at the Burn Site

This section describes the contaminant source term and the distribution of contaminants in BSG. The only COC detected above the MCL in BSG is nitrate; perchlorate has also been detected in one BSG monitoring well at a concentration above the screening level required by the Order. Other contaminants investigated include fuel constituents. This section also discusses the adequacy of the existing groundwater monitoring network to characterize the distribution and transport of contaminants in BSG.

3.3.1 Contaminant Sources

Nitrate and perchlorate in BSG may be derived from both natural and anthropogenic sources. Organic constituents in groundwater are likely associated with open detonation of high explosives and with fuels used in burn tests.

Subsequent sections describe these natural and anthropogenic sources of nitrate, perchlorate and selected organic contaminants.

3.3.1.1 Nitrate

A nitrate source evaluation was conducted to establish background nitrate concentrations in soil and spring water and to determine if significant non-point nitrate sources are present in the vadose zone. Both near-surface and deep soil borings were collected and analyzed for nitrate, HE compounds, and other analytes. Water samples were also collected from nearby springs and analyzed for nitrate and water quality parameters. The results of these field activities are presented in the "Field Report Burn Site Groundwater – Nitrate Source Evaluation" (Skelly January 2005) and were summarized as Attachment B of the Burn Site IMWP (SNL/NM May 2005).

Evaluation of the data led to the following observations and conclusions:

- Nitrate in alluvium and groundwater at the Burn Site is a result of both natural phenomena and historical Burn Site operations.
- Measured background nitrate concentrations in spring water and groundwater range from below detection limits to less than 2.6 mg/L as nitrogen.
- Elevated nitrate concentrations in soil near the Burn Site and in a groundwater plume emanating from the Burn Site are likely the result of historical Burn Site operations, followed by leaching of nitrate into the subsurface.
- Nitrate remains in the vadose zone alluvium at the Burn Site; however, this nitrate does not represent an active source that would significantly increase nitrate concentrations in groundwater. A conservative estimate indicates that the nitrate remaining in the vadose zone is unlikely to result in groundwater contamination at concentrations higher than observed in the past. As demonstrated in the Burn Site IMWP (SNL/NM May 2005; Appendix C of Attachment B) the maximum concentration of nitrate in pore water that could reach the underlying groundwater was between 12 and 37 mg/L (depending on the assumed porosity of alluvial materials). This does not represent a significant increase above the observed maximum groundwater nitrate concentration of 32.6 mg/L.

In summary, nitrate in BSG at concentrations exceeding the MCL may be derived either from nitrate residue following open detonation of HE or from concentration of naturally-occurring nitrate via evapotranspiration of rainfall that infiltrated canyon alluvium. Nitrate from either source could accumulate in alluvial deposits in the canyon floor and could be mobilized by subsequent wetting events that provide sufficient moisture to infiltrate brecciated fault zones and migrate downward to groundwater flow systems in low-permeability fractured rocks.

3.3.1.2 Organic Contaminants

Wastewater from fire control and cooling at the LAARC Unit was discharged into an adjacent, unlined pit (SWMU 94F) (Figure 3-7) from 1980 to 1983. This pit was used to collect wastewater from burn tests that were conducted using JP-4. Remedial activities in 2000 at the unlined pit consisted of excavation to bedrock. A brecciated fault zone was located in bedrock beneath the pit in the course of excavation (Figure 3-7). This fault zone may have provided a point of recharge to the underlying groundwater system for wastewater containing diesel range organics (DROs) disposed to the pit.

Jet fuels used for burn tests also may have been released to the subsurface through transfer pipeline leaks downgradient from the Burn Site well. A spill site (SWMU 94H) (Figure 3-1) was discovered in August 2000 during an excavation for a piping upgrade approximately 600 ft to the east of the LAARC Unit in an underground pipeline supplying JP-8 to burn test facilities. Soil samples collected from the base of the excavation indicated that the contamination was limited. Following subsequent remedial activities, a human health and ecological risk assessment demonstrated that the concentrations are acceptable for industrial and residential land-use scenarios (SNL/NM September 2002).

3.3.1.3 Perchlorate

Section IV.B of the Order stipulates that a select group of groundwater monitoring wells be sampled for perchlorate at SNL/NM (NMED April 2004). The wells in the perchlorate screening groundwater monitoring well network were either specifically listed in the Order (CYN-MW1D and CYN-MW5), or were categorized as "new" wells (any well installed after the Order was finalized). For example, CYN-MW6, CYN-MW7, and CYN-MW8 qualified as new wells. Perchlorate analysis has been completed for a minimum of four quarters in these five BSG monitoring wells. Quarterly reports have been submitted for wells actively in the perchlorate-screening monitoring-well network since February 2006 (SNL/NM March 2008).

As discussed in previous reports, the source for the perchlorate in the groundwater at CYN-MW6 is unknown. Soil sampling completed in 2001 at Solid Waste Management Unit (SWMU) 65—Lurance Canyon Explosives Test Site, or SWMU 94—Lurance Canyon Burn Site did not reveal detectable concentrations of perchlorate in site soils (NMED January 2001; Skelly and Griffith January 2003; and SNL/NM June 2006). Recent studies have determined that a substantial reservoir of natural perchlorate is present in vadose zone soils of the arid and semi-arid southwestern United States. The perchlorate is thought to occur with meteoric chloride that has accumulated in these soils over thousands of years. The vadose zone perchlorate reservoir can affect groundwater when recharge from irrigation or other anthropomorphic activities flushes accumulated salts from the unsaturated zone (Rao et al., June 2007). Perchlorate in groundwater thought to be tens of

thousands of years old in the Middle Rio Grande Basin of New Mexico has been inferred to be meteoric in origin (Plummer et al., February 2006). This may be the case at Burn Site where water-filled pits used for testing may have released water to the subsurface and mobilized perchlorate to groundwater.

As with nitrate, perchlorate in BSG at concentrations exceeding the screening level/Method Detection Limit (MDL) may be derived either from open detonation of perchlorate bearing explosives, burning of rocket motors, or from concentration of naturally-occurring perchlorate via evapotranspiration of rainfall that infiltrated canyon alluvium. Perchlorate from either source could accumulate in alluvial deposits in the canyon floor and could be mobilized by subsequent wetting events that provide sufficient moisture to infiltrate brecciated fault zones and migrate downward to groundwater flow systems in low-permeability fractured rocks.

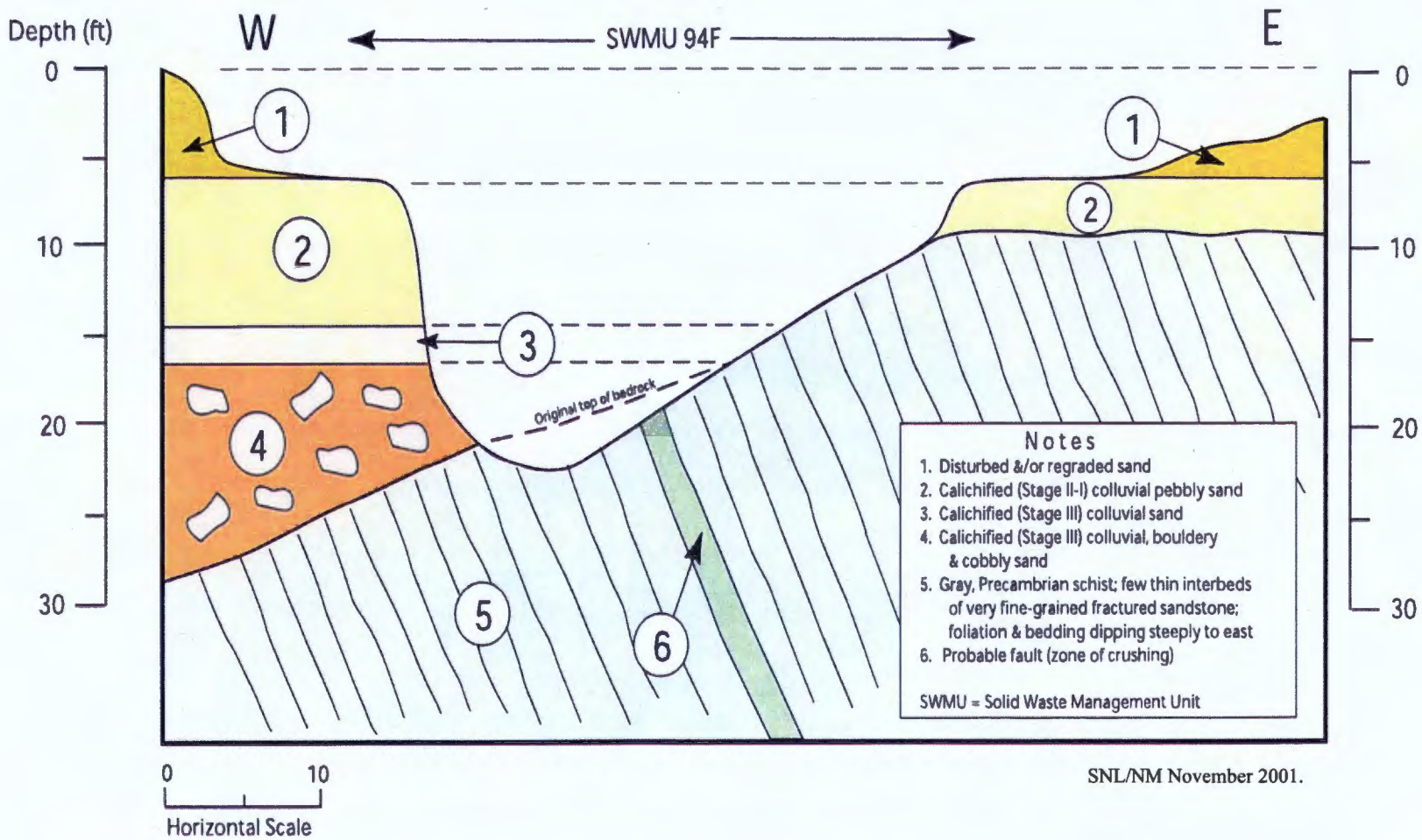


Figure 3-7. Cross section showing unlined pit (SWMU 94F) and apparent brecciated fault zone.

