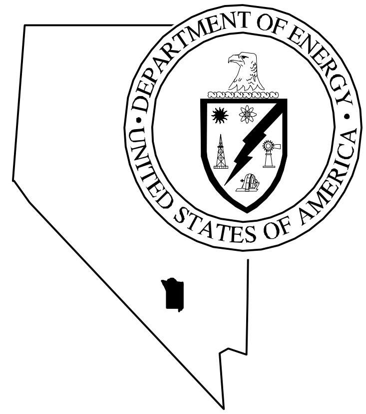
Nevada
Environmental
Restoration
Project

DOE/NV--513



Corrective Action Investigation Plan for Corrective Action Unit 447: Project Shoal Area, Nevada Subsurface Site

Controlled Copy No.: **Uncontrolled**
Revision No.: 1

November 1998

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Environmental Restoration
Division

U.S. Department of Energy
Nevada Operations Office

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CORRECTIVE ACTION INVESTIGATION PLAN FOR CORRECTIVE ACTION UNIT 447: PROJECT SHOAL AREA, NEVADA SUBSURFACE SITE

DOE Nevada Operations Office
Las Vegas, Nevada

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CORRECTIVE ACTION INVESTIGATION PLAN
FOR CORRECTIVE ACTION UNIT 447:
PROJECT SHOAL AREA, NEVADA
SUBSURFACE SITE

Approved by: Signature on file Date: 11/19/98
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Offsites Subproject

Approved by: Signature on file Date: 11/19/98
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Nevada Environmental Restoration Project

Table of Contents

Table of Contents *(Continued)*

Table of Contents *(Continued)*

List of Figures

List of Tables

Number ***Title*** ***Page***

List of Acronyms and Abbreviations

AEC	U.S. Atomic Energy Commission
ASTM	American Society for Testing and Materials
BET	Brunauer-Emmet-Teller
BLM	U.S. Bureau of Land Management
CAA	*Clean Air Act*
CADD	Corrective Action Decision Document
CAI	Corrective Action Investigation
CAIP	Corrective Action Investigation Plan
CAP	Corrective Action Plan
CAS	Corrective Action Site
CAU	Corrective Action Unit
CERCLA	*Comprehensive Environmental Response Compensation and Liability Act*
CX	Categorical Exclusion
cm	Centimeter(s)
cm/s	Centimeter(s) per second
cm/yr	Centimeter(s) per year
CWA	*Clean Water Act*
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOE/NV	U.S. Department of Energy, Nevada Operations Office
DQO	Data Quality Objective
DRI	Desert Research Institute
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
ESA	*Endangered Species Act*
FFACO	*Federal Facility Agreement and Consent Order*
FLPMA	*Federal Land Policy and Management Act*
FMP	Fluid Management Plan
ft	Foot (feet)
ft/s	Feet per second

List of Acronyms and Abbreviations (Continued)

ft/yr	Feet per year
in.	Inch(es)
in./s	Inch(es) per second
in./yr	Inch(es) per year
km	Kilometer(s)
km^2	Square kilometer(s)
m	Meter(s)
MCL	Maximum Contaminant Limits
mg/L	Milligram(s) per liter
mi	Mile(s)
mi^2	Square mile(s)
m/yr	Meter(s) per year
mrem/yr	Millirem(s) per year
NDEP	Nevada Division of Environmental Protection
NEPA	*National Environmental Policy Act*
NHPA	*National Historic Preservation Act*
NPDES	National Pollutant Discharge Elimination System
NTS	Nevada Test Site
pdf	Probability distribution factor
PSA	Project Shoal Area
RCRA	*Resource Conservation and Recovery Act*
SDWA	*Safe Drinking Water Act*
UIC	Underground Injection Control

