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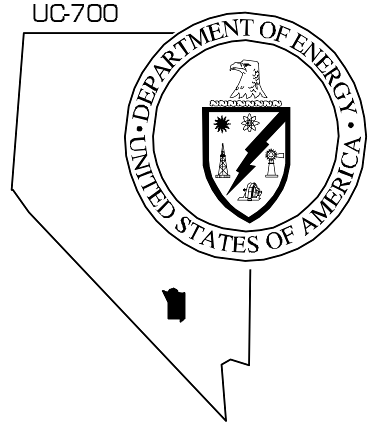

Corrective Action Investigation Plan for the Central Nevada Test Area Subsurface Sites (Corrective Action Unit No. 443)

Controlled Copy No.:______

Revision No.: 0

February 1998

Environmental Restoration
Division

U.S. Department of Energy
Nevada Operations Office

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CORRECTIVE ACTION INVESTIGATION PLAN FOR THE CENTRAL NEVADA TEST AREA SUBSURFACE SITES (CORRECTIVE ACTION UNIT NO. 443)

DOE Nevada Operations Office
Las Vegas, Nevada

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CORRECTIVE ACTION INVESTIGATION PLAN
FOR THE CENTRAL NEVADA TEST AREA
SUBSURFACE SITES
(CORRECTIVE ACTION UNIT NO. 443)

Approved by: ______________________________ Date: 2/12/98
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List of Acronyms and Abbreviations

AEC	U.S. Atomic Energy Commission
Am	Americium
Ar	Argon
ASTM	American Society for Testing and Materials
C	Carbon
Ca	Calcium
CAIP	Corrective Action Investigation Plan
CAS	Corrective Action Site
CAU	Corrective Action Unit
CFR	*Code of Federal Regulations*
Cl	Chlorine
Cm	Curium
CNTA	Central Nevada Test Area
Co	Cobalt
Cs	Cesium
DOE	U.S. Department of Energy
DQO	Data quality objective
Eu	Europium
ft	Foot (feet)
ft^2	Square foot (feet)
H	Hydrogen
I	Iodine
in.	Inch(es)
K	Hydraulic conductivity
k_d	Distribution coefficient
kg	Kilogram(s)
km	Kilometer(s)
km^2	Square kilometer(s)
Kr	Krypton
m	Meter(s)
mg/kg	Milligram(s) per kilogram
mg/L	Milligram(s) per liter
m/d	Meter(s) per day

List of Acronyms and Abbreviations *(Continued)*

μg/kg	Microgram(s) per kilogram
mi	Mile(s)
mi^2	Square mile(s)
m/yr	Meter(s) per year
mrem/yr	Millirem(s) per year
Na	Sodium
Ni	Nickel
Pm	Promethium
PTRW	Particle-tracking random walk simulation method
Pu	Plutonium
pCi/L	Picocurie(s) per liter
REECo	Reynolds Electrical and Engineering Company, Inc.
Sb	Antimony
Sm	Samarium
Sn	Tin
Sr	Stontium
Tc	Technetium
TCLP	Toxicity Characteristic Leaching Procedure
U	Uranium

1.0 Introduction

This Corrective Action Investigation Plan (CAIP) describes the U.S. Department of Energy's (DOE's) planned environmental investigation of the subsurface Central Nevada Test Area (CNTA) Corrective Action Unit (CAU) No. 443. The CNTA is located in Hot Creek Valley in Nye County, Nevada, adjacent to U.S. Highway 6, about 48 kilometers (km) (30 miles [mi]) north of Warm Springs, Nevada. The CNTA was the site of Project Faultless, a nuclear device detonated in the subsurface by the U.S. Atomic Energy Commission (AEC) in January 1968. The purposes of this test were to gauge the seismic effects of a relatively large, high-yield detonation completed in Hot Creek Valley (outside the Nevada Test Site) and to determine the suitability of the site for future large detonations. The yield of the Faultless test was between 200 kilotons and 1 megaton. Two similar tests were planned for the CNTA, but neither of them was completed (AEC, 1974).

1.1 Purpose

The purpose of the subsurface investigation, as described in Appendix VI of the *Federal Facility Agreement and Consent Order,* is to evaluate groundwater flow and potential contaminant transport at the CNTA. This will be accomplished by conducting hydrogeologic modeling the results of which will be used to predict a CAU boundary that encompasses the extent of any groundwater contamination.

1.2 Scope

A three-dimensional flow and transport model will be constructed for the Central Nevada Test Area subsurface. The model will be developed to locate an acceptable contaminant boundary within which water use restrictions will be implemented to prevent exposure to partially contaminated groundwater. Existing information will be used to provide input parameters to the flow and transport modeling.

In the first major decision point for the Central Nevada Test Area Subsurface Corrective Action Investigation, a determination will be made as to whether the modeling results are acceptable (Figure 1-1). The shaded portion of the diagram illustrates the portion of the process that will take place during the Corrective Action Investigation. If the modeling results are accepted, then a boundary will be established, and the results will be presented to the Nevada Division of

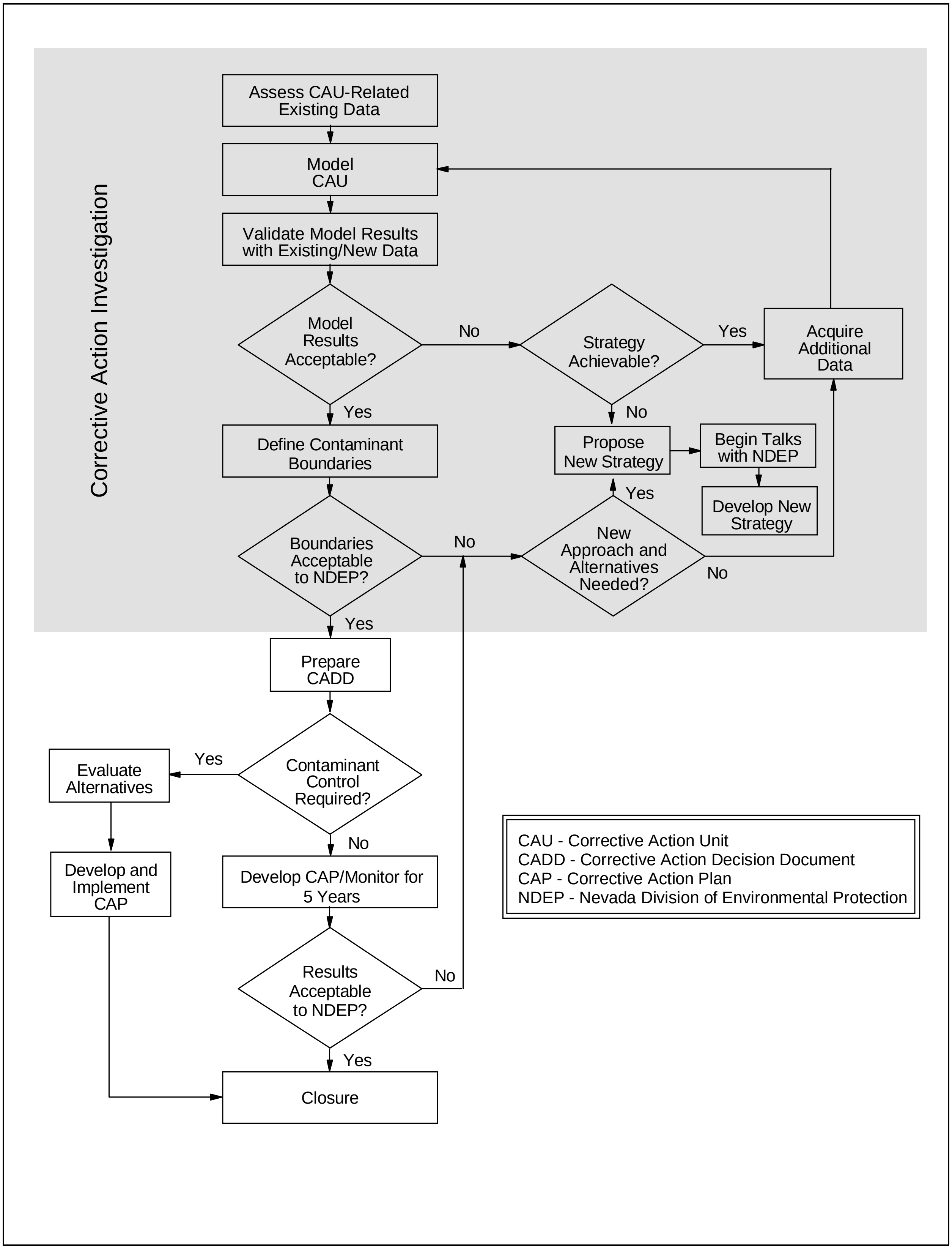


Figure 1-1
Process Flow Diagram for Underground Test Area Corrective Action Units

Environmental Protection. If the State agrees to the boundary, a monitoring network will be designed, and compliance criteria will be recommended. If the State agrees to the monitoring network design, a Corrective Action Decision Document will be prepared.

1.3 Summary of the CAIP

Section 1.0 introduces the purpose and scope of the CAIP. Section 2.0 states the legal/regulatory requirements. Section 3.0 describes the investigative background and site history, lists the Corrective Action Sites (CASs), and discusses the physical setting and historic waste inventory. Section 3.0 also contains a conceptual model of the CAU and covers the Corrective Action levels. The Data Quality Objectives (DQOs) process is summarized in Section 4.0, and Appendix A presents the DQO worksheets. Section 5.0, which describes the Corrective Action Investigation, details the modeling approach, including model selection, model attributes, data availability, model validation, the definition of contaminant boundaries, and determination of model acceptability. Section 6.0 discusses the topic of field investigation, Section 7.0 is quality assurance, and Section 8.0 covers the availability of data and other records. Section 9.0 is a reference list.

2.0 Overall Legal/Regulatory Requirements

2.1 Federal Facility Agreement and Consent Order

The regulatory driver for conducting this Corrective Action Investigation is the *Federal Facility Agreement and Consent Order* (1996). In addition, U.S. Department of Energy policies, regulations, and orders also apply.

3.0 Description of Corrective Action Unit

3.1 Investigative Background

Investigations of the geology and hydrogeology of the CNTA and surrounding region have taken place from the late 1960s to the present, encompassing geologic mapping, geophysical logging, analysis of water chemistry (including major ions, metals, and both stable and radioactive isotopes), and hydraulic testing. Site investigation activities associated with CNTA have been identified and documented in the *Final Environmental Impact Statement for the Nevada Test Site and Off-Site Locations in the State of Nevada* (DOE, 1996a).

Geologic maps of the area have been produced by Anderson et al. (1967), Ekren et al. (1968; 1970; 1973a; 1973b), and Quinlivan and Rogers (1974). Overviews of regional geology are provided by Fiero et al. (no date) and Rush and Everett (1966). Site-specific stratigraphy based on drill cores and cuttings is discussed by Hoover (1968) and Thordarson (1987). McKeown et al. (1970) examine the geologic phenomena resulting from the detonation, a topic also touched on by Dinwiddie and West (1970). Geophysical logs, cores, and cuttings from over 20 wells in central Nevada are available for study at the U.S. Geological Survey Core Library in Mercury, Nevada (Magner, 1996).

Hydraulic test results are given by Dinwiddie (1968; 1969a; 1969b; 1970a; 1970b; 1970c; 1970d), Dinwiddie and Schroder (1971), and Thordarson (1987). Potentiometric surface data were provided by Dinwiddie (1972), Dinwiddie and Schroder (1971), Dinwiddie and West (1970), Fiero et al. (no date), Fiero and Illian (1969), Rush and Everett (1966), and Thordarson (1985; 1987), with Dinwiddie (1972), Dinwiddie and West (1970), and Thordarson (1985; 1987) focusing on post-detonation changes to water levels in the area.