3.3.2 Contaminant Distribution and Transport in Groundwater

Nitrate has been detected at concentrations above the MCL in groundwater at the Burn Site. Trace concentrations of organic constituents have been detected and perchlorate has also been detected at concentrations above the Order-specified screening level/MDL in groundwater at the Burn Site. Distribution of contaminants in groundwater supports the concept of a series of locally complex flow systems controlled by fault orientation and general distribution and degree of interconnection of fractures. Although the potentiometric surface indicates generally westward groundwater flow, the likely north-trending brecciated fault zones likely permits migration of contaminants along those zones. Contaminant migration to the west occurs through the low-permeability fracture network that poorly connects brecciated fault zones.

3.3.2.1 Nitrate

Table 3-3 summarizes the historical maximum concentration and the most recently measured nitrate concentration observed in water from Burn Site wells. Nitrate data for each well in the Burn Site monitoring well network are included in Appendix A (Figures A-1 through A-7).

Table 3-3. Maximum and most recent concentrations of nitrate in groundwater from Burn Site wells.

Contaminant	Historical Maximum Concentration	Recent Maximum Concentration	Regulatory Limit (MCL)
Nitrate[a]	32.6 mg/L[b]	29.3 mg/L[c]	10 mg/L[d]

mg/L = milligrams per liter.
MCL = Maximum Contaminant Level.
a. Nitrate or nitrate plus nitrite (NPN) both expressed as nitrogen.
b. Detected in a sample from well CYN-MW6 collected in June 2006. Duplicate result was 29.5 mg/L.
c. Detected in a sample from well CYN-MW6 collected in December 2007. Duplicate result was 27.7 mg/L.
d. 40 CFR 141.62, "Maximum Contaminant Levels for Inorganic Contaminants."

The Burn Site well was installed in 1986 but no groundwater samples from the Burn Site well were analyzed for nitrate until 1996. The reported nitrate concentration in 1996 was 25 mg/L. The measured concentration in October 1997 was 23.2 mg/L. Earlier reported concentrations were of similar magnitude. Since the completion of wells CYN-MW1D (December 1997), CYN-MW3 (June 1999), and CYN-MW6 (January 2006), nitrate concentrations above the MCL have been detected in these wells. Nitrate concentrations in water from the other wells (CYN-MW4, CYN-MW5, CYN-MW7, and CYN-MW8) have typically been less than 3.0 mg/L and have not exceeded 6.0 mg/L.

Nitrate concentrations in water samples collected from CYN-MW5 since July 2002 ranged from 1.32 to 2.62 mg/L. Nitrate concentrations in water samples collected from Coyote Spring since April 1997 ranged from 0.08 to 0.85 mg/L. Measured nitrate concentration changes in water from selected monitoring wells (CYN-MW1D, CYN-MW3, CYN-MW6, and the Burn Site well) are shown in Figure 3-8. Nitrate concentrations in water from the Burn Site well decreased from 24.3 mg/L in 1996 to 5.5 mg/L in 2001. Concentrations in water from CYN-MW3, have ranged from 3.3 to 22 mg/L with an average of approximately 12 mg/L. Nitrate concentrations in samples collected from CYN-MW6 have ranged from 22 to 33 mg/L.

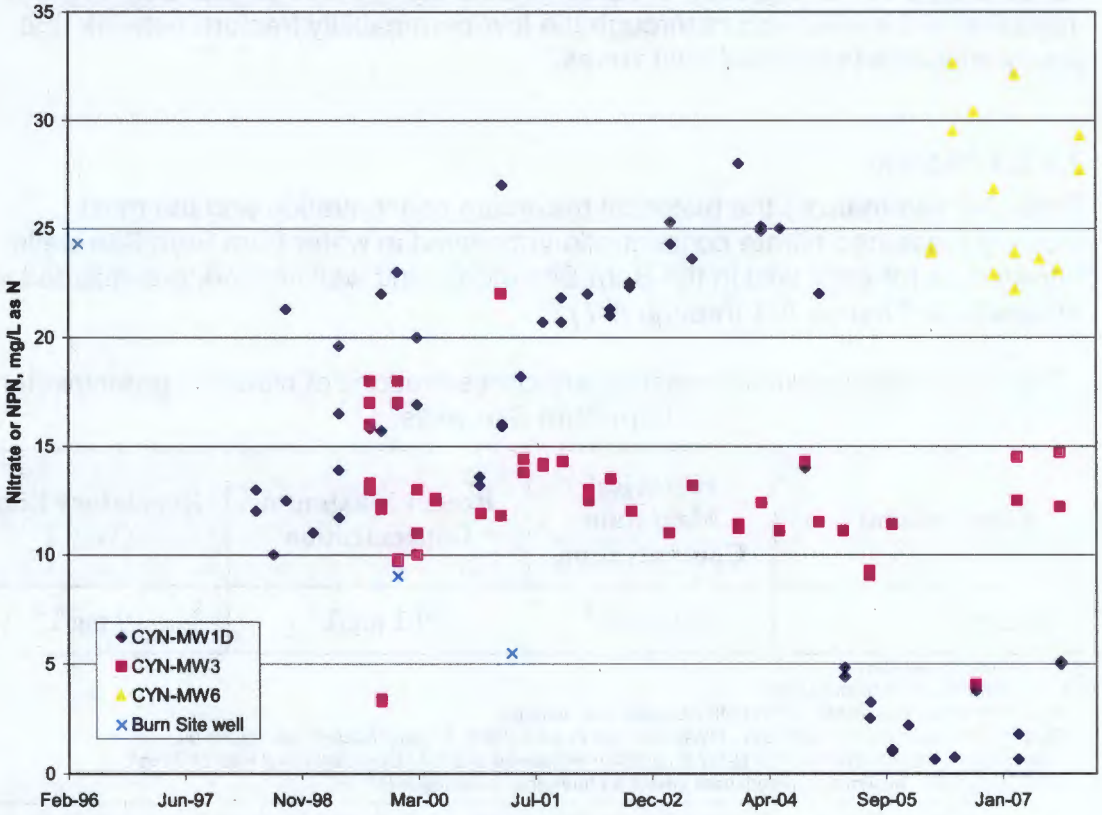


Figure 3-8. Nitrate concentrations with time in water from selected Burn Site wells.

Nitrate concentrations in water from well CYN-MW1D, located approximately 3,400 ft downgradient of the Burn Site well, increased from approximately 10 mg/L to more than 28 mg/L from 1998 through 2003. However, beginning in 2004, the concentration of nitrate in water from CYN-MW1D began to rapidly and significantly decline. Since March 2005 the concentration of nitrate in CYN-MW1D has fluctuated between a low of 0.645 mg/L (March 2006) to a high of 5.09 mg/L (December 2007). The concentration trends in the Burn Site well and CYN-MW1D suggest that a pulse of nitrate-enriched groundwater may have migrated from the Burn Site well and past CYN-MW1D. However, this pulse of

nitrate-enriched groundwater has not been observed at the recently installed sentry wells (CYN-MW7 and CYN-MW8). Monitoring wells CYN-MW7 and CYN-MW8 define the downgradient extent of nitrate contaminated groundwater as required by the NMED. The relatively stable nitrate concentrations in water from CYN-MW3 do not reflect this pulse. However, these wells may not be hydraulically connected as also reflected by water level trends (Section 3.2.2.1).

3.3.2.2 Organic Constituents

Organic constituents in groundwater are probably residuals from Burn Site operations. Remediation of fuel-contaminated soils has been completed as summarized in Section 3.3.1.2. As stated in the Order, "Fuel constituents below state and U.S. Environmental Protection Agency (EPA) standards have also been detected in some wells" (NMED April 2004). Groundwater monitoring data, collected subsequent to issuing of the Order, indicate that these fuel constituents are gradually decreasing below historical maximum concentrations, which were not of regulatory concern. Therefore, fuel constituents are not COCs in groundwater at this site. The data are summarized here to provide a complete conceptual model.