1.0 Introduction

This Corrective Action Investigation Plan (CAIP) describes the U.S. Department of Energy's (DOE's) continued environmental investigation of the subsurface Project Shoal Area (PSA) Corrective Action Unit (CAU) 447. The PSA is located in the Sand Springs Mountains in Churchill County, Nevada, about 48 kilometers (km) (30 miles [mi]) southeast of Fallon, Nevada. Project Shoal was part of the Vela Uniform Program which was conducted to improve the United States' ability to detect, identify, and locate underground nuclear detonations. The test consisted of detonating a 12-kiloton nuclear device deep underground in granitic rock to determine whether seismic waves produced by an underground nuclear test could be differentiated from seismic waves produced by a naturally occurring earthquake. The test was a joint effort conducted by the U.S. Atomic Energy Commission (AEC) and the U.S. Department of Defense (DoD) in October 1963 (AEC, 1964).

1.1 Purpose

The purpose of the subsurface investigation, as described in Appendix VI of the *Federal Facility Agreement and Consent Order* (FFACO) (1996) is to evaluate groundwater flow and potential contaminant transport from the PSA test cavity in the Sand Springs Mountains. This was accomplished by the drilling and hydrogeologic modeling that were conducted in 1996 and 1997. However, an evaluation of the groundwater model results indicates that further delineation of the subsurface conditions is required to reduce uncertainties in the model input parameters. This CAIP is being prepared to guide the collection of additional hydrologic data in order to reduce the uncertainties in the input parameters. This is allowed by the FFACO Appendix VI which states: "If the modeling results are not acceptable to establish CAU boundaries and buffer zones prior to defining the tritium contaminant boundary, an addendum to the CAIP will be issued..." However, since a separate subsurface CAIP was never prepared for PSA CAU 447, a new CAIP was prepared instead of an addendum to the existing combined surface and subsurface CAIP issued in August 1996 (DOE/NV, 1996a).

1.2 Scope

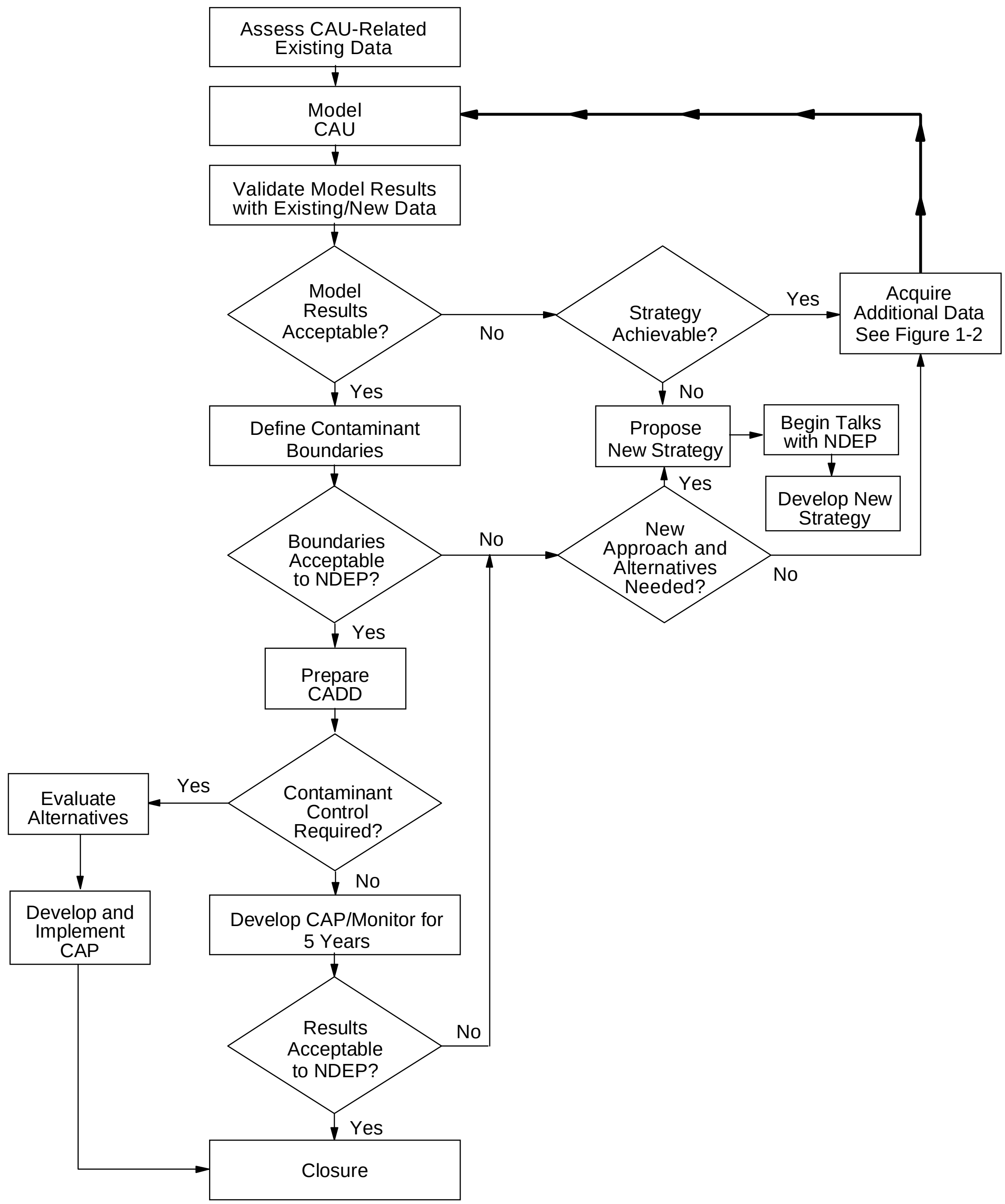
A three-dimensional flow and transport model was constructed for the PSA subsurface. The model was developed to locate an acceptable contaminant boundary within which water use restrictions will be implemented to prevent exposure to potentially contaminated groundwater.