Regional flow systems are described by Dinwiddie and Schroder (1971), Fiero et al. (no date), Fiero and Illian (1969), two studies by Fiero et al. (1974; no date), and Rush and Everett (1966). The flow model of the CNTA will rely principally on 91 hydraulic head measurements. Most of these values were measured in the mid-1960s while some, particularly several local supply wells, have measurement dates in the 1950s and even 1940s (Rush and Everett, 1966). The Hot Creek Valley hydrologic system is large and has not been subject to excessive withdrawals (1,890 acre-feet per year were committed out of a perennial yield of 5,500 as of 1988; State of Nevada, 1988) such that significant fluctuations in regional water levels are not expected through time. Despite the probable steady-state conditions, confirmation of current regional water levels was considered desirable to allow greater certainty to be placed on the head values used for the modeling. Water levels were determined from available wells in Hot Creek Valley, the northern portion of Reveille Valley, and the southern portion of Big Sand Springs Valley between August 11, 1997, and August 17, 1997. A total of 34 wells were investigated, four of which were dry and 10 of which did not have access for measuring equipment. The potentiometric map produced using those data is consistent with the previous one, describing groundwater flow basically down the valley axis, from north to south Local hydrologic conditions at CNTA have been monitored for many years and reveal a complex near-field system affected by the nuclear test (Thordarson, 1985 and 1987; Chapman et al., 1994; Davisson et al., 1994; Mihevc et al., 1996). Recent hydrologic logging and sampling have continued with a data collection effort between October 20 and 26, 1997. Chemical and temperature logs were run in wells HTH-1, HTH-2, UC-1-P-1S, and UC-1-P-2SR, and flowmeter measurements made. Samples were collected for major ions, metals, and stable isotope analysis. In addition, chimney water was also collected for analysis of source term parameters such as strontium-90 (^{90}Sr), gamma emitters (cobalt-60 [^{60}Co], antimony-125 [^{125}Sb], cesium-137 [^{137}Cs]), carbon-14, and tritium. Analytical results and data interpretation are pending.

Water chemistry data are provided by Buddemeier et al. (1985), Chapman et al. (1994), Davisson et al. (1994), Dinwiddie (1972), Dinwiddie and West (1970), Dinwiddie and Schroder (1971), Fiero et al. (1974), Mihevc et al. (1996), Nork et al. (1971), Rush and Everett (1966), Schroder et al. (1971), and Thordarson (1985; 1987).

Nork et al. (1971) supply distribution coefficients (k_d) values for calcium-45 (^{45}Ca), ^{85}Sr, and ^{137}Cs determined from laboratory studies using rock samples from drill holes in Hot Creek Valley. Additional sorption experiments are currently underway using CNTA cores previously stored at the U.S. Geological Survey Core Library in Mercury, Nevada. The study will generate the geochemical parameters describing equilibrium partitioning of radionuclides and contaminants of concern between the aqueous phase and aquifer material. The mineralogic composition of the rocks has been determined. Experiments are being conducted with both cations and anions. Strongly and weakly binding cations and anions are used to establish sorption parameters corresponding to limiting transport scenarios. Lead and strontium cations are used as strongly and weakly binding cation analogs, respectively. Selenite and chromate anions will be used as strongly and weakly binding anion analogs, respectively. Parametric sorption studies will be conducted as a function of pH, solid and solute concentration, and solution composition.

Site demobilization activities are described by the AEC (1973; 1974) and Eberline Instrument Corporation (1973).

Two analyses of the human health risk caused by migration of contaminants in groundwater from the Faultless cavity have been performed. Pohlmann et al. (1995) modeled potential migration of tritium away from the cavity and evaluated the risk due to tritium to an individual consuming groundwater for a lifetime centered around the peak tritium concentration as part of the Environmental Impact Statement for DOE activities in Nevada. Johnson et al. (1996) employed the same scenario and transport parameters identified by Pohlmann et al. (1995), but used a nuclear reactor computer code to calculate the source term. In addition, they considered risk due to cesium and strontium, but found that the risk due to these two contaminants is effectively zero.

The U.S. Environmental Protection Agency, which monitors groundwater around CNTA annually as part of the Long Term Hydrologic Monitoring Program, has consistently found tritium concentrations below the minimum detectable concentration (approximately seven to ten picocuries per liter [pCi/L]). They conclude that, to date, migration into the sampled wells has not taken place and that no event-related radioactivity has entered area drinking water supplies (Chaloud et al., 1992).

3.2 Site History

The CNTA consisted of several separate land withdrawals, land easements, and special land-use permits obtained by the AEC from the U.S. Bureau of Land Management. For the Faultless device emplacement boring (UC-1), a 2.59-square-kilometer (km^2) (one-square-mile [mi^2]) land withdrawal was formalized between the AEC and U.S. Bureau of Land Management on December 6, 1968, under Public Land Order #4338. On December 2, 1969, subsequent additional withdrawals were made for emplacement borings UC-3 and UC-4 under Public Land Order #4748. The withdrawals for the UC-3 and UC-4 sites are larger than the UC-1 site by about 1.3 km^2 (0.5 mi^2). Other permits and easements were obtained for exploratory borings, weather stations, and miscellaneous support facilities in Hot Creek Valley. In total, the CNTA consisted of about 20 separate properties.

Under the direction of the AEC, the CNTA was operated and maintained by Holmes and Narver and its subcontractors. Other federal agencies assisted in the operations, including the following:

- National Environmental Research Center (formerly the U.S. Public Health Service)
- Air Resources Laboratory (formerly the U.S. Weather Bureau)
- U.S. Geological Survey
- National Ocean Service

Scientific programs at the CNTA, implemented by AEC subcontractors, were jointly administered by Lawrence Livermore National Laboratory and Los Alamos Scientific Laboratory (AEC, 1974).

Project Faultless facilities consisted of a base camp and a separate control point area (Figure 3-1). Originally, the Base Camp was a temporary Holmes and Narver support camp, but during 1968 and 1969, after the Faultless project, the Base Camp and the Control Point areas were improved for reuse. Selected facilities were purchased from Holmes and Narver, new buildings were constructed, and other buildings were replaced with portable trailers from the Nevada Test Site.

Emplacement boring UC-1 was completed about 35 km (22 mi) north of Base Camp at Nevada State coordinates (central zone) North 1,414,340 feet (ft), East 629,000 ft (AEC, 1974). The boring was advanced through about 700 meters (m) (2,300 ft) of alluvium and penetrated a confined aquifer in volcanic tuff (DRI, 1988). The two additional emplacement borings (UC-3 and UC-4) were also completed as planned about 4.8 km (3 mi) to the north (UC-4) and south (UC-3) of UC-1. Emplacement boring UC-3 and additional support facilities were to be used for Project Adagio, but the project was never completed. Similarly, emplacement hole UC-4 was to be used for a future project (unnamed), but the project was never completed (AEC, 1973).

Large-diameter, deep boreholes were completed for the emplacement borings. Boring UC-1 is a 1.8-m (72-inch [in.]) to 1.0-m (42-in.) diameter borehole advanced to 998 m (3,275 ft) below grade. It is cased from grade to about 122 m (400 ft) below grade with 1.2-m (48-in) and 0.27-m (10.75-in.) casing. Boring UC-3 is a 3-m (120-in.) diameter borehole advanced to 1,477 m (4,846 ft) below grade. It is cased from grade to 1,458 m (4,782 ft) below grade with 1.3-m (54-in.) casing. Boring UC-4 is a 3.6-m (144-in.) to 3-m (120-in.) diameter borehole advanced to 1,676 m (5,500 ft) below grade. UC-4 is cased with 3.1-m (122-in.) casing from grade to 127 m

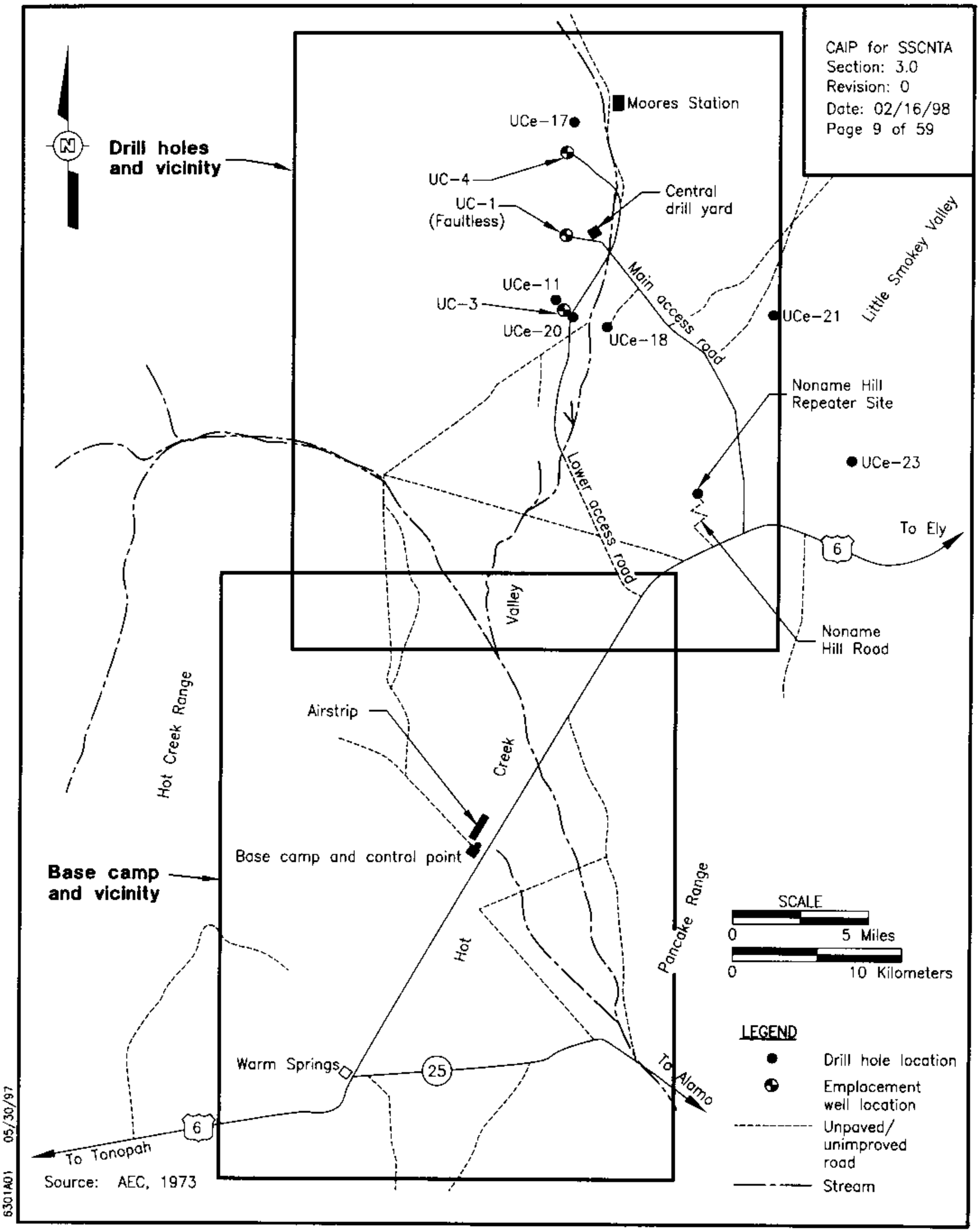


Figure 3-1
Site Map, Central Nevada Test Area, Nye County, Nevada

(415 ft) below grade and is uncased from that depth to the bottom of the hole (Fenix and Scisson, 1973).