Analytes monitored in groundwater to detect residuals from burning operations consisted of DROs, gasoline range organics (GROs), volatile organic compounds (VOCs), and semivolatile organic compounds (SVOCs). GROs were not detected in water from any of the Burn Site monitoring wells except for well CYN-MW4 in September 2005 (28.9 micrograms per liter [µg/L]). DRO data for sampled wells in the Burn Site monitoring well network are plotted in Appendix A (Figure A-8). DRO concentrations in CYN-MW1D during the period from August 1999 through December 2007 ranged from less than 50 to more than 400 µg/L. Concentrations in water from wells CYN-MW3 and CYN-MW4 ranged from less than 50 µg /L to 381 µg/L. The presence of DRO in water from well CYN-MW4 indicates that contaminants may have migrated northward along the brecciated fault zone. As shown in Figure A-8, DRO concentrations have gradually decreased in water from most monitoring wells in the BSG monitoring well network since approximately 2003.

As discussed in Section 1.1, NMED required the installation of one additional monitoring well "adjacent to Solid Waste Management Unit (SWMU)-94F in order to establish groundwater conditions in this petroleum-contamination source area." Monitoring well CYN-MW6 was installed downgradient to SWMU 94F in December 2005, and was sampled starting in March 2006. DRO was detected in samples from CYN-MW6 above the MDL in concentrations ranging from 21.4 to 66 µg/L. Most of the detected concentrations of DRO in CYN-MW6 were qualified during data validation as non-detect. These results indicate that groundwater downgradient of SWMU 94F was not substantially contaminated with petroleum constituents. DRO concentrations in CYN-MW7 and CYN-MW8 during the period from March 2006 through December 2007 ranged from less than 22 to 62 µg/L.

As with the CYN-MW6 DRO detections, most of the detected concentrations of DRO in CYN-MW7 and CYN-MW8 were qualified during data validation as non-detect.

Trace concentrations of SVOCs and VOCs have been detected in water from all Burn Site wells. VOCs detected in CYN-MW1D and CYN-MW4 mainly included hydrocarbons associated with fuels (toluene, ethylbenzene, and xylene) and were detected at concentrations below their respective MCLs and generally were estimated concentrations that were below practical quantitation limits. Other VOCs detected in Burn Site wells have included common laboratory contaminants, including acetone and methylene chloride. SVOCs in Burn Site wells were detected at concentrations below their respective MCLs and were estimated concentrations that were below practical quantitation limits.

Chemical compounds associated with HE are monitored in water from Burn Site wells. Concentrations of HE constituents (e.g. 1,3,5-trinitrobenzene, 1,3-dinotrobenzene, 2-nitrotoluene, 3-nitrotoluene, 4-nitrotoluene, 2,6 dinitrotoluene, 2-amino- 4,6-dinitrotoluene, and tetryl) have been detected below MCLs in water from CYN-MW1D and CYN-MW3. However, no HE constituents have been detected in water from CYN-MW4, CYN-MW5, CYN-MW6, CYN-MW7, and CYN-MW8.

3.3.2.3 Perchlorate

Since June 2004 (the start of sampling required by the Order), perchlorate has only been detected above the screening level/MDL in one of the Burn Site wells in the perchlorate-screening monitoring-well network (CYN-MW6). Due to the detection of perchlorate in the samples from CYN-MW6 in March 2006, DOE/Sandia submitted the "Notification of Release, Perchlorate at Well CYN-MW6, May 2006" (SNL/NM May 2006) to the NMED.

Table 3-4 summarizes the historical maximum concentration and the most recently measured perchlorate concentration observed in water from Burn Site wells. Perchlorate data for each well in the Burn Site monitoring well network are included in Appendix A.

Table 3-4. Maximum and most recent concentrations of perchlorate in groundwater from Burn Site wells.

Contaminant	Historical Maximum Concentration	Recent Maximum Concentration	Screening Level (MDL)
Perchlorate	8.93 µg/L[a]	6.56 µg/L[b]	4 µg/L[c]

µg/L = micrograms per liter.
MDL = method detection limit.
a. Detected in a sample from well CYN-MW6 collected in December 2006, duplicate result was 8.46 µg/L.
b. Detected in a sample from well CYN-MW6 collected in December 2007, duplicate result was 6.20 µg/L.
c. Screening level required by the Order (NMED April 2004).

Perchlorate concentrations in water samples collected from CYN-MW6 since March 2006 ranged from 5.94 to 8.93 µg/L. Measured perchlorate concentration in water from monitoring well CYN-MW6) are shown in Appendix A, Figure A-9.

Since 2004, four other monitoring wells in the vicinity of the Burn Site have been sampled and analyzed for perchlorate, including CYN-MW1D, CYN-MW5, CYN-MW7, and CYN-MW8. All of these wells were sampled for four quarters and all results were non-detect for perchlorate at the Order-required screening level/MDL of 4 µg/L (Appendix A). All of these wells are located downgradient of the CYN-MW6, indicating that the elevated concentrations at CYN-MW6 are limited in areal extent.

The concentration trend of perchlorate in CYN-MW6 shows minor concentration fluctuations over the eight quarters of data collected. No explanation for the minor concentration fluctuations is readily available.

Per the Order (NMED April 2004), a human health risk screening was conducted to determine whether perchlorate in groundwater in CYN-MW6 might pose a potential unacceptable risk to human receptors at the Burn Site. The maximum groundwater perchlorate concentration was used as the exposure point concentration in the screening risk evaluation. The current and future land use at the burn site is industrial. However, under an industrial scenario there is no current viable exposure pathway for contact with groundwater. Therefore, residential land use was evaluated as the primary decision scenario for the human health screening risk assessment and the primary pathway for residential exposure to groundwater is ingestion (SNL/NM March 2008).

For calculation of risk, the Hazard Index (HI) is the sum of individual Hazard Quotients. Based on the maximum concentration for perchlorate, the Hazard Quotient (HQ) is 0.35, which is less than the NMED target level of a Hazard Index (HI) of 1.0 (NMED June 2006). Therefore, the perchlorate concentrations in groundwater from CYN-MW6 do not pose an unacceptable risk to human health under a residential scenario (SNL/NM March 2008).

3.3.3 General Chemistry of Burn Site Groundwater

General water-chemistry data have been collected from selected Burn Site wells as part of annual monitoring activities. These data include major ions, metals, and field parameters; they are presented in annual reports (SNL/NM March 2001; SNL/NM March 2002; SNL/NM March 2003; SNL/NM March 2004; SNL/NM September 2005; and SNL/NM March 2007).

Table 3-5 presents selected general water-chemistry parameters from Burn Site monitoring wells from November 2004 through December 2007. Based on these data, BSG ranges from anaerobic to aerobic (dissolved oxygen ranging from 0.13 mg/L to 7.89 mg/L). This wide range of dissolved oxygen and other parameters indicate that water chemistry is variable and complex, even within the same well.

Table 3-5. General water chemistry parameters from selected wells at the Burn Site (November 2004 to December 2007).

Well	Date	Sulfate (mg/L)	Alkalinity (mg/L)	Dissolved Oxygen (mg/L)	Oxidation Reduction Potential (millivolts)	pH (unitless)
CYN-MW1D	11/22/04	95.2	96	1.72	-45.1	7.74
	3/9/05	93	63	1.33	-269.1	8.40
	6/27/05	113	58	0.65	-279.6	8.40
	9/28/05	113	46.1	1.66	-299.2	8.50
	12/6/05	NA	NA	1.76	-281.1	8.60
	3/27/06	NA	NA	0.46	-262.4	8.54
	6/21/06	104	NA	0.13	-293.6	8.49
	9/19/06	NA	NA	0.63	-78.5	8.46
	3/22/07	NA	NA	0.18	-201.9	8.30
	9/19/07	NA	NA	0.22	-153.7	7.81
CYN-MW3	11/18/04	181	241	4.27	162.7	7.16
	3/1/05	159	235	6.56	106.7	7.21
	6/22/05	174	232	4.19	192.8	7.13
	9/27/05	176	239	7.89	166.9	7.24
	6/20/06	167	NA	2.03	30.2	7.12
	9/18/06	NA	NA	5.61	360.8	7.52
	3/15/07	NA	NA	6.19	276.3	7.27
	9/14/07	NA	NA	6.28	302.4	6.95
CYN-MW4	11/17/04	139/140	231	1.60	33.7	7.08
	3/3/05	127/151	213	2.33	66.1	7.24
	6/22/05	134	217	4.19	192.8	7.13
	9/26/05	133	221	5.16	106.1	7.26
	6/19/06	135	NA	2.24	24.8	7.14
	9/15/06	NA	NA	1.87	332.6	7.54
	3/19/07	NA	NA	2.28	209.7	7.31
	9/11/07	NA	NA	2.23	385.2	7.25

Table 3-5 (concluded). General water chemistry parameters from selected wells at the Burn Site (November 2004 to December 2007).