Existing data and data collected during installation and testing of the new groundwater investigation wells were used to develop the model. However, an evaluation of the groundwater model results indicate that further delineation of the subsurface conditions is required to reduce uncertainties in the input parameters.

At the first major decision point on the Process Flow Diagram for Underground Test Area Corrective Action Units (Figure 1-1), the DOE determined that the modeling results were unacceptable. Following the "No" path from the "Model Results Acceptable" box to the "Strategy Achievable" box, it was determined that the strategy was achievable, moving everything on the "Yes" path to the "Acquire Additional Data" box for which this CAIP is a part. The highlighted path from the "Acquire Additional Data" box back to the "Model CAU" box is detailed in Figure 1-2. The unshaded boxes on Figure 1-2 illustrate the processes that will take place during the Corrective Action Investigation. After NDEP has approved this CAIP, a data decision analysis will be completed to determine what data should be collected to refine the groundwater model. Once this has been determined an addendum (or technical change) to the CAIP will be prepared followed by the acquisition of the additional data. The data is then collected and entered into the model and a second phase of modeling runs will be completed. If, after the acquisition of new data is complete and the data have been incorporated in the model, the DOE accepts the modeling results, then a boundary will be established, and the results will be presented to the Nevada Division of Environmental Protection. If the State of Nevada agrees to the boundary, a Corrective Action Decision Document (CADD) 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. Section 5.0, which describes the Corrective Action Investigation, details the modeling approach including: model selection, model attributes, data availability, model validation, 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.