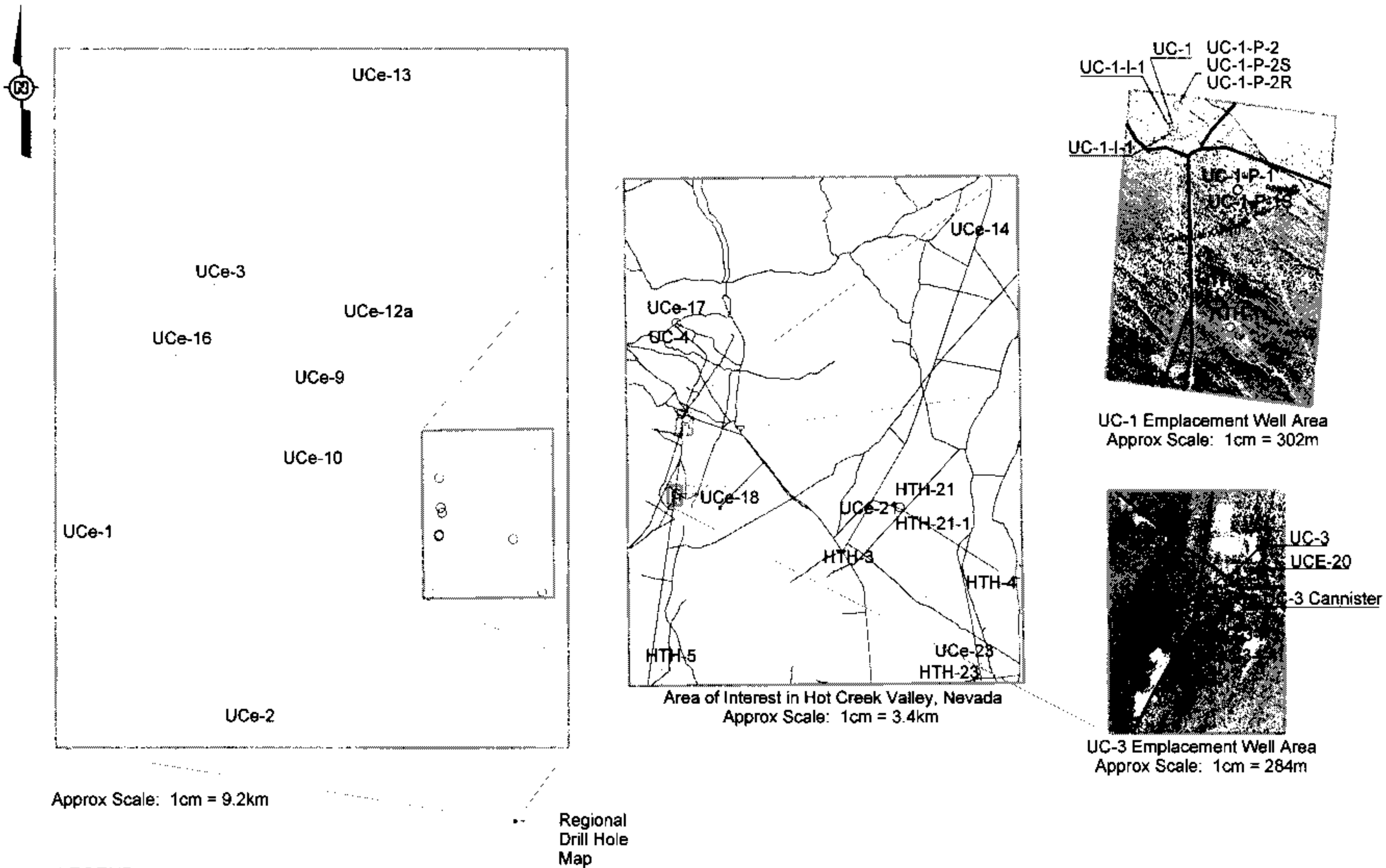
In addition to the three emplacement borings completed at the CNTA, several other boreholes were completed for pre-shot and post-shot hydrologic testing and geologic exploration (Figure 3-2). Eight boreholes were completed to install downhole instruments for the Faultless event; eight borings were completed for hydrologic testing; and fifteen boreholes were completed for geologic exploration. Three additional boreholes were completed for post-shot hydrologic and geologic testing. The depths of the test boreholes and wells ranged from about 94 m (307 ft) to 1,986 m (6,516 ft) (Fenix and Scisson, 1973).

The Faultless device was detonated on January 19, 1968, at a depth of 975.4 m (3,200 ft) in emplacement boring UC-1. The shot breached both the volcanic unit at the working point and the overlying surficial alluvium. The detonation produced an asymmetric collapse graben bounded by several fractures and scarps evident in the surface ground zero area. Surface fractures range up to 2,700 m (9,000 ft) long. The surface expression of the graben is irregular in comparison to the typical, shallow, cone-shaped or semicircular craters generally characteristic of subsurface detonations.

The surface ground zero area is now a nearly triangular subsidence block bounded by fresh fault scarps. Typical maximum vertical fracture displacements at surface ground zero are about 4 m (15 ft), and horizontal offsets are about 1 m (3 ft). Some of the displacement occurred at the time of detonation, with additional displacement related to post-shot subsidence. The total surficial area of subsidence is about 371.6 m^2 (4,000 square feet [ft^2]). Seismic data from the test were approximately the same as predicted by the Environmental Research Corporation (DRI, 1988).

The CNTA site was decommissioned in 1973, and demobilization of the site commenced. All drilling sites, equipment, support facilities, and materials, including radiologically contaminated materials, were addressed in the site demobilization. In addition, areas disturbed by AEC operations were delineated. The DOE retained control of some limited areas, while the U.S. Bureau of Land Management and the U.S. Air Force assumed responsibility for most of the area. Most borings and wells were abandoned, but five wells were left open for the CNTA Long-Term Hydrologic Monitoring Program (AEC, 1973; 1974).

Figure 3-2
Boring and Well Locations, Central Nevada Test Area



Area of Interest in Hot Creek Valley, Nevada
Approx Scale: 1cm = 3.4km

UC-1 Emplacement Well Area
Approx Scale: 1cm = 302m

UC-3 Emplacement Well Area
Approx Scale: 1cm = 284m

LEGEND

- Drill hole
- Road
- Contours
- Arroyo

Source: Photos obtained from DOE/NV Remote Sensing Lab

The abandonment of emplacement wells UC-3 and UC-4 at CNTA is documented by Fenix and Scisson (1973) and AEC (1973; 1974). The well casings at both wells UC-3 and UC-4 are sealed at the surface by a 5-centimeter (2-in.) thick steel plate and a 0.6-m (2-ft) thick reinforced concrete pad. The plates were welded to the casing; then a reinforced concrete pad measuring about 4 by 4 by 0.6 m (14 by 14 by 2 ft) was poured over each wellhead.

The DOE, Lawrence Livermore National Laboratory, and Los Alamos Scientific Laboratory completed several pre-shot and post-shot research projects at the CNTA, including post-shot radiological safety surveys. A radiological survey was completed by Reynolds Electrical and Engineering Company, Inc. (REECo) in 1973 prior to demobilization and restoration of the CNTA site. The survey detected only background radioactivity (REECo, 1973). A second radiological and hazardous waste survey was completed by REECo in 1986 at several off-site DOE facilities, including the CNTA. Again, at the CNTA, only background radiation was detected, but chromium (from a drilling mud additive) was detected in an uncovered drilling mud pit (REECo, 1986).

3.3 Corrective Action Sites

The CNTA subsurface CAU No. 443 consists of three CASs, boreholes UC-1, UC-3, and UC-4, all of which were planned as device emplacement holes. However, only UC-1 was used for the Faultless test, and neither UC-3 nor UC-4 was used as a test site. During the DQO process, it was determined that UC-3 was just an open, cased shaft which should not be evaluated further because there is no evidence of any associated subsurface contamination. Table 3-1 lists the coordinates, depth, and CAS number for each CAS. In accordance with the requirements in the *Federal Facility Agreement and Consent Order*, DOE will propose to the State of Nevada that CAS 58-30-01 (UC-3) be transferred to the *Federal Facility Agreement and Consent Order* Appendix IV, “Corrective Action Strategy.”

3.4 Physical Setting

3.4.1 Regional Setting

Regional groundwater conditions at the CNTA have been generally outlined in several previous studies of the Hot Creek Range and Hot Creek Valley vicinity by DOE, the Desert Research Institute, and the U.S. Geological Survey. The CNTA is located near the eastern flank of the Hot

Table 3-1
Central Nevada Test Area Subsurface Corrective Action Sites

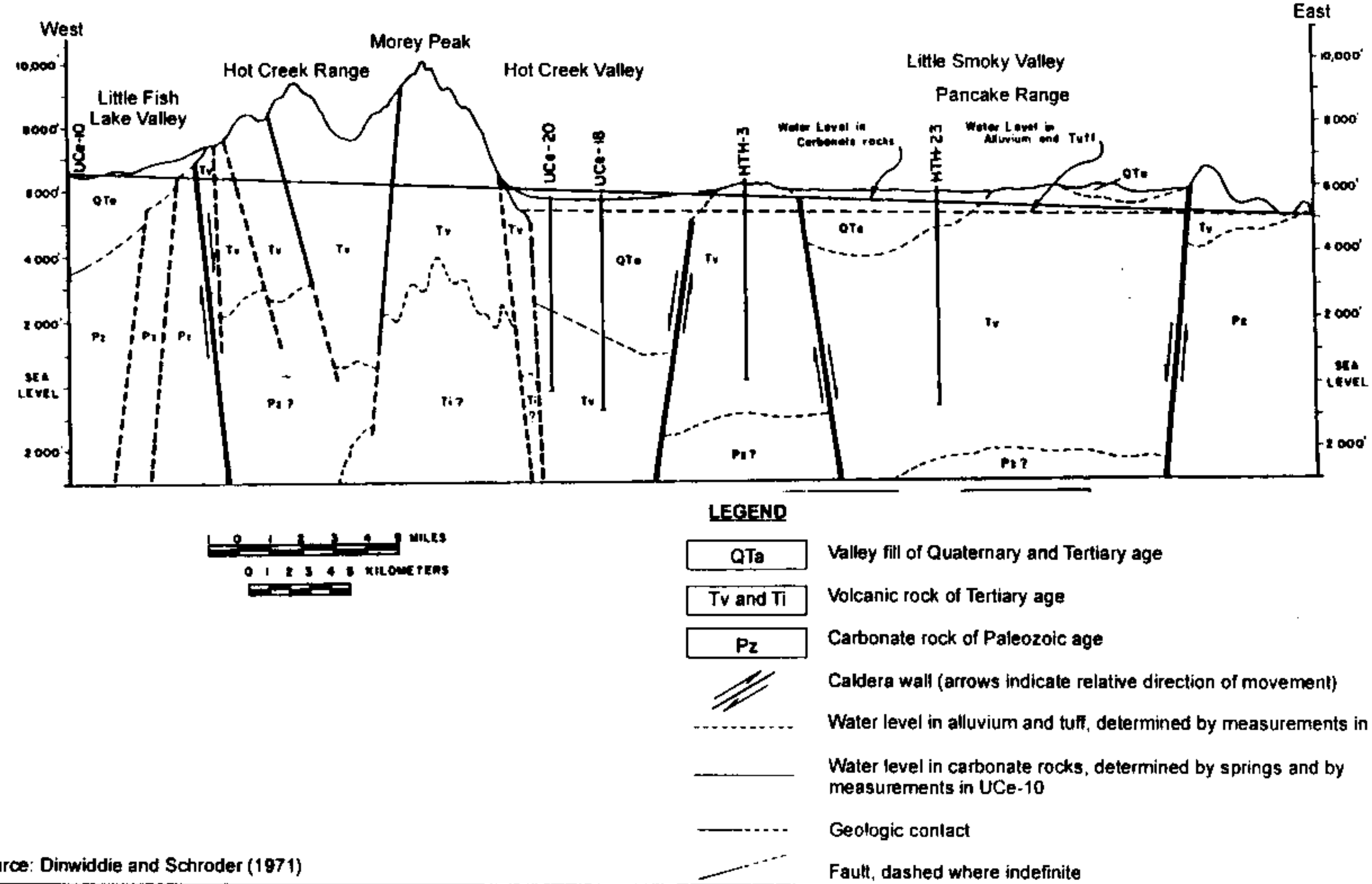
CAS Name	Nevada State Coordinates[a]	Total Depth m (ft)[b]	CAS No.
UC-1	N 1,414,339.91 E 628,920.87	998 (3,275)	58-57-001
UC-3	N 1,399,948.43 E 628,092.24	1,482 (4,862)	58-30-01
UC-4	N 1,430,564.49 E 628,253.4	1,676 (5,500)	58-03-02

[a]Nevada Central coordinates, NAD27, in feet
[b]m = meters; ft = feet

Creek Range on the western slope of the Hot Creek Valley coalesced alluvial fan system. The Hot Creek Valley and Range are a graben and horst pair typical of the Great Basin province in Nevada and the Basin and Range province in Nevada and California. The thick sequence of alluvium in the valley gradually thins to the west to meet the volcanic and carbonate units in the adjacent range. Rush and Everett (1966) mapped a groundwater flow divide in the range that splits groundwater into westerly and easterly components about 8 km (5 mi) west of the Faultless surface ground zero.

The hydrogeology of Hot Creek Valley is controlled, in part, by the Basin-and-Range topography. Figure 3-3 is a cross-sectional view across Hot Creek Valley, crossing near the UC-3 withdrawal area, showing geologic contacts and water levels. The valley is a long graben containing a sequence of Quaternary and Tertiary alluvial fill (up to 1200 m [3,937 ft]) underlain by a thick section of Tertiary volcanic rocks. The bounding ranges on either side of the valley contain Paleozoic carbonates overlain by Tertiary volcanics (Thordarson, 1987). Boreholes close to the site generally penetrate approximately 610 m (2,001 ft) of alluvium underlain by tuffaceous sediments and volcanic rocks.