Well	Date	Sulfate (mg/L)	Alkalinity (mg/L)	Dissolved Oxygen (mg/L)	Oxidation Reduction Potential (millivolts)	pH (unitless)
CYN-MW5	11/16/04	25.7	158	4.91	232.0	5.63
	2/22/05	26.8	139	5.21	226.4	5.70
	6/20/05	31.3	147	6.20	7.1	6.30
CYN-MW6	3/23/06	NA	NA	2.42	118.7	7.09
	6/22/06	150	NA	4.21	365.8	7.11
	9/20/06	NA	NA	2.42	313.2	7.02
	12/15/06	140	NA	2.55	311.6	7.00
	3/14/07	144	NA	2.49	240.6	7.03
	6/27/07	128	NA	2.76	226.0	7.22
	9/12/07	128	NA	2.50	282.1	6.70
	12/18/07	129/127	NA	2.10	387.4	6.97
CYN-MW7	3/20/06	NA	NA	1.46	-50.9	7.19
	6/13/06	71.5	NA	1.53	-39.4	7.23
	9/13/06	NA	NA	2.14	60.9	7.36
	12/11/06	NA	NA	2.18	185.7	7.08
	3/21/07	NA	NA	1.98	95.4	7.08
	6/26/07	NA	NA	2.48	125.1	7.24
	9/17/07	NA	NA	2.77	158.3	6.80
	12/10/07	NA	NA	2.69	400.3	6.99
CYN-MW8	3/21/06	NA	NA	3.51	-37.4	7.16
	6/14/06	117	NA	0.83	8.1	7.19
	9/14/06	NA	NA	2.03	148.5	7.37
	12/12/06	NA	NA	2.74	251.3	7.11
	3/20/07	NA	NA	3.28	91.3	7.15
	6/25/07	NA	NA	3.54	184.5	7.27
	9/18/07	NA	NA	3.45	216.4	6.82
	12/17/07	NA	NA	4.19	406.3	7.04

mg/L = milligrams per liter.
NA = Not Available, parameter was not collected or is not available.

3.3.4 Adequacy of the Burn Site Groundwater Monitoring Networks

Groundwater monitoring wells in the Burn Site identified by the "Sandia National Laboratories: Long-Term Monitoring Strategy for Groundwater" (SNL/NM February 2001) include CYN-MW1D, CYN-MW3, CYN-MW4, and the Burn Site well. Well CYN-MW5 provides additional downgradient information. Monitoring wells CYN-MW6, CYN-MW7, and CYN-MW8 were installed as outlined in the IMWP (SNL/NM May 2005) with the purpose of characterizing the downgradient extent of the nitrate contamination (CYN-MW7 and CYN-MW8) and characterizing the extent of fuel contamination (CYN-MW6). The location of these wells in the vicinity of the Burn Site are shown in Figure 1-2. A brief description of the wells is provided below:

- **Burn Site well**. The Burn Site well was drilled in February 1986 to provide a source of non-potable water for fire suppression during burn tests. The borehole was drilled to a depth of 350 ft below ground surface (bgs) in the drainage of the Arroyo del Coyote. The well has a 4-in. diameter and is screened at an interval of 231 to 341 ft bgs, which includes water-bearing fractures below an aquitard (the aquitard is believed to be between 29 and 222 ft bgs). Water-level measurements in this well have not been made since 1986 because of the lack of an access port for the water-level sounder.

- **CYN-MW1D**. This 5-in. diameter well, located approximately 3,400 ft downgradient of the Burn Site well, was drilled in December 1997 to determine the extent of potential contamination. The total depth of the well is 392 ft bgs. The well is screened at a 10-ft interval from 372 to 382 ft bgs.

- **CYN-MW3**. This 5-in. diameter well was drilled in June 1999 approximately 1,400 ft downgradient of the Burn Site well. The well is completed at a total depth of 135 ft bgs and is screened at a 10-ft interval from 120 to 130 ft bgs.

- **CYN-MW4**. This 5-in. diameter well was drilled in June 1999 approximately 1,650 ft upgradient and north of the Burn Site well. It was originally intended to be a background well. The well is completed at a total depth of 290 ft bgs and is screened over a 20-ft interval from 260 to 280 ft bgs.

- **CYN-MW5**. This 5-in. diameter well was drilled in August 2001 approximately 2.7 miles (14,000 ft) west of the Burn Site well at a location downgradient of the Burn Site in Lurance Canyon. The well is completed at a total depth of 160 ft bgs and is screened at a 20-ft interval from 135 to155 ft bgs.

- **CYN-MW6**. This 5-in. diameter well was drilled in December 2005 approximately 300 ft downgradient SWMU 94F. The well is completed at a

total depth of 162 ft bgs and is screened at a 20-ft interval from 141 to 161 ft bgs.

- **CYN-MW7**. This 5-in. diameter well was drilled in December 2005 approximately 1,000 ft downgradient of CYN-MW1D. The well is completed at a total depth of 335 ft bgs and is screened at a 20-ft interval from 315 to 335 ft bgs.

- **CYN-MW8**. This 5-in. diameter well was drilled in January 2006 approximately 500 ft downgradient of CYN-MW1D. The well is completed at a total depth of 363 ft bgs and is screened at a 20-ft interval from 338.5 to 358.5 ft bgs.

In addition to these monitoring wells, two 2-in. diameter piezometers, 12AUP-01 and CYN-MW2S, were constructed to monitor possible flow along the interface between alluvium and bedrock to detect perched flow at the Burn Site.

Two natural springs have also been active at the Burn Site, the Burn Site Spring and Hidden Spring. The ephemeral Burn Site Spring is located about 2,500 ft east northeast of the Burn Site well. Hidden Spring was reportedly present near the current site of the Burn Site well, but was obscured after construction of the Burn Site facility.

The Burn Site monitoring well network includes wells located at or near potential sources for groundwater contamination, including CYN-MW3, CYN-MW1D, CYN-MW6, and CYN-MW8. Additionally, the network includes a cross-gradient well (CYN-MW4) that monitors potential contaminant migration through the north-trending brecciated fault zone. The network also includes two sentry wells or wells located downgradient of contamination, CYN-MW5, and CYN-MW7. Although no upgradient background well is located east of the Burn Site, the Burn Site spring located east and upgradient of the Burn Site as well as springs to the west that drain a much larger area can be used to determine background water chemistry. The Burn Site well is a supply well that has provided additional information about contaminant distribution.

4.0 SUMMARY

In Section IV.C of the Order, NMED requires a CME of SNL/NM BSG contamination (NMED April 2004). Remediation of COCs in groundwater at the Burn Site requires a current conceptual model of contaminant transport that will provide the basis for a technically defensible remediation program.

Nitrate has been identified as the only COC in BSG. DRO contaminants and other organic constituents also have been detected in groundwater, but concentrations have been below levels of regulatory concern. Perchlorate has been detected in one well above the Order-required screening level, but at concentrations that do not pose an unacceptable risk to human health (SNL/NM March 2008). Key elements of the current conceptual model of contaminant transport at the Burn Site are summarized in subsequent sections. These elements consist of contaminant sources and contaminant transport in groundwater.

4.1 Contaminant Sources

Nitrate in groundwater from Burn Site wells is attributed to non-point sources either from residual nitrate disseminated from open detonation of HE from 1967 until the early 1980s at sites within SWMU 65 or from naturally concentrated nitrate present in rainwater that has been evaporated or transpired from alluvial deposits in Lurance Canyon. Nitrate from either source could accumulate in alluvial deposits in the canyon floor and could be mobilized by subsequent wetting events that provide sufficient moisture to infiltrate brecciated fault zones and migrate downward to groundwater flow systems in low-permeability fractured rocks (SNL/NM May 2005).

Organic constituents in groundwater have been derived from fire-suppression wastewater, spills, and HE. These constituents are not considered to be COCs because concentrations are less than EPA and state standards. However, they do provide information about the movement of groundwater in the Burn Site. DRO and other organic constituents may have migrated along brecciated fault zones to groundwater.

As with nitrate, perchlorate in BSG at concentrations exceeding the screening level/MDL may be derived either from open detonation of perchlorate bearing explosives, burning of rocket motors, or from concentration of naturally-occurring perchlorate via evapotranspiration of rainfall that infiltrated canyon alluvium. Perchlorate from either source could accumulate in alluvial deposits in the canyon floor and could be mobilized by subsequent wetting events that provide sufficient moisture to infiltrate brecciated fault zones and migrate downward to groundwater flow systems in low-permeability fractured rocks (SNL/NM March 2008).

4.2 Contaminant Transport in Groundwater

Groundwater in rocks underlying the SNL/NM Burn Site in Lurance Canyon moves as semiconfined fracture flow, eventually discharging to unconsolidated basin-fill deposits in the Albuquerque Basin to the west. Some discharge takes place at springs at the base of the Manzanita Mountains. Local recharge to this low-permeability system occurs through a series of north-trending brecciated fault zones crossing the Burn Site and the Lurance Canyon drainage. These fault zones provide a permeable conduit between the land surface and the fractured water-bearing rocks at depth.

Based on the limited streamflow information and Burn Site piezometer data, streamflows at the Burn Site that are sufficient to saturate channel sediments and to provide a source of recharge to brecciated fault zones are sporadic and infrequent. Infiltrating water from these streamflows temporarily saturates alluvial sediments of the arroyo. Much of the water retained as bank and channel bottom storage most likely returns to the atmosphere through evapotranspiration. If infiltrating water from a flow event or sequence of events is adequate to exceed evapotranspiration losses, water moves downward through the canyon alluvium and is available to enter the underlying bedrock through brecciated fault zones. Data indicate that shallow groundwater is intermittently present in canyon alluvial fill.