Source: FFACO, 1996

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

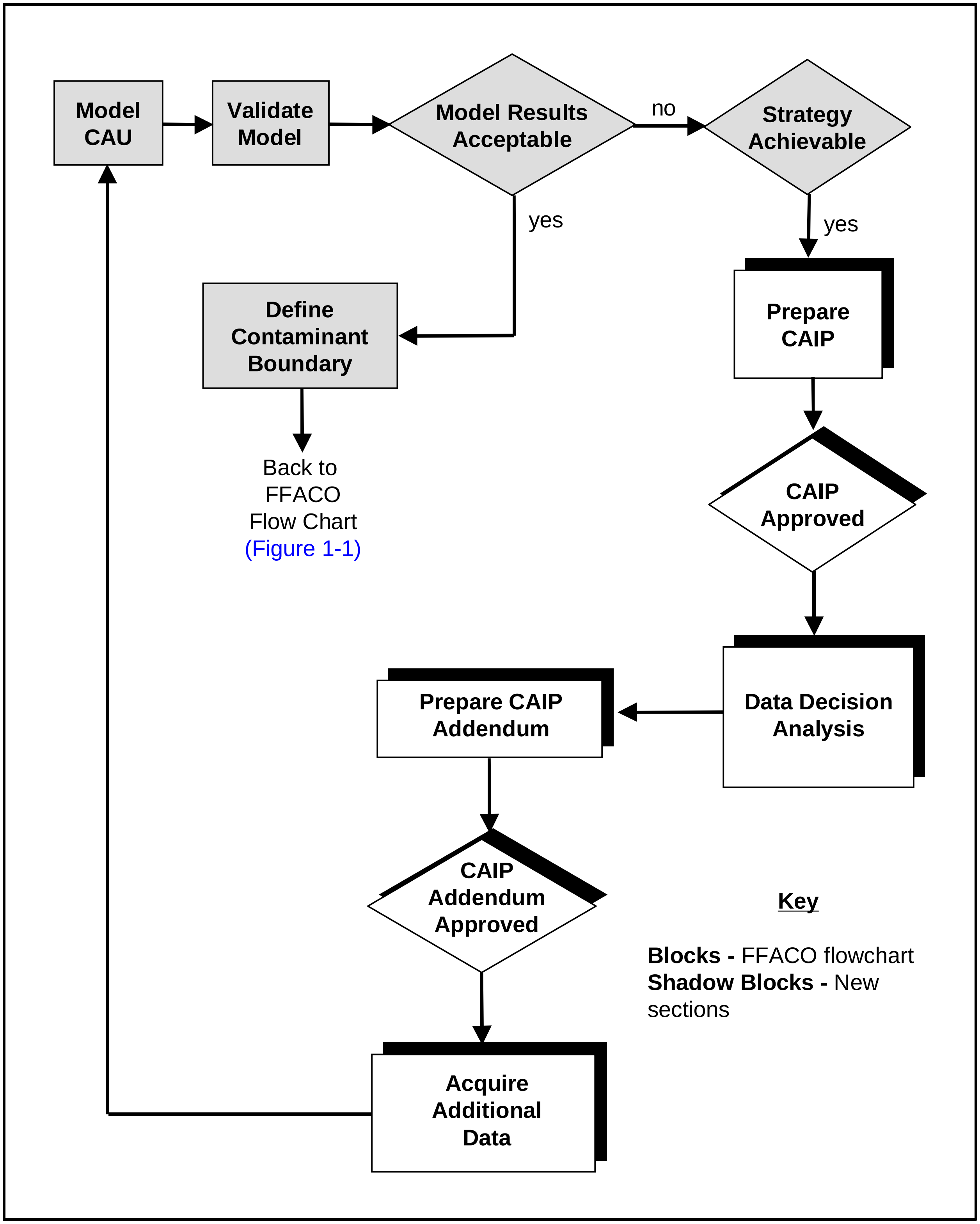


Figure 1-2
Paths for Acquiring Additional Data

2.0 Legal/Regulatory Requirements

The DOE, DoD, and the Nevada Division of Environmental Protection (NDEP) have negotiated a *Federal Facility Agreement and Consent Order* to address environmental restoration activities at U.S. Department of Energy, Nevada Operations Office (DOE/NV) facilities and sites. The FFACO is the primary regulatory driver for DOE environmental restoration activities in Nevada, and the regulatory requirements that may be applicable to the PSA Subsurface Corrective Action Investigation (CAI) are discussed in this section.