Hydraulic head measurements are available for 91 unique positions within the regional hydrologic system (Dinwiddie and Schroder, 1971; Rush and Everett, 1966; Fiero et al., no date). The water table in Hot Creek Valley generally occurs within the alluvium. Figure 3-4 is a water



Source: Dinwiddie and Schroder (1971)

Figure 3-3
Cross Section Across Hot Creek Valley

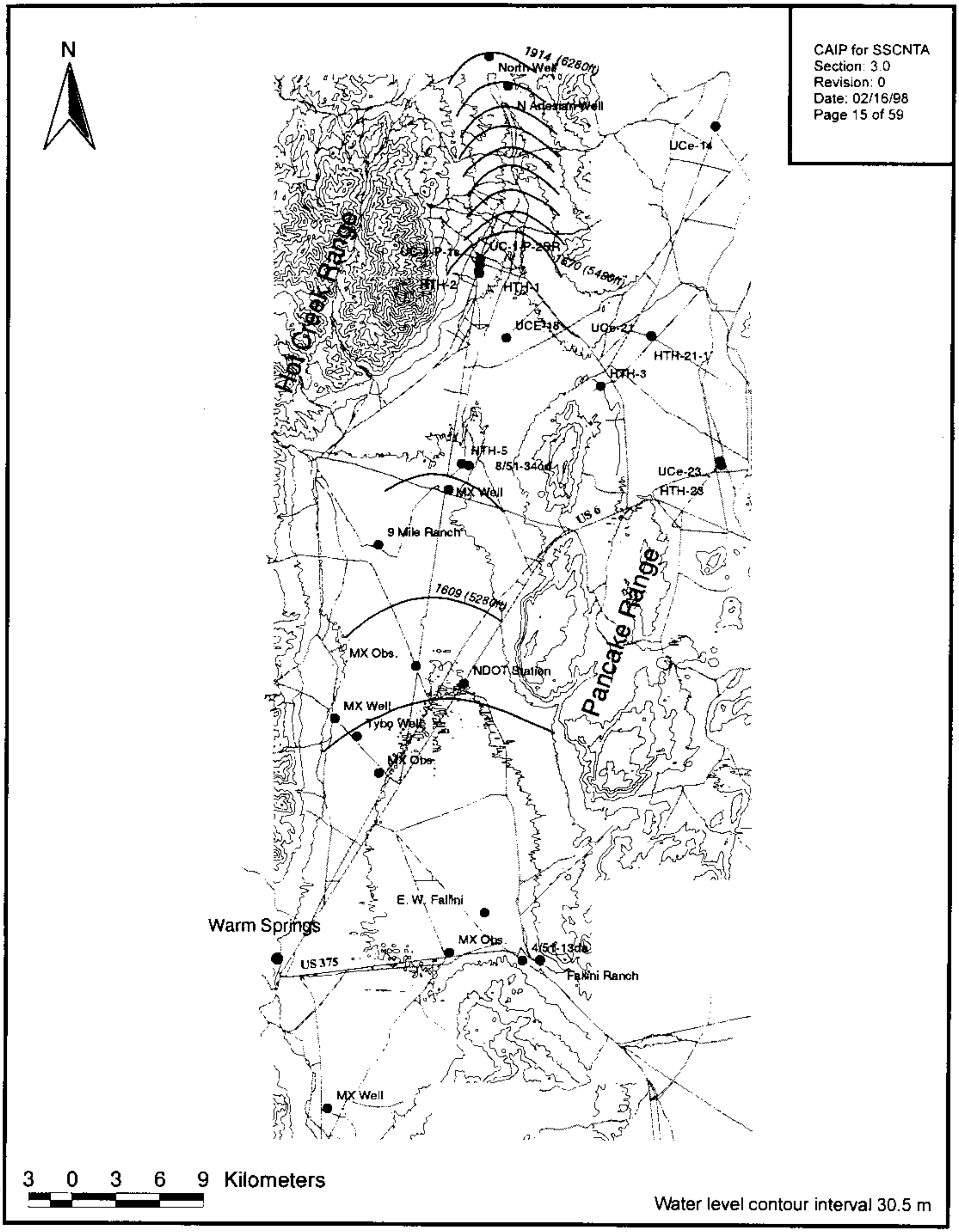


Figure 3-4
Water Level Contours in Hot Creek Valley

level contour map of the alluvial aquifer using 15 water level measurements collected in 1997 and 3 from earlier work, needed where data were not available in 1997. Groundwater in the alluvium is believed to follow the general direction of surface flow (Figure 3-4) (Rush and Everett, 1966; Fiero and Illian, 1969) with recharge in the mountain range to the west (Hot Creek Range) and discharge by evaporation in low portions of the valley (the area around Twin Springs Ranch), with a minor amount of subsurface flow out of Hot Creek Valley to Railroad Valley (Rush and Everett, 1966). Differences in hydraulic head, water chemistry (48 parameters measured in samples from 38 intervals in 11 wells), and temperature suggest that the alluvium and volcanics are distinct water-bearing zones (Dinwiddie and Schroder, 1971). Head values in the upper 340 m (115 ft) of saturated section indicate that groundwater movement is generally south to southeastward. Head values measured in units 1,500 to 2,100 m (4,921 to 6,980 ft) below land surface reveal that the deep component of the flow system moves northeastward and eastward to Railroad Valley. Evaluation of vertical head gradients indicates a potential for downward flow in the north end of the valley while an upward potential for flow exists over the southern part of the valley.

3.4.2 Local Setting

The immediate test area is in a region of predominantly lateral flow toward the axis of the valley between these recharge and discharge areas. Dinwiddie and Schroder (1971) concluded that vertical movement is slow relative to lateral flow, based on the anisotropy of hydraulic properties.

Two wells are open within the subsidence block (Figure 3-5), UC-1-P-1S and UC-1-P-2SR, and they reveal very different hydraulic conditions within the approximate square-mile area of the block (Chapman et al., 1994). Both of the wells were drilled as post-shot sampling holes; thus, they were drilled at an angle into the chimney, complicating interpretations. However, the hydraulic head in UC-1-P-2SR is depressed from the pre-shot level and is below that measured in nearby wells completed in both the volcanic and alluvial units (Mihevc, 1996). The depressed water level in the well is the result of thermal and compressional forces generated by the Faultless test and the resultant bulking produced by the collapse of the rubble chimney into the explosion-produced cavity. The subsequent water-level increase is due to infilling of the cavity and chimney from surrounding saturated rocks. Following a delay in infilling due to unknown causes (essentially a static water level from 1969 to 1974), there has been a regular rise in the water level (Thordarson, 1987). Recent measurements indicate the level is still depressed by about 50 m (164 ft) compared to pre-shot conditions, but rising at a rate of approximately

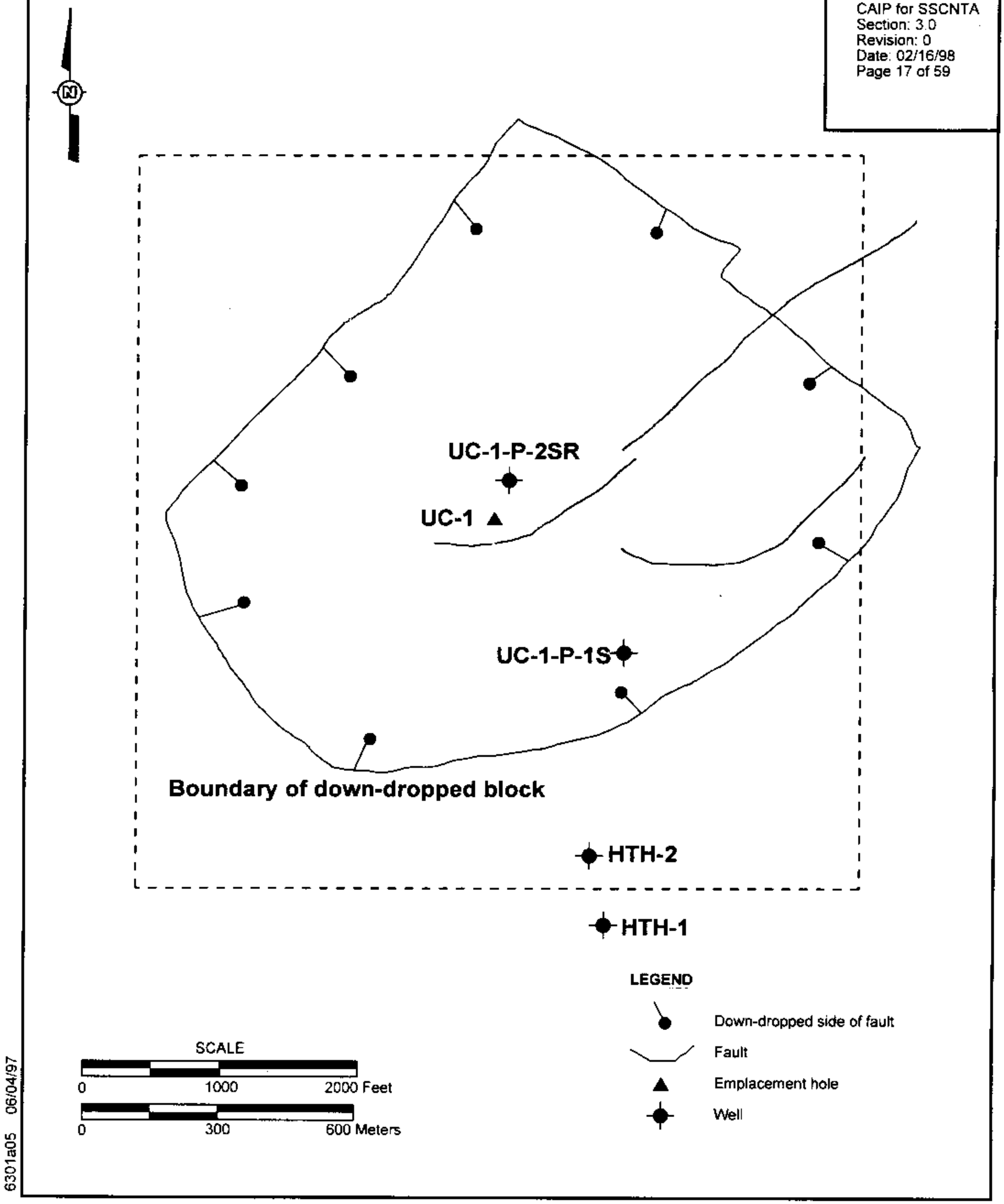


Figure 3-5
Location of Wells Near the Faultless Site

7.8 meters per year (m/yr) (25.6 ft/yr) (Chapman et al., 1994) so that pre-event conditions are expected to be reached between the years of 2004 and 2009. On the other hand, UC-1-P-1S was artesian at the time it was drilled immediately after the Faultless test, and the water level remains greatly elevated relative to pre-shot conditions (currently 83 m [272 ft] below land surface as compared to an estimated pre-shot depth of about 167 m [548 ft]). In addition, the source of the water sampled in each well is different. Based on the chemical and isotopic characteristics, the water in UC-1-P-2SR is consistent with water from the deeper volcanic units, and the water in UC-1-P-1S is similar to water in the shallow alluvial system. Tritium from the Faultless test is present in samples from UC-1-P-2SR, but has not been found above the detection level in UC-1-P-1S (Chapman et al., 1994).

Strong vertical flow with inflow and outflow zones have been measured in UC-1-P-2SR, suggesting the presence of thermally driven water flow through the chimney from the cavity area below (Chapman et al., 1994). The most recent measurements show the water level in the post-shot well to be below that measured in nearby wells that were completed in both the volcanic and alluvial units (the 1995 water elevation in UC-1-P-2SR was 1,649.6 m [5,412 ft] while the water elevation in volcanic well HTH-1 was 1,668.5 m [5,474 ft] and 1,667.2 m [5,470 ft] in alluvium well HTH-2), so that migration away from the chimney is unlikely to have occurred yet (Mihevc et al., 1996). The high hydraulic head measured at UC-1-P-1S indicates that when transport occurs, it will not be in the pre-event downgradient direction in the alluvium because the ridge of high hydraulic pressure at UC-1-P-1S is in the path. The high head at UC-1-P-1S may be the result of the development of low conductivity zones along collapse faults downgradient of the well, creating a groundwater dam (Brikowski, 1993). Another fault separates the chimney and UC-1-P-1S (at least on the surface) and presumably prevents the excess head at UC-1-P-1S from draining into the chimney. The hydraulic properties of the faults created by the Faultless event are unknown, particularly the impact on groundwater flow across the faults defining the down-dropped block. Hydraulic heads in both the alluvium and volcanic units outside the block have also been altered by the test. Heads measured over 20 years after Faultless in HTH-1 and HTH-2 remain elevated 3 to 6 m (10 to 20 ft) relative to pre-shot conditions (Chapman et al., 1994).