Nitrate in groundwater from Burn Site wells is attributed to non-point sources. The Burn Site monitoring wells with nitrate concentrations currently (as of December 2007) exceeding the MCL of 10 mg/L expressed as nitrogen are CYN-MW3 and CYN-MW6. The downgradient extent of the nitrate-contaminated groundwater has been defined.

Organic constituents present in BSG are not considered to be COCs because concentrations are less than EPA and state standards. However, these constituents do provide information about groundwater flow and contaminant migration. These organic contaminants may have moved with wastewater or jet fuel, entering bedrock at buried exposures of the brecciated fault zones that cross the Burn Site. Trace concentrations of HE constituents in groundwater are attributed to the open detonation of HE. These constituents may have been concentrated by evapotranspiration and mobilized by infiltrating precipitation and runoff, migrating to fault zones and to the water table.

Perchlorate in groundwater from Burn Site wells is attributed to non-point sources and is not considered to be a COC because concentrations do not pose an unacceptable risk to human health. The very low concentrations of perchlorate in groundwater from Burn Site well CYN-MW6 is attributed to non-point sources either from nitrate disseminated from open detonation of perchlorate bearing

explosives from 1967 until the early 1980s from SWMU 65 or from naturally concentrated perchlorate present in rainwater that has been evaporated or transpired from alluvial deposits in Lurance Canyon. The downgradient extent of the perchlorate-contaminated groundwater has been defined.

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APPENDIX A
Contaminant Concentrations in Burn Site Groundwater

This Appendix presents historical (1998) through more recent (December 2007) concentrations of the nitrate, diesel range organics, and perchlorate. Figure 1-2 illustrates the complete Burn Site monitoring well network. The BSG monitoring wells with nitrate concentrations currently (as of December 2007) exceeding the EPA maximum contaminant level (MCL) of 10 mg/L expressed as nitrogen are CYN-MW3 and CYN-MW6.

Figures A-1 through A-7 are plots of concentration versus time for nitrate at each well in the BSG monitoring well network. Nitrate was measured as nitrate or nitrate plus nitrite (NPN). Both measurements were expressed as nitrogen in order to compare to the MCL of 10 mg/L expressed as nitrogen. Figure A-8 is a plot of DRO at selected Burn Site area wells. Figure A-9 is a plot of concentration versus time for perchlorate at CYN-MW6, the only Burn Site area well with detectable concentrations of perchlorate. Where applicable, non-detect results are plotted as the method detection limit on these figures.

These data resulted in the following observations:

- As shown in Figure A-1, concentrations of nitrate or NPN in samples from CYN-MW1D from 1997 through 2004 were above the MCL (ranging from 10 to 28 mg/L). However, beginning in 2005 the nitrate or NPN concentrations in samples from CYN-MW1D have dropped to below the MCL (ranging from 0.6 to 5.1 mg/L).
- As shown in Figure A-2, concentrations of nitrate or NPN in samples from CYN-MW3 have generally been above the MCL (ranging as high as 22 mg/L), with a mean concentration of 12.4 mg/L.
- As shown in Figure A-3, concentrations of nitrate or NPN in samples from CYN-MW4 have generally been very low (<1.0 mg/L) with a maximum measured concentration of 0.65 mg/L and a mean concentration of 0.13 mg/L.
- As shown in Figure A-4, concentrations of nitrate or NPN in samples from CYN-MW5 have been below the MCL (ranging from 1.3 to 2.6 mg/L), with a mean concentration of 2.1 mg/L.
- As shown in Figure A-5, concentrations of nitrate or NPN in samples from CYN-MW6 have been above the MCL (ranging from 22.2 to 32.6 mg/L), with a mean concentration of 26.6 mg/L.
- As shown in Figure A-6, concentrations of nitrate or NPN in samples from CYN-MW7 have been below the MCL with a maximum measured concentration of 2.3 mg/L and a mean concentration of 1.4 mg/L.

• As shown in Figure A-7, concentrations of nitrate or NPN in samples from CYN-MW8 have been below the MCL with a maximum measured concentration of 5.9 mg/L and a mean concentration of 4.8 mg/L.

• As shown in Figure A-8, since approximately 2003 there is generally a gradual decrease in DRO concentrations in samples from the monitoring wells in the Burn Site monitoring well network.

• As shown in Figure A-9, concentrations of perchlorate in samples from CYN-MW6 have all been above the required screening level mandated by the Compliance Order on Consent (ranging as high as 8.9 μg/L), with a mean concentration of 7.0 μg/L.

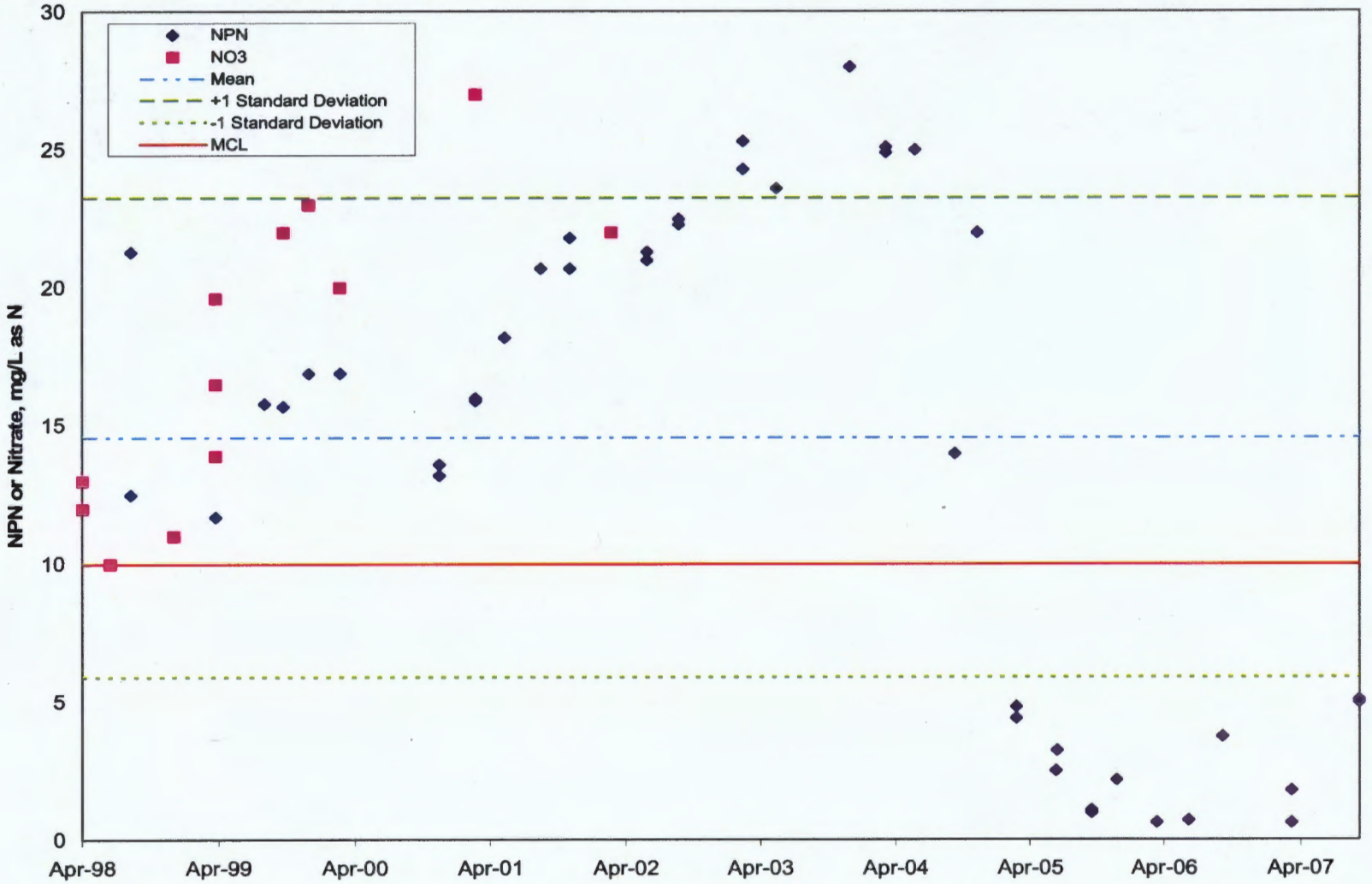

Figure A-1. Concentrations of nitrate or NPN (expressed as nitrogen) in samples from CYN-MW1D through December 2007.