2.1 Federal Facility Agreement and Consent Order

This section includes a summary of the FFACO requirements and the Off-Sites corrective action strategy as described in the FFACO (1996).

2.1.1 FFACO Requirements

The FFACO requirements that are applicable to PSA subsurface are discussed in this section.

2.1.1.1 General Requirements

The FFACO sets the framework and contains the regulations for prioritizing and enforcing the environmental restoration activities of contaminated DOE/NV facilities and sites. Technical strategies for these activities are also provided in the FFACO. The DOE, through the Off-Sites Subproject, is responsible for completing corrective actions for two CAUs associated with historical underground nuclear testing off the Nevada Test Site (NTS) but within the State of Nevada. The Off-Site CAUs are Project Shoal Area and the Central Nevada Test Area. The CAUs were defined based on geography.

Several plans and reports are prepared to document the corrective action process. These documents provide details about the activities needed to ensure the completion of the corrective action. Documents that are applicable to the Off-Site CAUs include the following:

Corrective Action Investigation Plan

This is a required document that provides or references all specific information for planning investigation activities associated with corrective action units or sites.

Corrective Action Decision Document

This is a required report that documents the corrective action investigation. It describes the results of the CAI, the selected correction action, and the rationale for its selection.

Corrective Action Plan (CAP)

This required planning document describes the CAIP and explains the corrective action completion process.

Closure Report

This required report documents the corrective action completion process to verify that the corrective action was conducted in accordance with the approved corrective action plan. It also provides all necessary supporting information.

Notice of Completion

This is a document issued by the State of Nevada marking the completion of the corrective action in accordance with approved plans.

2.1.1.2 Specific Requirements

The PSA subsurface corrective action investigation will be planned and conducted in accordance with the appropriate investigation purposes of the FFACO as outlined in Subparts II.1.b.ii, II.1.c as well as the requirements of Subparts IV.14, and IV.15 (FFACO, 1996). Each of these specific subparts of the FFACO (1996) are provided below, followed by a description of how their requirements are being fulfilled during the CAI.

Subpart II.a.b.ii states:

> "Determine whether releases of pollutants and/or hazardous wastes or potential releases of pollutants and/or hazardous wastes are migrating or potentially could migrate, and if so, identify the constituents, their concentration(s), and the nature and extent of that migration..."

In accordance with this Subpart, specific drilling and subsurface sampling and groundwater flow and transport models designed to determine whether releases are migrating or could potentially migrate, have been conducted and/or are planned in the CAI as described in Sections 5.0 and 6.0.

Also, in accordance with this Subpart, a preliminary list of the constituents and their concentrations is provided in Section 3.5. A description of the nature and extent of the contaminant migration based on the current information is presented in Sections 3.4 and in 3.6 of this report. This description will be updated based on the findings of the CAI.

Subpart II.1.c states:

> "Providing all parties with sufficient information to enable adequate evaluation of appropriate remedies by specifying the radioactive and hazardous constituents for each corrective action unit."

As required by this Subpart, a preliminary list of radioactive and hazardous constituents for the PSA Subsurface Corrective Action Unit are specified in Section 3.5 of this report in order to provide all parties with sufficient information to enable adequate evaluation of appropriate remedies. The list will be updated based on the findings made during the CAI.

Subpart IV.14 states:

> "Corrective action investigation (CAI) shall mean an investigation conducted by DOE and/or DoD to gather data sufficient to characterize the nature, extent, and rate of migration or potential rate of migration from releases or discharges of pollutants or contaminants and/or potential releases or discharges from corrective action units identified at the facilities."