3.5 Historic Waste Inventory

The Faultless underground nuclear test produced significant quantities of radionuclides as a result of nuclear reactions and neutron activation. The radionuclides in the post-shot environment are from three primary sources: radioisotopes produced by neutron activation, radionuclides produced by the fission of plutonium-239, and any of the nuclear fuel from the device that was not consumed by the test. The amount (if any) of unburned nuclear fuel (including isotopes of plutonium, uranium, and hydrogen) and the precise types and quantities of radionuclides produced are available in a classified report (Goishi et al., 1995), but unclassified analyses of groundwater from the post-shot well UC-1-P-2SR are publicly available (Thordarson, 1985; Davisson et al., 1994; Chapman et al., 1994). Using the unclassified data and estimates of chimney volume, Pohlmann et al. (1995) calculated a tritium source term for the Faultless event of 4.3×10^{18} pCi. Davisson et al. (1994) also reported concentrations of up to 27,093 pCi/L of krypton-85 (^{85}Kr), 434 pCi/L of argon-39, and above-background ^{36}Cl/Cl ratios (the symbol for chlorine is Cl) of up to 1×10^{-8} in water samples from the post-shot hole, but technetium-99 (^{99}Tc) was not detected nor was gamma activity above analytical background for ^{60}Co, ^{125}Sb, and ^{137}Cs.

Nonradioactive, but possibly hazardous, materials were also used during emplacement hole drilling, completion, stemming, and testing (Bryant and Fabryka-Martin, 1991). These can include drilling fluids and mud, grout, steel casing, a test rack to support the device and instruments (which can include large quantities of polyethylene and other organic materials, extensive use of lead for shielding, and some other metals), and backfill material (often magnetite powder followed by gravel layers with epoxy plugs).

The contaminants of concern for UC-1 are those radionuclides and hazardous substances created by or remaining after the Faultless test that could be mobile in groundwater. The amount of the radionuclide source term available for transport in groundwater is called the “hydrologic source term” and is smaller than the radiologic source because many of the radionuclides cannot be transported by groundwater due to their incorporation in the relatively insoluble melt glass or rapid decay (Smith et al., 1995). Those radionuclides that do leach slowly from melt debris often have strong sorbing properties that also limit migration. The few radionuclides produced in forms that are mobile in water are of greatest concern for radionuclide transport: tritium, ^{85}Kr, ^{36}Cl, iodine-125 (^{125}I), ^{99}Tc, and ^{125}Sb. Of these, tritium is present in the largest concentration for 100 to 200 years after a test (Smith et al., 1995). Many of the nonradioactive components remaining after the detonation are also expected to be in relatively immobile forms, dependent on mineralogy and geochemical conditions.

The contaminants of concern for UC-4 are the hazardous constituents in the drilling mud that was used during the drilling process. Early REECo analytical data (Table 3-2) indicated the drilling fluids consisted of a bentonite drilling mud with diesel fuel and chrome lignosulfonate additives. The extraction procedure toxicity testing of the samples collected at the mud pit indicated 8 milligrams per liter (mg/L) of chromium in the leachate. The chromium is likely from chrome lignosulfonate, a drilling mud conditioner used to minimize drilling water loss (DRI, 1988). Additional sampling conducted in 1995 by DOE (Table 3-3) confirmed the 1986 data. More data will be available to confirm or adjust the results once the investigation activities have been completed for the surface CAU No. 417 at CNTA (DOE, 1997).

3.6 Conceptual Model of the CAU

The Faultless detonation occurred at a depth of 975 m (3,199 ft) in Tertiary tuffaceous alluvial fill, a unit which is similar in texture, grain size, and general appearance to the overlying Quaternary alluvium (Hoover, 1968). Groundwater in the test vicinity occurs about 170 m (558 ft) below ground surface. Thus, the Faultless hydrologic source term is in contact with groundwater. Post-shot drilling data indicate the Faultless shot cavity is about 244 m (800 ft) in height and is divided almost equally between alluvial and tuffaceous sediments (Thordarson, 1987); thus, contaminant transport could occur through either the alluvium or volcanics or both. Once the rubble chimney is filled with groundwater, migration of contaminants from Faultless will be governed by the transport characteristics of the contaminants and the transport characteristics of the groundwater system.

Nuclear detonations typically cause a temporary unsaturated zone in the immediate vicinity of the blast as a result of high temperatures and pressures and increased porosity in the cavity and chimney. This region of depressed water levels recovers after the test as water from adjacent, saturated sediments infills the cavity and chimney. Significant migration of groundwater, and thus contaminants, away from the test area cannot occur while the hydraulic head in the cavity and chimney is lower than in adjacent aquifers (the force of the nuclear explosion can move some radioactive materials ahead of the cone of depression in a process known as “prompt injection,” but the contaminant mass involved is believed to be minor compared to the total mass involved in the test).

Table 3-2
Analytical Data from the 1986 REECo Survey

Sample Location	Sample Number	Parameter	EP[a] Toxicity		Halocarbon	
			Detected (mg/L)[b]	Regulatory Limit (mg/L)[c]	Detected (μg/kg)[d]	Regulatory Limit (kg)[e]
Runoff Ditch	1	Lead	0.3	5.0		
Central Mud Pit	2 (oily crust)	Chromium	7.9	5.0		
	2 (oily dirt)	2-Butanone			37	1,000
		Chromium	8.1	5.0		

[a] Extraction Procedure
[b] Milligram(s) per liter
[c] Regulatory limit as listed in Title 40 Code of Federal Regulations (CFR) 261.24 (CFR, 1995)
[d] Microgram(s) per kilogram
[e] Regulatory limit as listed in Title 40 CFR 261.33 (CFR, 1995)

Source: REECo, 1986

Table 3-3
Central Mud Pit and UC-4 Mud Pit 1995 Analytical Results

Sample	Depth (in.)	Total Petroleum Hydrocarbons (mg/kg)[b]	TCLP[a] Chromium (mg/L)[c]
Central Mud Pit			
1A	0 - 3	680	23.0
2A	3 - 6	220	25.6
3A	0 - 3	840	15.7
4A	0 - 3	190	12.3
5A	0 - 3	610	14.5
1B	18 - 21	470	0.99
2B	20 - 23	150	2.20
3B	20 - 23	260	1.80
4B	20 - 23	290	1.29
5B	20 - 23	59	1.50
5C	66 - 72	< 25	0.93
5D	72 - 75	< 25	0.65
UC-4 Mud Pit			
6A	0 - 3	150	6.60
7A	0 - 3	96	6.80
8A	0 - 3	130	10.7
6B	20 - 23	140	0.96
7B	20 - 23	< 25	0.53
8B	20 - 23	< 25	10.8

[a]Toxicity Characteristic Leaching Procedure
[b]The action level (NAC, 1996) for total petroleum hydrocarbons is 100 milligram(s) per kilogram (mg/kg).
[c]The maximum concentration, as listed in 40 CFR 261.24 (CFR, 1995), for TCLP chromium is 5 mg/L.

3.7 Corrective Action Levels

At UC-1, the modeling objective is to predict an acceptable contaminant boundary. This will be achieved through flow and transport modeling of contaminants from the underground test through the affected aquifer systems. The contaminant boundary will be provided as part of the Corrective Action Decision Document.

At UC-4, the modeling objective is to define the release function for the contaminants of concern (chrome and total petroleum hydrocarbons) from the drilling mud. This will be achieved through geochemical modeling over a 70-year time frame. If the DOE determines that significant releases are projected, flow and transport modeling will be performed.

4.0 Summary of Data Quality Objectives, Processes and Results

The DQO process is a systematic planning tool for establishing criteria for data type, quantity, and quality and for developing data collection programs that satisfy the needs of the project. It is an iterative, seven-step process:

- State the problem
- Identify the decision
- Identify the inputs to the decision
- Define the study boundaries
- Develop decision rules
- Specify limits on the decision errors
- Optimize the design for obtaining data

These seven steps have been applied to the CNTA subsurface CASs, and they support a course of action for investigating the CNTA CAUs. The worksheets summarizing this process are presented in Appendix A. There is no worksheet for UC-3 because the work group evaluating the objectives for the CNTA subsurface sites determined that, because there is no evidence of regulated contaminants in UC-3, it should not be examined further.

The DQOs implement the *Federal Facility Agreement and Consent Order* (1996) strategy for underground test site corrective actions, which is to monitor compliance with the CAU boundary. As of the writing of the *Federal Facility Agreement and Consent Order*, no specific, cost-effective technologies had been demonstrated to either remove radioactive contaminants from the groundwater, stabilize them, or remove the source of the contaminants at the CASs subject to the agreement.

5.0 Corrective Action Investigation

Appendix VI of the *Federal Facility Agreement and Consent Order* (1996) details the strategy that the U.S. Department of Energy will use to achieve closure of the underground nuclear test CAUs. The objective of the strategy for underground nuclear test sites is to define boundaries around each CAU that establish areas containing water that may be unsafe for domestic and municipal use. This will be achieved by modeling groundwater flow and transport and by estimating the movement of contaminants using hydrogeologic data specific to the CAU.

As shown in Figure 1-1, the first step in the strategy is to assess existing data related to the CAU. References that have been identified are listed in Section 9.0. Following that assessment, the CAU-specific modeling will be conducted, and the model results will be validated using relevant existing or new data, as available. If the model results are judged to be acceptable, the model will be used to define a contaminant boundary, which will be proposed in the Corrective Action Decision Document.

5.1 Analytic/Numerical Model(s) Applied to CAU Data

5.1.1 Model Selection

Certain capabilities are required of the groundwater flow and contaminant transport codes to meet the modeling objectives for UC-1. Selection of the final codes follows a process whereby available codes are evaluated based on these capabilities, which include:

- Fully three-dimensional processes
- Heterogeneous and anisotropic properties
- Flexible boundary conditions
- Steady-state or transient conditions
- Hydrologic sources and sinks
- Advection, dispersion, adsorption, matrix diffusion
- Radioactive decay, daughter products
- Minimal numerical dispersion
- Capability for Monte Carlo runs

There are additional considerations that relate to running large three-dimensional models of multiple data sets, including data formats, efficient data handling, pre- and post-processors, efficient numerical solvers, and compatibility with existing software and hardware. Finally, access to the source code provides the opportunity for site-specific modifications, so public-domain codes will be preferred. It is likely that separate codes may be used for the flow and transport steps.

5.1.2 Model Discussion/Documentation/Data Availability

Model Discussion

The land withdrawal area around the UC-1 Faultless cavity is a 2.6 km^2 (1-mi^2) tract, the southeast corner of which is S67°34'33"W, 3,367,115 m (11,046,966 ft) from the southeast corner of Township 9 north, Range 51 east, Mt. Diablo Meridian. This is known as the Project Faultless Withdrawal and was acquired on December 6, 1968, under Public Land Order #4338. Because the impact of the Faultless test on Nevada's resources is of primary concern, the study area will be expanded around this withdrawal. An additional reason for expanding the study area beyond the legal boundary is the need to have groundwater model boundaries at a sufficient distance from the area of concern so that flow and transport calculations are not overly constrained by the boundary conditions.

The initial study area will include that portion of Hot Creek Valley north of Nevada Highway 375 (Figure 3-4) and slightly east to include hydraulic testing data from several wells in Big Sand Spring Valley. This area will allow inclusion of data from 26 wells to define regional flow conditions around and downgradient from the Faultless test. This also includes many of the wells drilled as part of CNTA investigations for which there are geophysical logs and hydraulic test data. These wells will form the basis for simulating heterogeneity in the groundwater flow environment. Though the precise model boundaries should not be specified until preliminary data analysis occurs, they are unlikely to include the large region described above as the study area. Based on scoping-level calculations (Pohlmann et al., 1995), the downgradient model boundary is likely to extend no farther than the UC-3 withdrawn area, approximately six kilometers to the south (Figure 5-1).