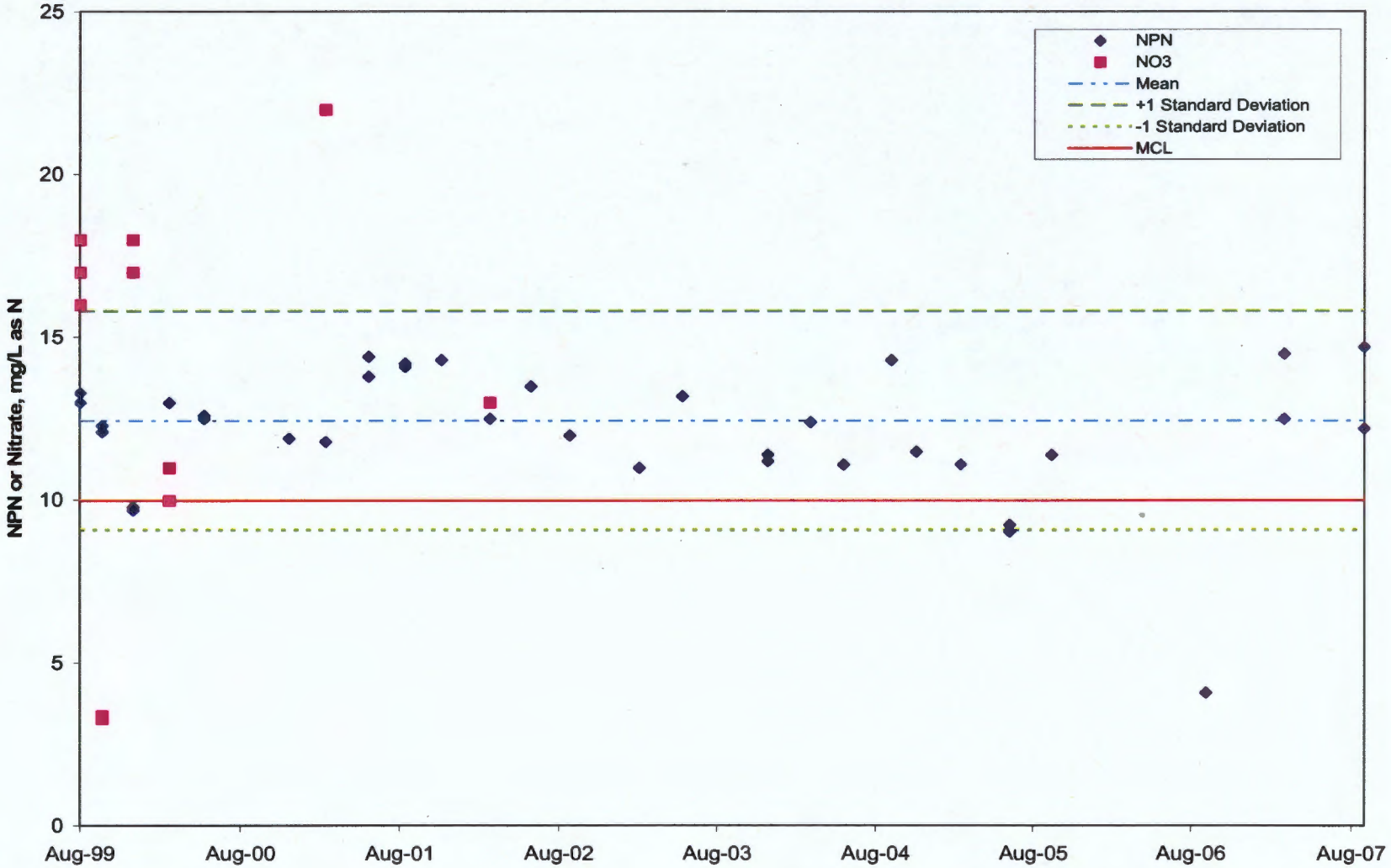

Figure A-2. Concentrations of nitrate or NPN (expressed as nitrogen) in samples from CYN-MW3 through December 2007.

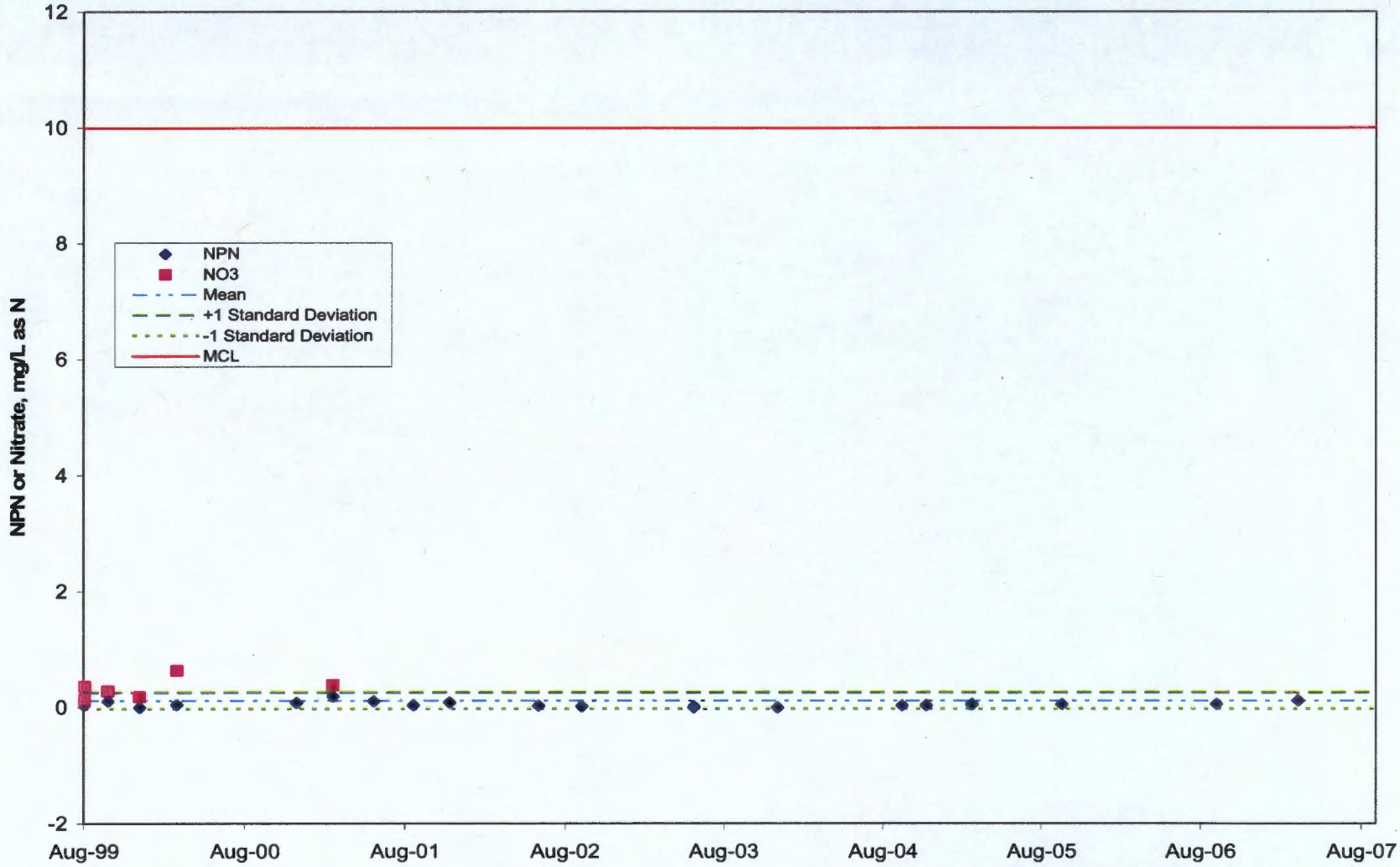

Figure A-3. Concentrations of nitrate or NPN (expressed as nitrogen) in samples from CYN-MW4 through December 2007.

Figure A-4. Concentrations of nitrate or NPN (expressed as nitrogen) in samples from CYN-MW5 through December 2007.