In accordance with this Subpart, the PSA Subsurface Corrective Action Investigation will be conducted by DOE to gather sufficient data to characterize the nature, extent, and rate of migration or potential rate of migration from releases or potential releases of contaminants from the PSA Subsurface Corrective Action Unit. This CAIP describes the planned investigation activities which include field data gathering (Section 6.0) and fate and transport modeling (Section 5.0).

Subpart IV.15 states:

> "Corrective action investigation plan (CAIP) shall mean a document that provides or references all of the specific information for planning investigation activities associated with corrective action units or corrective action sites. A CAIP may reference information

> in the optional CAU work plan or other applicable documents. If a CAU work plan is not developed, then the CAIP must include or reference all of the management, technical, quality assurance, health and safety, public involvement, field sampling, and waste management information needed to conduct the investigations in compliance with established procedures and protocols."

In accordance with Subpart IV.15, this CAIP provides or references all of the specific information for planning investigation activities associated with the PSA Subsurface Corrective Action Units. This CAIP includes or references all of the management, technical, quality assurance, health and safety, public involvement, field sampling, and waste management information needed to conduct the investigations in compliance with established procedures and protocols as described in Section 1.0.

All information provided in this CAIP is based on the current state of knowledge and will be updated following completion of the CAI. The results will be reported in the CADD.

2.1.2 Corrective Action Strategy

The strategy negotiated between DOE and NDEP for the Off-Sites (FFACO, 1996) and its implementation by DOE are described in this section.

2.1.2.1 Description of Corrective Action Strategy

The objectives of the Off-Site strategy are to predict the location of the contaminant boundary for each CAU, develop and implement a corrective action, and close each CAU. The contaminant boundary has been defined in Appendix VI of the FFACO (1996) as follows:

> "CAU models utilizing tritium as the source term will be used to establish the contaminant boundary for each CAU. The boundary will be composed of a perimeter boundary and a lower hydrostratigraphic unit boundary. The perimeter boundary will define the aggregate maximum extent of contamination transport at or above the concentration of concern for the CAU. The lower hydrostratigraphic unit boundary will define the lowest aquifer unit affected by the contamination. Long-lived radionuclides, besides tritium, will be included to evaluate the relative extent of migration of different radionuclides in the future. If it is predicted that another radionuclide will migrate farther than tritium at concentrations of concern, the contaminant boundary will include that prediction."

Also, as explained in the FFACO, uncertainties will be associated with the contaminant boundary predictions using the CAU models (FFACO, 1996). These uncertainties can be expressed as confidence levels as shown on Figure 2-1. As explained in Appendix VI of the FFACO (1996):

> "Each contour reflects an increased level of confidence that no contaminants exceeding a given regulatory concentration will ever cross that boundary. As confidence increases, the distance from the CAU increases. The confidence levels could lead to the development of different contaminant boundaries, depending on the degree of certainty decision makers need to select appropriate controls."

The distance from the source of contamination (the CAU in Figure 2-1) to the contaminant boundary increases as the confidence level increases.

The process to achieve the strategy is defined in the flow diagram on page VI-3-6 of FFACO Appendix VI (Figure 1-1). The part of the process that will take place during this corrective action investigation is presented in more detail in Figure 1-2.

The first steps of the strategy were the field data collection and modeling efforts conducted in 1996 and 1997. However, it was determined that the transport model had unacceptable levels of uncertainty so a reasonable contaminant boundary could not be defined. As provided for in the FFACO, if the model is determined to be unacceptable or the contaminant boundary cannot be agreed upon between DOE and NDEP, then DOE and NDEP will determine if the strategy is achievable. If the strategy can be achieved, DOE will propose work scope to collect additional data. The new data will then be used in the CAU model, and the process will be repeated. This CAIP proposes possible additional work scope for collecting new data to reduce the uncertainties in the transport model.

After this CAIP has been approved by the state, a data decision analysis will be conducted to determine which of the proposed tasks will be implemented. After the new data has been collected the CAU model will be rerun and contaminant boundaries will be determined.