When environmental concerns focus on groundwater transport, a careful description of the subsurface, and hydrogeologic heterogeneity in particular, becomes necessary. To develop support for the transport calculations, there must be an adequate understanding of the geologic and hydrologic environment at CNTA. In virtually all regulated settings in the subsurface, the volume of aquifer modeled is many orders of magnitude greater than the volume of geologic

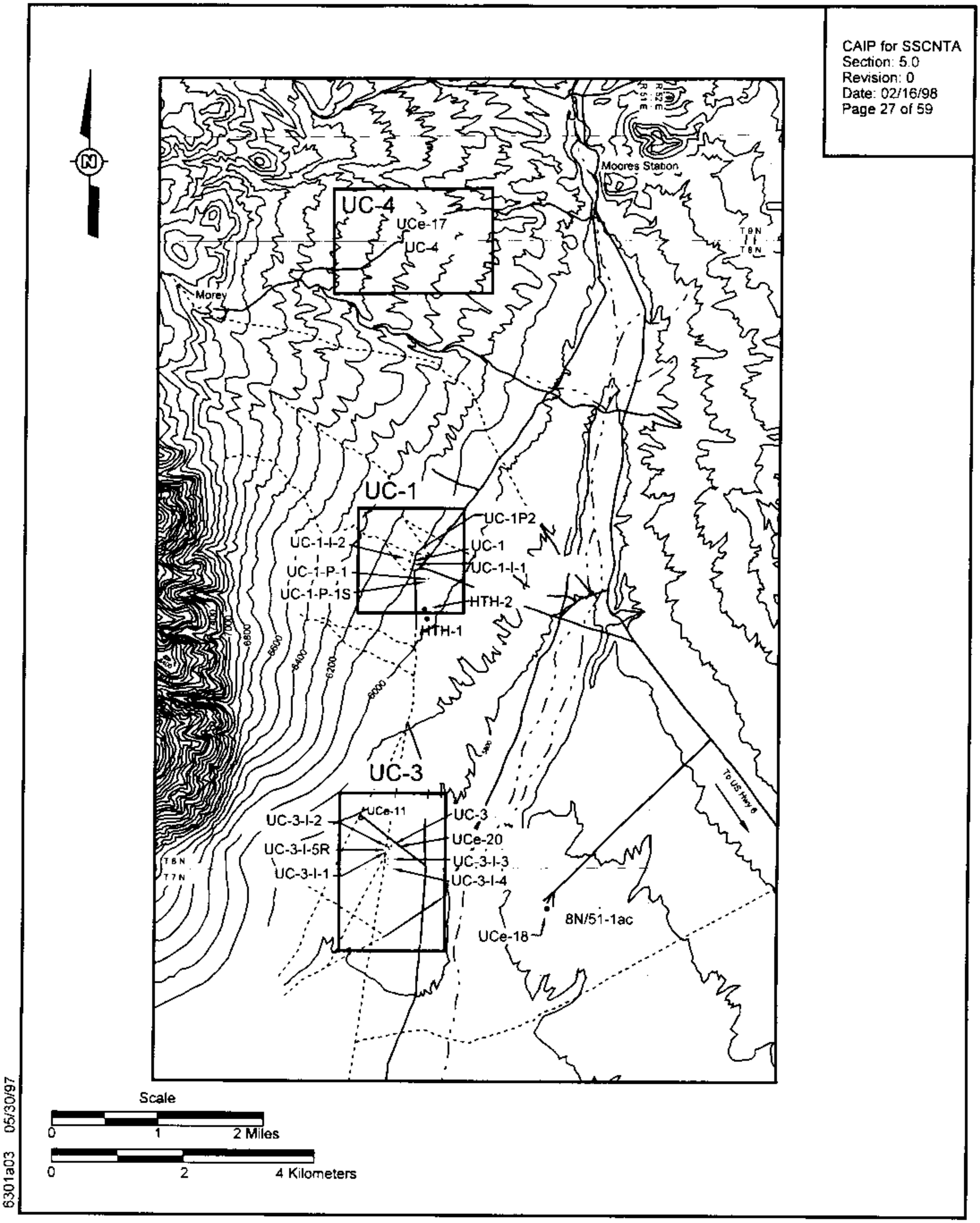


Figure 5-1
Wells Near DOE Land Withdrawals in Northern Hot Creek Valley

material actually observed or sampled (Journel and Alabert, 1989), and this is also true at CNTA. Extrapolation is necessary and introduces significant uncertainty into the geologic understanding. As a result, the modeling effort contains uncertainties that are a direct result of incomplete knowledge.

The approach will be to assemble and synthesize historic well data at CNTA and augment those data with recent measurements of hydraulic and chemical properties. Predictive models will then be created using the observed data, recognizing that the true range in hydrologic parameters may be much greater than observed. Parameter ranges for aquifers in alluvium and volcanic sediments at other sites will be used to help bound the spatial variability possible at CNTA.

The use of all available types of data (geological, geophysical, and hydrological) is needed to describe the geologic heterogeneity at CNTA in three dimensions and to quantify the uncertainty. The first work element will supplement the hydrologic data from former wells, emplacement holes, instrument holes, and existing wells by using geophysical logs. Specifically, resistivity, gamma, and neutron logs will be used to infer permeable zones, and these high-resolution data will be used for stochastic simulations of the three-dimensional subsurface using sequential indicator simulation methods to generate maps of hydrogeologic heterogeneity. This volume-data generation technique has been applied in a variety of environments. For example, sequential indicator simulation methods and geophysical data have been applied to hydrogeologic environments in Central Yucca Flat (Pohlmann and Andrecevic, 1994), at Frenchman Flat (Shirley et al., 1996; Pohlmann et al., 1996), and at the Shoal Site in Churchill County. As described by Alabert (1987), the sequential indicator simulation algorithm estimates a value of the subsurface attribute at an unsampled location such that the new value is consistent with the inferred spatial correlation structure of that variable. The newly simulated value is then added to the existing data set (conditioning data), and the process is repeated. The original conditioning data include only the known data, but as the simulation proceeds, the conditioning data set grows with the addition of each newly simulated data point. Therefore, the final simulated map honors the known data at their locations, as well as the spatial correlation structure inferred from the known data set.

The analysis in Yucca Flat used geophysical log data and sequential indicator simulation methods to infer the three-dimensional distribution of fractured tuffs, while the Shoal application simulates fracture patterns in granite. The sequential indicator simulation method can also include other structural features, such as faults, if needed. Application of the technique to CNTA will involve identifying logs that are likely to distinguish properties important to groundwater flow, correlating between the geophysical logs and available hard data on hydraulic properties (hydraulic conductivity), then generating three-dimensional maps of hydraulic conductivity that characterize spatial anisotropy and connectivity patterns to be used as input for a numerical model of groundwater flow. The 58 measurements of hydraulic conductivity from previous CNTA investigations will provide the link between the geophysical data and hydraulic parameters. A large suite of geophysical logs (typically including caliper, gamma, neutron, density, temperature, resistivity, velocity, and three dimensional velocity) is available for over 20 wells, in addition to cores and cuttings.

Difficulties applying the technique to CNTA center on the issue of data density. Though many wells were drilled and tested prior to the Faultless event (Dinwiddie and Schroder, 1971), the purpose of the drilling program was to select a location for CNTA, so the wells are spread out through several valleys (Hot Creek, Little Fish Lake, Monitor, and Little Smoky) with many kilometers between wells. Although several wells are located close to the Faultless test, the nuclear test has altered the natural hydrologic system, and the role the down-dropped block and faults play in flow and transport is not clearly understood. These problems will persist in the flow modeling, although the flow calculations will have the advantage of the three-dimensional permeability structure based on geophysical data.

The groundwater flow model will be based on the three-dimensional maps of hydraulic conductivity and will be used to solve for groundwater flux at all cells of the model domain, given the gradient of hydraulic head. The fluxes are converted to groundwater velocities using the value of effective porosity appropriate for each cell of the model. Three codes that incorporate the capabilities and considerations for modeling groundwater flow at CNTA include MARFLOW (Mose et al., 1994), TOUGH-2 (Preuss, 1991), and FEHMN (Zyvoloski et al., 1995).

Contaminant migration will then be simulated using the particle-tracking random-walk (PTRW) method and the previously simulated velocity fields that include the hydrogeologic heterogeneity. The PTRW method has several important advantages over other numerical methods for solving contaminant migration problems, including ease of implementation, inherent conservation of mass, and lack of numerical errors (Tompson et al., 1987). In the PTRW method, the solute mass is divided evenly into a large number of hypothetical indivisible particles. The movement of the particles in the groundwater flow field is primarily a function of the groundwater velocity, and to a lesser degree, the microscopic dispersivity. By increasing the number of particles used in the simulation, the solution becomes more consistent and reliable, and predictions of solute concentrations at specific locations become more accurate. However, the accuracy of the prediction of overall plume behavior does not increase to the same degree. Since average plume behavior is of interest in this type of study, the total contaminant mass is generally divided evenly into 10,000 particles. Selection of the PTRW code to be used for transport modeling at UC-1 from the many available public-domain PTRW codes will be based on the capabilities and considerations described previously.

Contaminant plume migration is described in terms of the contaminant breakthrough curve (contaminant mass plotted against time) crossing a specified plane placed at an appropriate distance downgradient from the source and in terms of the spatial distribution at an appropriate time after the release. The breakthrough curve is statistically evaluated using multiple calculations, known as realizations, by superimposing the center of mass of each realization of the breakthrough curve at the average travel time (Andricevic and Cvetkovic, 1996, Figure 1). This procedure allows for the description of the relative dispersion and provides the contaminant breakthrough curve that includes actual spreading due to velocity fluctuations on a scale smaller than the plume size, and removes the meandering of the plume as a whole which results from the large-scale velocity fluctuations. The ensemble curve obtained in this way is more likely to be representative of actual measurements in the field, as opposed to a single breakthrough curve resulting from a single aquifer realization. A similar analysis is performed to determine the spatial distribution of the plume and the extent of contaminant migration within the model domain. Many realizations are analyzed by superimposing the center of mass of each plume realization at the average displacement (see Rajaram and Gelhar, 1993). As with the ensemble breakthrough curve, the spatial distribution of the contaminant plume obtained in this way describes relative dispersion. It can provide a good indication of the possible extent of the plume that might be detected with field measurements.

The numerical PTRW analysis of contaminant transport is suitable for simulating the three-dimensional patterns of plume migration within several kilometers of the source. However, investigation of the effects of possible future downgradient water pumping scenarios would result in unwieldy domain sizes, overly large grid spacing, and ultimately, loss of resolution. Considering the large distances inherent to investigations at CNTA, these types of analyses are better handled using the solute flux method. This analytical method evaluates movement of a solute from the source to a plane perpendicular to the direction of flow and is not limited by distance or discretization issues.

The contaminant migration process is described in Dagan et al. (1992), Andricevic and Cvetkovic (1996), and Andricevic et al. (1994) through the Lagrangian concept of motion following a particle on the Darcy scale. Aquifer heterogeneity is included and represented by the variance of log-hydraulic conductivity, $\sigma^2_{\ln K}$, and the hydraulic conductivity correlation length, λ. The variance represents the variability of K in space and may range from near zero for homogeneous deposits to three, or higher, for extremely variable porous media (Hoeksema and Kitanidis, 1985). Because it is distributed in space, K usually has some degree of spatial correlation. The correlation length of K, λ, represents the distance beyond which there is no correlation between data points. The higher the value of λ, the greater the spatial continuity of K. When the lognormal distribution and the negative exponential covariance function are assumed, the heterogeneous, isotropic hydraulic conductivity field can be statistically characterized by three parameters: $\mu_{\ln K}$, $\sigma^2_{\ln K}$, and λ. The combination of the spatial variability of aquifer properties and the uncertainty in the estimates of these properties causes the solute flux to be a random function described by a probability density function. The mean and variance of the solute flux are converted to the flux-averaged concentration by dividing by the groundwater flux, Q. Importantly, the variance of the solute flux allows calculation of the standard deviation so that the transport results can be presented within desired confidence intervals.

As discussed by Smith et al. (1995), there are a number of factors that complicate the release function of various radionuclides from an underground test: heterogeneous spatial and chemical distribution (in melt matrix, on surfaces, etc.), solubility, sorption, and colloid formation. These factors are the focus of an intensive research program at the Nevada Test Site, and the strong analogies between many Nevada Test Site testing areas and the CNTA will allow extrapolating those findings to Faultless. Existing data on sorption properties of CNTA materials (Nork et al., 1971), combined with results from ongoing sorption experiments (see Section 3.1), will be used to describe equilibrium partitioning of radionuclides between the aqueous phase and aquifer material.

Data Availability

Regional and local data for hydraulic head and hydrochemical data are described in Section 3.4. Other data to be used in the flow and transport analysis are described below.

Hydraulic conductivity data are available from 58 packer tests and one pumping test. The packer tests were conducted in nine wells with nine measurements in alluvium and 49 measurements in volcanic rock. The aquifer test was conducted in the alluvial section of well HTH-1 with adjacent well HTH-2 used as an observation well (Dinwiddie and Schroder, 1971). The geometric mean of hydraulic conductivity for the nine packer tests in alluvium is 0.02 meters per day (m/d) with a standard deviation of the natural log of the hydraulic conductivity (lnK) of 1.35, where K is in units of m/d. The values range from a low of 6.2×10^{-5} to a high of 3.6×10^{-1} m/d. The pumping test at HTH-1 yielded a transmissivity of 102 m^2/d, which results in a range of hydraulic conductivity of between 0.56 and 0.96 m/d, depending on the assumed thickness of the contributing formation. The range in volcanic rock hydraulic conductivity from the packer tests is from 1.5×10^{-7} to 2.1 m/d with a geometric mean of 0.072 m/d and a standard deviation in lnK of 1.35. Variogram analysis of the data from volcanic units suggests a vertical correlation scale of about 120 m, according to studies conducted by the Desert Research Institute.