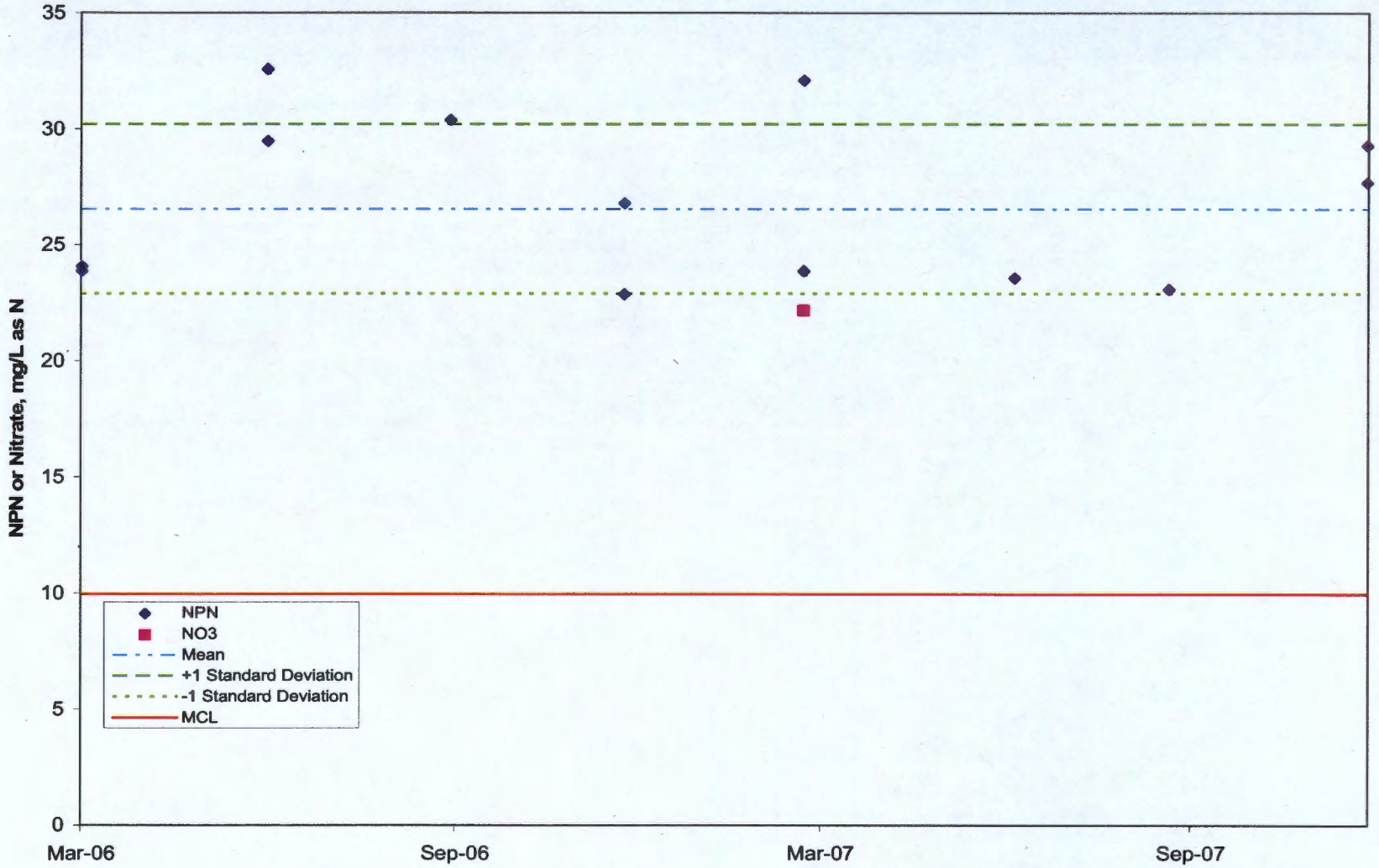

Figure A-5. Concentrations of nitrate or NPN (expressed as nitrogen) in samples from CYN-MW6 through December 2007.

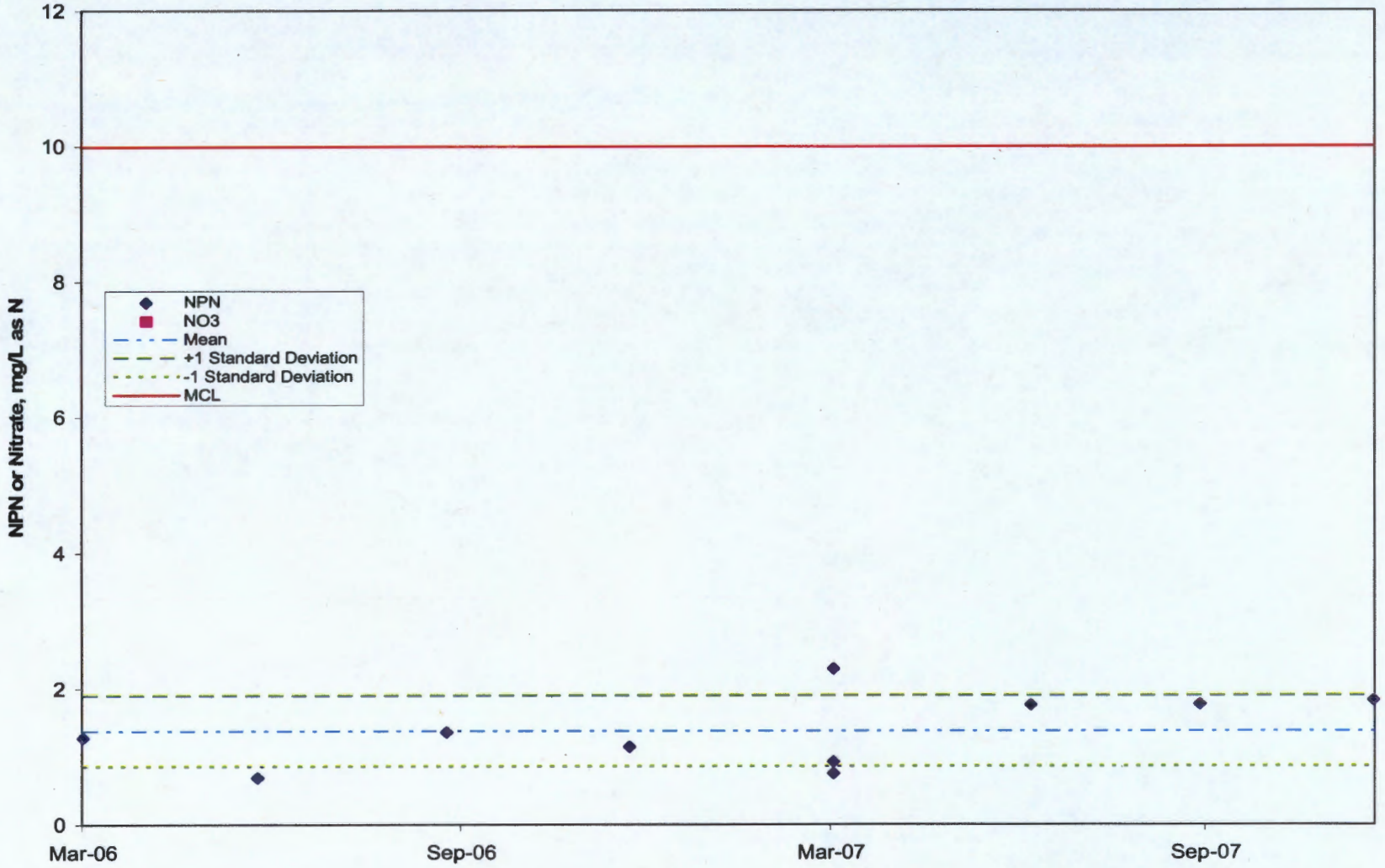

Figure A-6. Concentrations of nitrate or NPN (expressed as nitrogen) in samples from CYN-MW7 through December 2007.

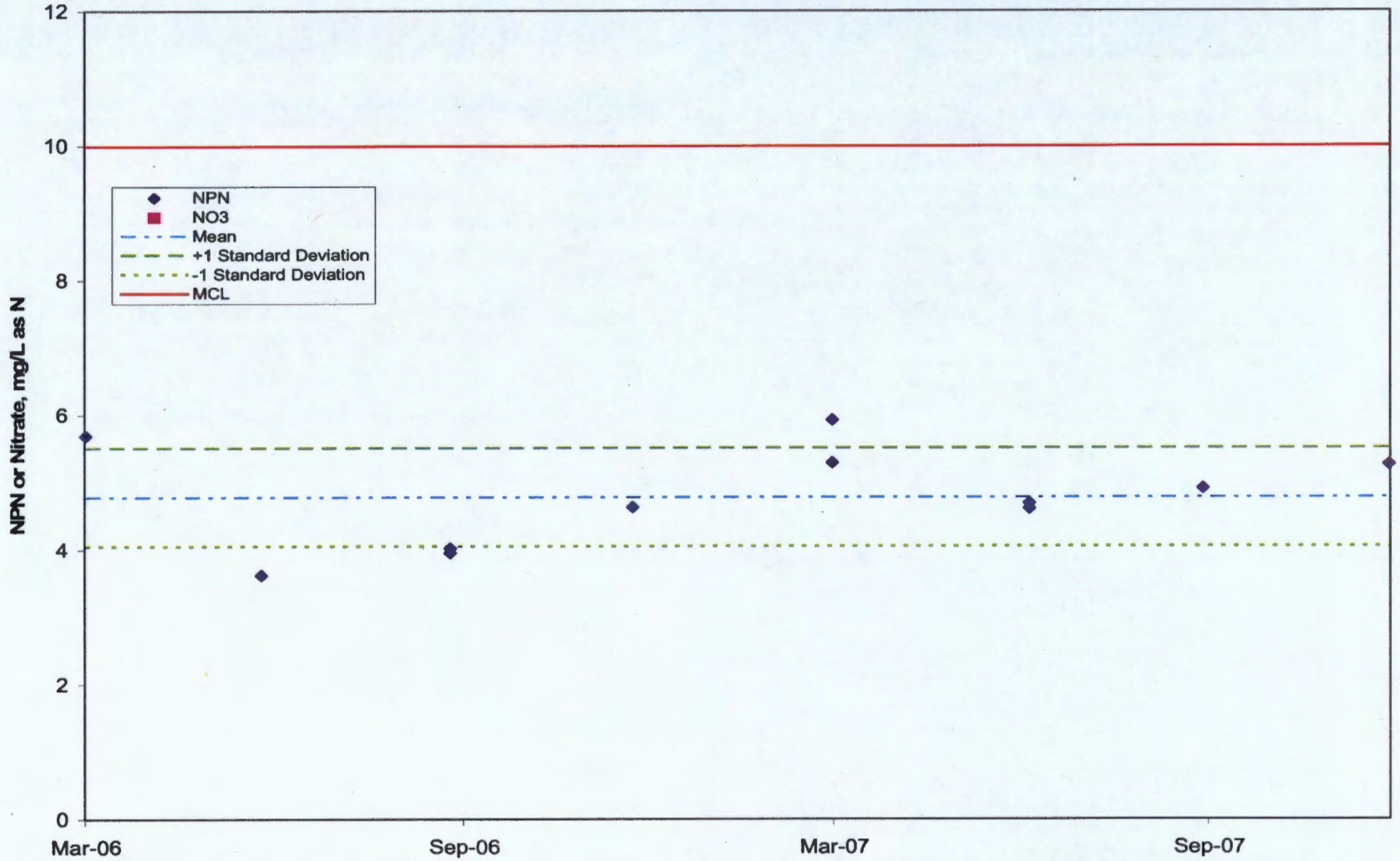

Figure A-7. Concentrations of nitrate or NPN (expressed as nitrogen) in samples from CYN-MW8 through December 2007.