After the contaminant boundaries have been defined and accepted, DOE will evaluate various remedial alternatives and propose a corrective action. The modeling results, contaminant boundary, and proposed corrective action will be documented in the CADD and submitted to NDEP for approval. After approval of the CADD, a Corrective Action Plan will be developed to

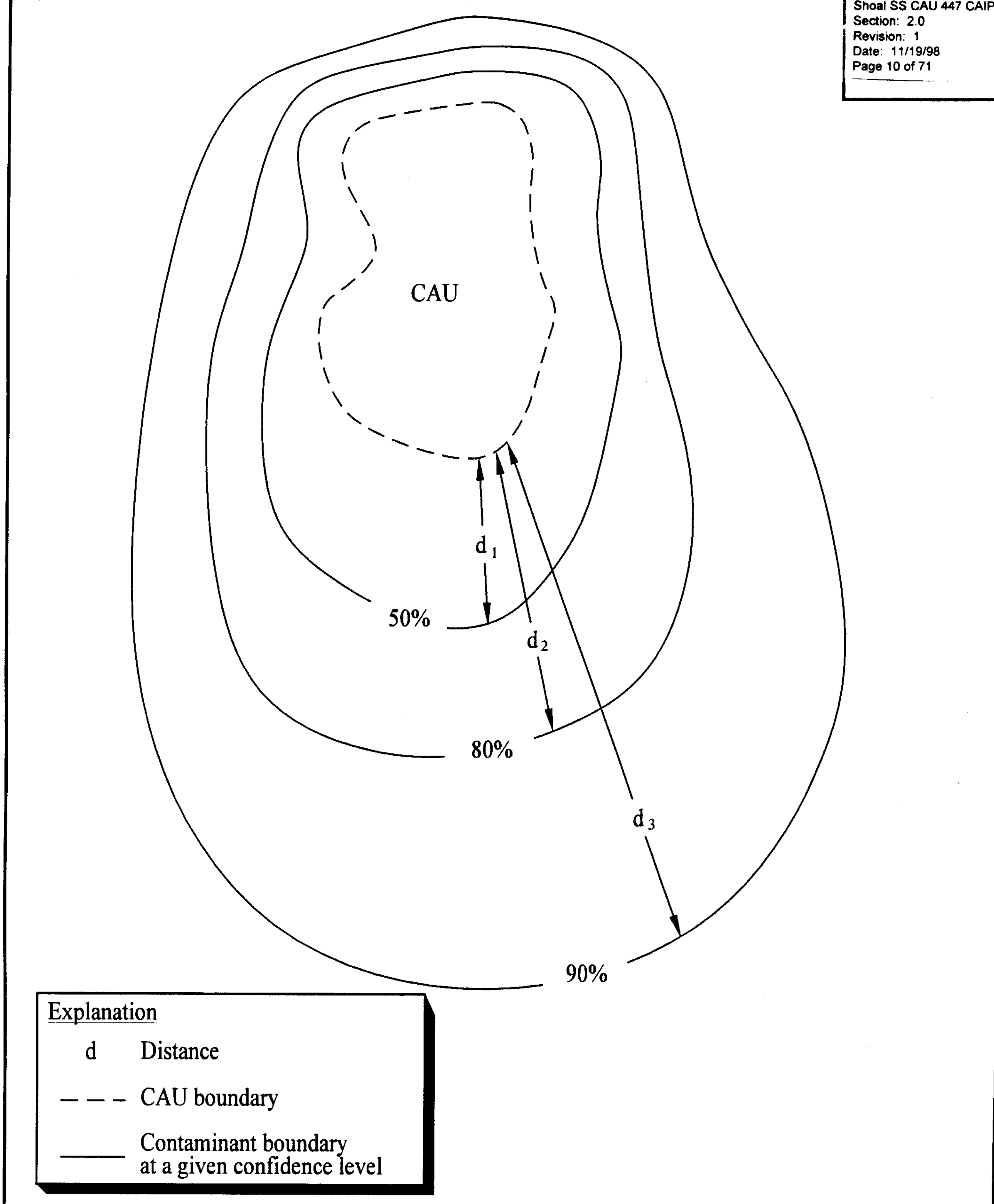


Figure 2-1
Example of Contaminant Boundary Confidence Levels

implement the corrective action. If the corrective action is long-term monitoring, a five-year proof-of-concept period will be initiated. This proof-of-concept period will allow DOE and NDEP to determine if the monitoring results support the model. If the monitoring results are acceptable, a Closure Plan will be developed for the CAU. If the results are not acceptable, then DOE and NDEP will need to determine if the strategy is achievable.

2.1.2.2 Implementation of Corrective Action Strategy

The DOE's approach for implementing the FFACO strategy for the Off-Site CAUs includes a corrective action investigation, correction action implementation, and CAU closure. The work on all of the CAUs is staggered over the life of the project as identified in the FFACO strategy schedule (FFACO, 1996).

2.2 Other Regulatory Requirements

This section includes a description of other potentially applicable environmental laws and their implementing regulations for the proposed PSA Subsurface CAI field activities and supporting operations. The applicability of specific regulations to the location of a given field activity must be considered on an activity-by-activity basis. Each contractor performing work under this CAI is obligated to comply with all federal, state, agency, and local requirements that are applicable or relevant to their individual characterization activities.

The discussion is intentionally broad in scope in an effort to include all of the applicable federal and state implementing regulations covered under the statute cited. In each case, the location of a proposed CAI activity must be considered first when determining regulation applicability. Next, the activity itself must be examined. For example, the conduct of a field experiment involving existing monitoring wells will undoubtedly have a different set of applicable regulations than a well drilling activity.