The hydraulic gradient for the water table in the test area was estimated at 0.04 from northwest to southeast by Dinwiddie and Schroder (1971). Further analysis of hydraulic head at CNTA suggests that hydraulic gradients are oriented more to the south or southwest. The gradient flattens dramatically downgradient, consistent with surface topography. Considering UCE-17 (near the UC-4 emplacement well to the north of the Faultless test) and UCE-20 and UCE-18 (both south of Faultless), a hydraulic gradient of approximately 0.025 results. When the heads are restricted to the area downgradient from Faultless (HTH-1, UCE-20, and UCE-18), the gradient is 0.004. Using the head at HTH-1 and the one measured at the first supply well downgradient from Faultless, Six-Mile Well, the gradient is 0.002. Dinwiddie and Schroder (1971) report a range of groundwater velocity in the Faultless area of 40 to 70 m/yr. Pohlmann et al. (1995) used a velocity of 42 m/yr for transport calculations in the immediate test area and a velocity of 2.8 m/yr for flow to Six Mile Well.

Effective porosity has not been measured directly on the alluvium or tuffaceous sediments of Hot Creek Valley. Values of effective porosity are needed to calculate groundwater velocities for transport calculations. In the absence of site-specific data on effective porosity, it is accepted modeling practice to base estimates of this parameter on published values for similar materials. This approach is generally appropriate because the range in values of effective porosity is usually small (one to two orders of magnitude) when compared to the range of hydraulic conductivity, which ranges over 12 orders of magnitude. Thus, there is considerably less uncertainty associated with estimates of effective porosity than hydraulic conductivity. Examination of cores, cuttings, and logs from wells drilled at and near Faultless led Hoover (1968) to conclude that the tuffaceous sediments and alluvium are very similar in texture and fragment size, though the tuffaceous sediments are more indurated and contain thin layers of volcanic ash. The alluvium is poorly sorted and contains fragments of volcanic and carbonate rock, similar to the alluvium in basins at the Nevada Test Site. The alluvium comprising the fans in northern Frenchman Flat at the Nevada Test Site has been studied extensively as part of site characterization activities for a radioactive waste management facility, and it provides an analog for alluvium in Hot Creek Valley. Porosities for over 200 core samples collected from wells and boreholes in Frenchman Flat are generally greater than 0.30 (REECo, 1993a; 1993b).

5.1.3 Validate Model Results Using Existing/New Data

Historical data sets will be utilized in this modeling effort. These data sets have been generated by numerous individuals over a considerable period of time. Such factors must be kept in mind when questions of confidence arise. Although the data sets will be obtained from sources of known credibiltiy, it will be necessary to ascertain that the quality of the data is appropriate for its intended use.

The reasonableness of the data sets used for CNTA will be determined by reviewing the range and distribution of data points.

The criteria used to select the data sets will be:

- Geographic proximity to the CNTA
- Hydraulic properties pertinent to groundwater flow and transport
- Geologic and geophysical parameters pertinent to hydrogeologic units
- Analogous hydrogeologic environments to CNTA, regardless of geographic proximity.

Calibration of a model is the process of matching historical data and is usually a prerequisite for making predictions with the model. Calibration refines the modeled representation of the hydrogeologic framework, hydraulic properties, and boundary conditions to achieve a desired degree of correspondence between the model simulations and observations of the groundwater flow system. Flow models are usually calibrated using either the manual (trial-and-error) method or an automated method.

The simulations will be compared to site-specific information such as measured water levels or flow rates. The calibration will produce quantitative and qualitative measures of the degree of correspondence between the simulation and site-specific information related to the physical hydrogeologic system. The degree of correspondence between the simulation and the physical hydrogeologic system can then be compared to that for previous simulations to ascertain the success of calibration efforts and, if needed, to identify potentially beneficial directions for further calibration efforts.

The groundwater flow and transport model for CNTA will be calibrated using American Society for Testing and Materials (ASTM) standard guidance for calibrating groundwater models. The Standard Guide for Calibrating a Ground-Water Flow Model Application (Section D18.21.10 Designation C-7, Draft No. 4, September 21, 1995) is a guide for calibrating porous medium (continuum) ground-water flow models. The method can be adjusted to use on other types of groundwater models such as multiphase models, noncontinuum (karst or fracture flow) models, or mass transport models.

The ASTM standard procedures that will be used to implement the guidance cover the use of site-specific information (D5490), applying modeling to site-specific problems (D5447), defining boundary (D5609) and initial (D5610) conditions, performing sensitivity analyses (D5611), and documenting groundwater flow model applications (D5718).

5.1.4 Define Contaminant Boundaries

Flow and transport modeling for the UC-1 and UC-4 corrective action investigation will be focused on CAS-specific modeling objectives as determined during the DQO process.

As indicated in Section 3.7, the UC-1 modeling objective is to predict an acceptable contaminant boundary. This will be achieved through flow and transport modeling of contaminants from the underground test through the affected aquifer systems. The contaminant boundary will be provided as part of the Corrective Action Decision Document.

At UC-4, the modeling objective is to define the release function for the contaminants of concern (chrome and total petroleum hydrocarbons) from the drilling mud. This will be achieved through geochemical modeling over a 70-year time frame. If the DOE determines that significant releases are projected, flow and transport modeling will be performed.

5.1.5 Determination of Model Acceptability

The CAU model will be considered complete when it has been calibrated in accordance with the criteria defined in Section 5.1.3, “Validate Model Results Using Existing/New Data.” The results of the model as well as the uncertainty will be evaluated for acceptability to determine whether modeling objectives have been met. Once the calibrated flow and transport model has been accepted, the location of the contaminant boundary, as negotiated for the Corrective Action Decision Document, can be predicted.

6.0 Field Investigation/No Field Investigation

6.1 Topical Areas of Field Investigation

Previously conducted field investigations relevant to the CNTA subsurface Corrective Action Investigation are described in Section 3.1.

6.2 No Field Investigation

In accordance with Sections 3.0 and 5.0 of Appendix VI, "Corrective Action Strategy," of the *Federal Facility Agreement and Consent Order* (FFACO, 1996), no field investigation is planned to be conducted in this Corrective Action Investigation. Field work, if conducted, would be subject to the requirements of DOE's Health and Safety Plan (DOE, 1996b). Such work would also require the preparation of a site-specific health and safety plan.

7.0 Quality Assurance

This CAIP for CAU No. 443 is designed and will be implemented in accordance with the *Federal Facility Agreement and Consent Order* (FFACO, 1996) and the *Underground Test Area Quality Assurance Project Plan* (DOE, 1998).

8.0 Duration and Records/Data Availability

8.1 Duration/Data Availability

The Corrective Action Investigation will begin within 90 calendar days following notification that the Nevada Division of Environmental Protection has approved the plan. The duration of the work described in this plan up to and including the preparation of the Corrective Action Decision Document is planned to be 18 calendar months. Quality-assured results of sampling will initially be available within 90 calendar days of the date on which they are collected for the purposes of this investigation, or in the case of existing data, identified as appropriate for use in the modeling that will be conducted as part of this investigation.

8.2 Document/Records Availability

This Corrective Action Investigation Plan is available in the DOE public reading rooms located in Las Vegas and Carson City, Nevada, and from the DOE Offsites Project Manager. The Nevada Division of Environmental Protection maintains the official Administrative Record for all activities conducted under the auspices of the *Federal Facility Agreement and Consent Order* (1996). For further information about where to obtain documents and other data relevant to this plan, contact Ms. Monica L. Sanchez, Project Manager, Offsites Subproject, at (702) 295-0160.

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Appendix A
Data Quality Objectives Worksheets

DATA QUALITY OBJECTIVES WORKSHEETS FOR THE SUBSURFACE CORRECTIVE ACTION UNIT UC-1 CORRECTIVE ACTION SITE April 22, 1997

I. STATE THE PROBLEM

A. Identify the members of the Scoping Team:

1. **Scoping Team**

DOE/NV	NDEP
R. Bangerter	C. Goewert
P. Sanders	K. Beckley
	H. van Drielen

IT Corp	DRI
P. Gretsky	J. Chapman
R. Deshler	R. Andricevic
	K. Pohlmann
	B. Lyles
	T. Mihevc

2. **Core Decision Team**
   R. Bangerter, C. Goewert

3. **Primary Decision Makers**
   S. Mellington, R. Bangerter

B. Develop/Refine the Conceptual Model:

1. **List sources of historic data associated with previous data collection activities.**
   Historical data sources are listed in Section 5.0, the reference list for the *Corrective Action Investigation Plan, Subsurface CAU No. 443, Central Nevada Test Area, Nevada*.

2. **List ongoing activities.**
   Surface CAU corrective action investigation
   Subsurface CAU corrective action investigation for Emplacement Well UC-3 CAS
   Subsurface CAU corrective action investigation for Emplacement Shaft UC-4 CAS
   FY97 CNTA continuing studies
   Long-Term Hydrological Monitoring Program
   Cattle grazing

3. **List known or suspected sources of contamination.**
   CAS No. 58-57-001 - Faultless event cavity

4. **List types of contaminants and affected media.**
   a. Hydrologic source term: radionuclides such as carbon-14, cesium-137, iodine-129, plutonium 239/240, tritium, uranium-238

b. *In situ* materials: lead, radiochemical detectors, radioactive tracers (yttrium, zirconium, thulium, and lutetium)
c. Radionuclides in order of decreasing risk from contaminated drinking water as determined by the Technical Working Group Source Term Committee: ^{241}Am; $^{239/240}$Pu; ^{244}Cm > ^{129}I; ^{234,238}U; ^{146}Sm; ^{134,137}Cs > ^{22}Na; ^{152,154}Eu > ^{36}Cl; ^{125}Sb; ^{14}C > ^{121}Sn; ^{155}Eu; ^{99}Tc; ^{41}Ca; ^{147}Pm > ^{63}Ni; ^{151}Sm > tritium
d. Affected medium: groundwater in the vicinity of the shot cavity.

5. List known or potential routes of migration.
Horizontal groundwater flow in alluvium and volcanic bedrock and potential vapor transport of tritium through the unsaturated zone.

6. List known human and environmental receptors.
At the current time, there are no known human receptors being affected by existing conditions.

C. Define the exposure pathway(s)
For purposes of defining an exposure pathway, a human receptor who installs a drinking water well in the aquifer is postulated.

1. Define the exposure pathway(s).
Although there are currently no known receptors, humans are postulated to be exposed to groundwater used as drinking water.

2. Define the current and future land use.
Current and future - cattle grazing and recreation (hunting, camping)

3. Define applicable or relevant and appropriate requirements or preliminary remediation goals.
The corrective action strategy is based on the complex corrective action process as outlined in the *Federal Facility Agreement and Consent Order* (FFACO). The objective is to define boundaries around the UC-1 CAS that establishes an area that contains water that may be unsafe for domestic and municipal use (FFACO, p. VI-3-3).

The boundary restrictions are a dose rate limit defined as 50 mrem/yr with a 50% confidence level, representing the median value, over a 1,000-year period using appropriate exposure scenarios.

4. Develop the exposure scenario.
Migration of contaminants into and with groundwater

D. Specify the available resources

1. Specify monetary budget for the investigation.
To be determined based on budgetary constraints

2. Define relevant time constraints.
Corrective Action Investigation Plan (CAIP) to be completed for Nevada Division of Environmental Protection (NDEP) review on September 22, 1997

E. Description of the problem - combine the relevant background information into a concise description of the problem to be resolved.
Central Nevada Test Area was the site of one underground nuclear test which occurred below the water table. The test is likely to have contaminated the groundwater; however, the impact is unknown. The hydrologic flow model for CNTA is currently under development. Specific, proven, cost-effective technologies that are protective of worker safety and health and that have been demonstrated to either remove radioactive contaminants from the groundwater, stabilize them, or remove the source of the contaminants at the CASs do not currently exist. Such technologies may be perfected in the future, which may alter the choice of corrective action at that time. A contaminant boundary will be developed using a CAU-scale model.

II. IDENTIFY THE DECISION

A. Identify the principal study question
Can a contaminant boundary be defined using a CAU-specific model developed using existing data?

B. Identify alternative action that may be taken based on the findings of the investigation - select the actions that will be taken based on the outcome of the field investigation that corresponds with the selected decision
Additional field investigations may be necessary if the flow model, based on existing data, cannot provide an acceptable boundary location.

C. Identify relationships among decisions

1. Prioritize decisions.

a. Adequate data are available to develop the CNTA groundwater flow model.
b. After initial model is completed, identify data needs to refine the flow model, if needed.
c. Acquire additional data if boundary is unacceptable.