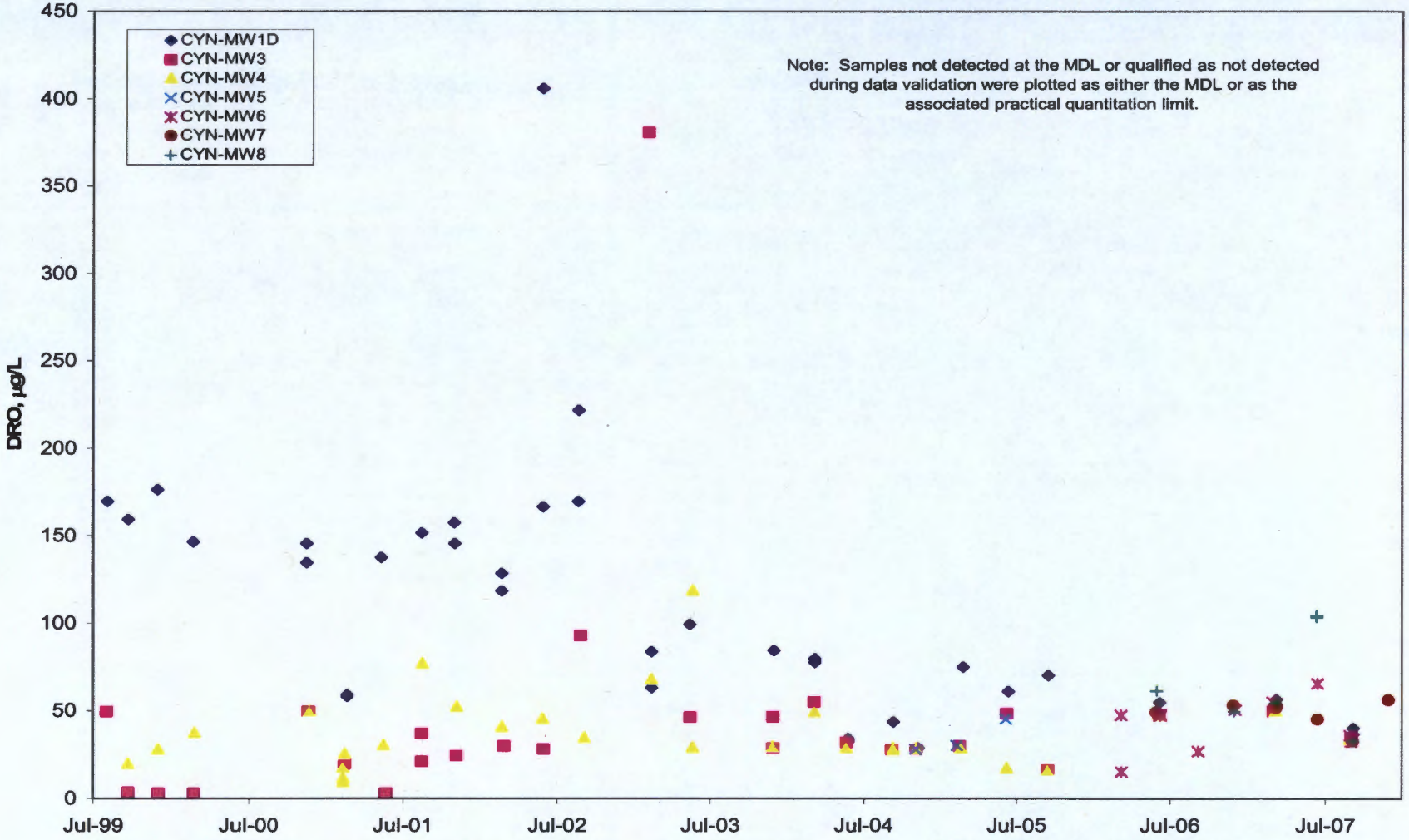

Figure A-8. Concentrations of DRO in samples from select Burn Site monitoring wells through December 2007.

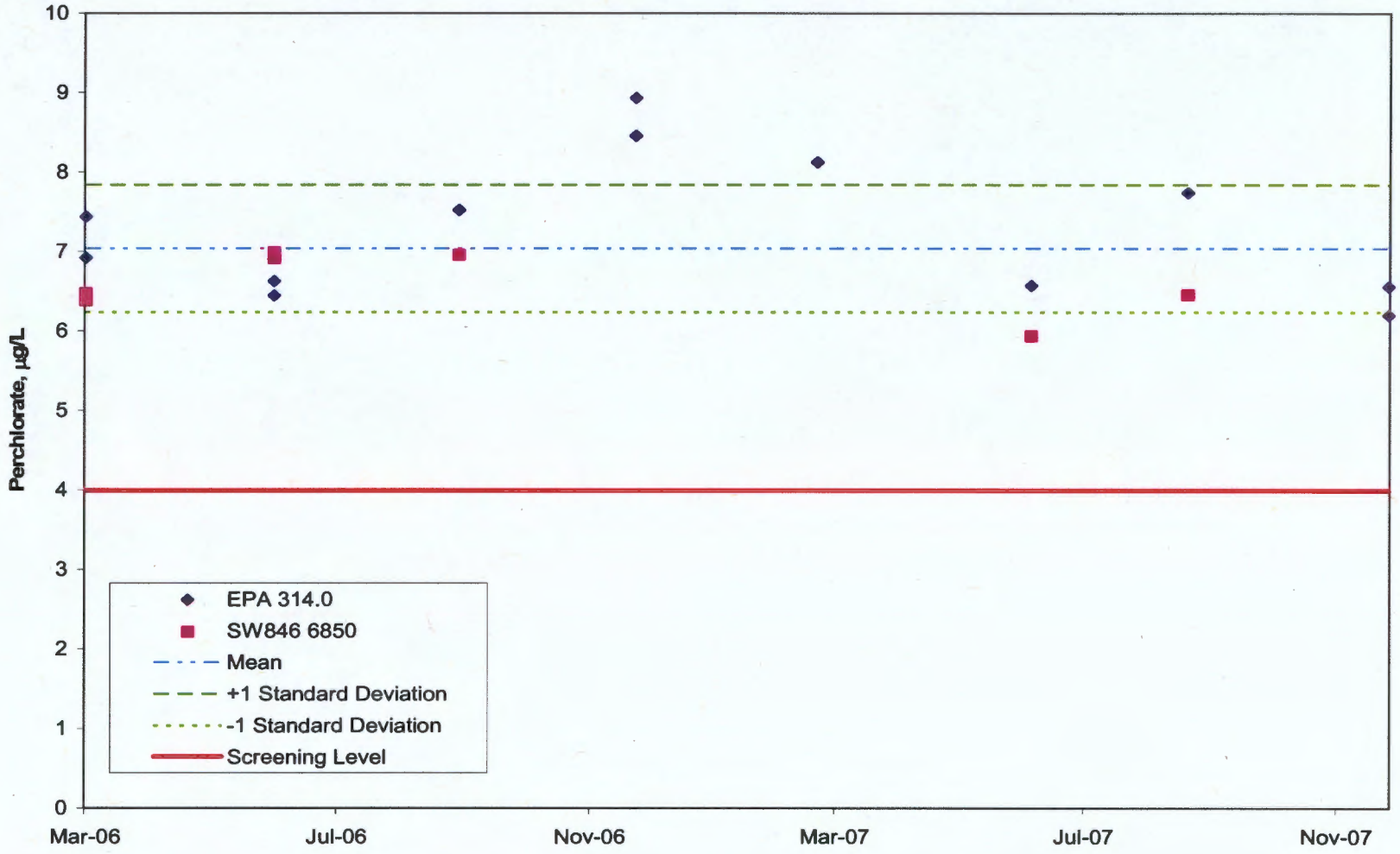

Figure A-9. Concentrations of perchlorate in samples from CYN-MW6 through December 2007.