2. Determine the logical sequence of actions.
To follow the flow chart in the FFACO, Figure 3-4.

III. IDENTIFY THE INPUTS TO THE DECISION

A. Identify the information inputs needed to resolve the decision

1. Model input needed to resolve the decision includes but is not limited to:

a. Scale adequacy
b. Source term
c. Release function
d. Transport processes
e Geological detail
f. Uncertainties in parametric values
g. Geochemistry
h. Hydraulic properties

B. Indicate how to generate the necessary data

1. Review of existing data

2. Inclusion of results from ongoing studies

3. Radionuclide transport analysis and simulation using computer modeling

C. Determine the basis for establishing contaminant-specific action level(s) - list the possible basis for establishing the action level (e. g., regulatory threshold, risk or exposure assessment, technological limits, reference based, standards, etc.)

Radionuclides: 50 mrem/yr with a 50% confidence over a 1,000 year period
Chemicals: Action levels will be determined in accordance with the NDEP Corrective Action regulation and will use the Integrated Risk Information System, Risk-Based Corrective Action, and other risk-based data.

D. Identify potential sampling approaches and appropriate analytical methods

CAU modeling will be used to determine the contaminant boundary using existing information. The modeling will consider both radionuclide and chemical contaminants. If additional information is required, the regional and local water levels will be verified, discrete interval packer testing will be conducted in well HTH-1, hydrologic logging and sampling will occur in local wells, and sorption studies will be conducted on archived core samples.

IV. DEFINE THE BOUNDARIES OF THE STUDY

A. Define the geographic areas of the field investigation

1. Define the domain or geographic area within which all decisions must apply (in some cases this may be defined by the Operable Unit).

At this time, the one-square-mile withdrawal area will be used. However, the area to be considered will be adjusted as determined by this study.

2. **Specify the characteristics that define the data population of interest.**
   Scale adequacy
   Source term
   Release function
   Transport processes
   Geological detail
   Uncertainties in parametric values
   Geochemistry
   Hydraulic properties

3. **When appropriate, divide the population into strata that have relatively homogenous characteristics.**
   Hydrostratigraphic units
   Types of sources

4. **Define the scale of decision making.**
   The scale of the decision is dependent on the scale of the model.

B. Define the temporal boundaries of the decision to which the study data apply
1,000 years

C. Identify any practical constraints on data collection
Budgetary, classification (security issues), regulatory (permitting, FFACO), and schedule (FFACO deadlines) issues; CAU spending priorities; worker health and safety issues

V. DEVELOP A DECISION RULE - DEFINE A LOGICAL BASIS FOR CHOOSING AMONG ALTERNATIVE ACTIONS

A. Specify the parameters that characterize the data base
Ranges of uncertainty associated with the data

B. Specify the action level or preliminary action level for the decision
Radionuclides: 50 mrem/yr at the 50% confidence level
Chemicals: As required in *Nevada Administrative Code* (NAC) 445A.2272, 445A.22735, or 445A.2275

C. Develop the decision rule - Combine the outputs of the previous DQO steps into "If...then..." decision rules that include the parameters of interest, the action levels, and the alternative actions
If the uncertainty in the 50-mrem/yr boundary or the chemical of concern action level is unacceptable, then the problem will be reevaluated and negotiated as needed.

VI. SPECIFY ACCEPTABLE LIMITS ON DECISION ERRORS - SPECIFY DECISION ERROR LIMITS BASED ON THE CONSIDERATION OF THE CONSEQUENCES OF MAKING AN INCORRECT DECISION

A. Determine the upper and lower bounds for the parameter of interest using relevant historical site data

The parameters of interest are the concentrations of the contaminants of concern. The upper bound is the region above the action limit where there is a very high comfort level that sample analysis results would correctly identify the sample as contaminated. The lower bound is the detection limit as specified in the laboratory Statement of Work.

B. Define both types of decision errors and identify the potential consequences of each

If the contaminated area is defined as being larger than it actually is (false positives), more resources could be committed to the corrective action than are necessary.

If the contaminated area is defined as being smaller than it actually is (false negatives), less corrective action might be undertaken than is needed to ensure protection of human health or the environment.

VII. OPTIMIZE THE DESIGN -identify the most resource-effective design for collecting data to decrease the prediction uncertainty, that is expected to satisfy the DQOs.

Develop the CNTA flow model.

DATA QUALITY OBJECTIVES WORKSHEETS FOR THE SUBSURFACE CORRECTIVE ACTION UNIT EMPLACEMENT SHAFT UC-4 CORRECTIVE ACTION SITE

April 22, 1997

I. STATE THE PROBLEM

A. Identify the members of the Scoping Team:

1. Scoping Team

DOE/NV	NDEP
R. Bangerter	C. Goewert
P. Sanders	K. Beckley
	H. van Drielen

IT Corp	DRI
P. Gretsky	J. Chapman
R. Deshler	R. Andricevic
	K. Pohlmann
	B. Lyles
	T. Mihevc

2. Core Decision Team
R. Bangerter, C. Goewert

3. Primary Decision Makers
S. Mellington, R. Bangerter

B. Develop/Refine the Conceptual Model:

1. List sources of historic data associated with previous data collection activities.
Historical data sources are listed in Section 5.0, the reference list for the *Corrective Action Investigation Plan, Subsurface CAU No. 443, Central Nevada Test Area, Nevada*.

2. List ongoing activities.
Surface CAU corrective action investigation
Subsurface CAU corrective action investigation for Emplacement Well UC-3 CAS
Subsurface CAU corrective action investigation for UC-1 Cavity
FY97 CNTA continuing studies
Long-Term Hydrological Monitoring Program
Cattle grazing

3. List known or suspected sources of contamination.
Drilling mud in CAS No. 58-30-02, Emplacement Shaft UC-4

4. List types of contaminants and affected media.
a. Chromium and total petroleum hydrocarbons
b. Affected media: groundwater and drilling mud

DATA QUALITY OBJECTIVES WORKSHEETS FOR THE SUBSURFACE CORRECTIVE ACTION UNIT EMPLACEMENT SHAFT UC-4 CORRECTIVE ACTION SITE **April 22, 1997**

5. **List known or potential routes of migration.**
   Horizontal flow in the groundwater in the volcanic and alluvial aquifers

6. **List known human and environmental receptors.**
   At the current time there are no known receptors being affected by existing conditions.

C. **Define the exposure pathway(s)**
   For purposes of defining an exposure pathway, a human receptor who installs a drinking water well in the aquifer is postulated.

   1. **Define the exposure pathway(s).**
      Although there are currently no known receptors, humans are postulated to be exposed to groundwater used as drinking water.

   2. **Define the current and future land use.**
      Current and future - cattle grazing and recreation (hunting, camping)

   3. **Define applicable or relevant and appropriate requirements or preliminary remediation goals.**
      Resource Conservation and Recovery Act
      Safe Drinking Water Act
      Nevada Administrative Code (NAC) 445A.226 to .22755, Action Levels for Contaminated Sites

   4. **Develop the exposure scenario.**
      Migration of contaminants into and with the groundwater

D. **Specify the available resources**

   1. **Specify monetary budget for the investigation.**
      To be determined based on budgetary constraints

   2. **Define relevant time constraints.**
      Corrective Action Investigation Plan (CAIP) to be completed for NDEP review on September 22, 1997.

E. **Description of the contamination problem - combine the relevant background information into a concise description of the problem to be resolved.**
   Central Nevada Test Area was the site of one underground nuclear test and two planned tests which were never conducted. In preparation for the planned tests, two emplacement holes were drilled, UC-3 and UC-4. At UC-4, a 120-inch diameter hole was drilled to 5,500 feet below the ground surface. The hole was not cased below 415 ft. When the tests were canceled, the emplacement hole at UC-4 was left full of drilling mud. To close the hole, a 2-inch metal plate was welded to the 120-inch diameter casing and a 15-inch

reinforced concrete slab was poured over the steel plate. As a result of these activities, drilling mud is in an open hole that extends below the water table.

II. IDENTIFY THE DECISION

A. Identify the principal study question

Are there contaminants in the drilling mud which are migrating away from the site? Samples collected from the central mud pit and UC-4 mud pit will be used to characterize the mud in the UC-4 emplacement hole.

B. Identify alternative action that may be taken based on the findings of the investigation - select the actions that will be taken based on the outcome of the field investigation that corresponds with the selected decision

1. If contaminants are migrating, the options are:

a. Leave the mud in place and close the site.
b. Leave the mud in place and monitor the migration.
c. If significant migration is occurring, interim water well regulations will be considered relevant and appropriate, and the well will be plugged in accordance with these regulations.

C. Identify relationships among decisions

1. Prioritize decisions.

a. Determine whether there are contaminants of concern in the drilling mud.
b. If so, determine whether they are migrating away from the shaft at UC-4 at levels of concern.

2. Determine the logical sequence of actions.

See attached flow chart.

III. IDENTIFY THE INPUTS TO THE DECISION

A. Identify the information inputs needed to resolve the decision

Input needed to resolve the decision includes but is not limited to:

a. Contents of the drilling mud are the same in the UC-4 mud pit and the UC-4 drill hole
b. Engineering data on the shaft cover
c. Release function
d. Diameter of the shaft
e. Depth of the shaft
f. Condition of the shaft cover

B. Indicate how to generate the necessary data (e. g., sampling, modeling, etc.)

1. **Review of existing data**

2. **Permeameter and leaching tests on mudpit samples.**

3. **Modeling of contaminant release and migration from the mud**

4. **Model groundwater flow in the UC-4 area, if needed, based on contaminant release predictions.**

C. Determine the basis for establishing contaminant-specific action level(s) - list the possible basis for establishing the action level (e. g., regulatory threshold, risk or exposure assessment, technological limits, reference based, standards, etc.)
Action levels will be determined in accordance with the NDEP Corrective Action regulation and will use the Integrated Risk Information System, Risk Based Corrective Action, and other risk-based data.

D. Identify potential sampling approaches and appropriate analytical methods
Samples collected from the central mud pit and UC-4 mud pit are assumed to have the same chemical composition as the mud in the UC-4 emplacement hole.

IV. DEFINE THE BOUNDARIES OF THE STUDY

A. Define the geographic areas of the field investigation

1. **Define the domain or geographic area within which all decisions must apply (in some cases this may be defined by the Operable Unit).**
   The one-and one-half-square-mile withdrawal area around the UC-4 emplacement hole, to a depth of 6,000 feet below ground surface

2. **Specify the characteristics that define the population of interest.**
   The physical and chemical characteristics of the drilling mud

3. **When appropriate, divide the population into strata that have relatively homogenous characteristics.**
   Physical characteristics
   Chemical characteristics

4. **Define the scale of decision making.**
   The scale of the decision is dependent on the action level from the NAC 445A.226 to .22755, Action Levels for Contaminated Sites.

B. Define the temporal boundaries of the decision to which the study data apply
30 years AIHC Exposure Factors Sourcebook.

C. Identify any practical constraints on data collection
Budgetary, classification (security issues), regulatory (permitting, FFACO), and schedule (FFACO deadlines) issues; CAU spending priorities; worker health and safety issues

V. DEVELOP A DECISION RULE - DEFINE A LOGICAL BASIS FOR CHOOSING AMONG ALTERNATIVE ACTIONS

A. Specify the parameters that characterize the population of interest
Chemical concentration

B. Specify the action level or preliminary action level for the decision
Total Petroleum Hydrocarbons - 100 mg/kg
Resource Conservation and Recovery Act - soil Total Chromium (Cr) TCLP > 5 mg/L
Safe Drinking Water Act - Total Cr 100 µg/L
Resource Conservation and Recovery Act Subpart S Cr^{+6} - soil 400 mg/kg

C. Develop the decision rule - Combine the outputs of the previous DQO steps into "If...then..." decision rules that include the parameters of interest, the action levels, and the alternative actions
If the contaminants are migrating from the UC-4 shaft, then the risk to potential receptors will be evaluated.

VI. SPECIFY ACCEPTABLE LIMITS ON DECISION ERRORS - SPECIFY DECISION ERROR LIMITS BASED ON THE CONSIDERATION OF THE CONSEQUENCES OF MAKING AN INCORRECT DECISION

A. Determine the upper and lower bounds for the parameter of interest using relevant historical site data
The parameters of interest are the concentrations of the contaminants of concern. The upper bound is the region above the action limit where there is a very high comfort level that sample analysis results would correctly identify the sample as contaminated. The lower bound is the detection limit as specified in the laboratory Statement of Work.

B. Define both types of decision errors and identify the potential consequences of each
If the contaminated area is defined as being larger than it actually is (false positives), more resources could be committed to the corrective action than are necessary.

If the contaminated area is defined as being smaller than it actually is (false negatives), less corrective action might be undertaken than is needed to ensure protection of human health or the environment.

VII. OPTIMIZE THE DESIGN - identify the most resource-effective design for collecting data to decrease the prediction uncertainty that is expected to satisfy the DQOs. Determine whether *Nevada Administrative Code* (NAC) 445A.227 a through k exemption is feasible. If not, then complete fate and transport modeling.

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