Environmental laws and regulations potentially applicable to CAI field operations are discussed. The discussion is limited to the more significant federal, state, and agency requirements. In addition, statues or regulations applicable to laboratory activities conducted during experimentation related to the CAI are not considered.

National Environmental Policy Act (NEPA)

The NEPA (1996) requires that environmental impacts are considered and documented prior to activity on any major federal government project. There are two NEPA documents which cover the scope of the PSA Subsurface CAI: the NTS Site-Wide Environmental Impact Statement (EIS) (DOE/NV, 1997) and a PSA project-specific Categorical Exclusion (CX) (DOE/NV, 1996c).

The EIS for the NTS and other off-site locations in the State of Nevada examines alternatives for current and future missions at DOE sites in Nevada. The final NTS EIS was approved in the fall of 1996. The Record of Decision, which is a document that details the preferred alternative or course of action for activities and program development at the NTS, was issued on November 18, 1996.

A CX (DOE/NV, 1996c) was performed for PSA in 1996, prior to the start of environmental restoration activities. Categorical Exclusions are typically completed for projects with smaller scope than are addressed in the EIS or an Environmental Assessment. The DOE/NV Environmental Restoration Division prepares a CX when only minimal site disturbance will be required in conducting site characterization and monitoring.

The DOE has determined, through approval of a NEPA checklist (DOE/NV, 1998a), that the EIS and the Off-Site CX (DOE/NV, 1996c) satisfy the requirements under the NEPA (1996).

Clean Air Act (CAA) and Related Nevada Air Control Regulations

Implementing regulations under the CAA (1996) govern the emissions of regulated pollutants from new and existing sources. The two areas that should be considered for this CAI are particulate emissions from ground disturbance activities (i.e., constructing access roads or drill pads) and air emissions for equipment. The applicability of this permit to drilling activities will be determined on a site-by-site basis. At locations outside the NTS, an application for a surface disturbance permit may be warranted. Some drilling equipment, such as the drill rig and diesel generators, may require air emissions operating permits. However, one was not required during the 1996 drilling effort.

Clean Water Act (CWA) and Related Nevada Water Control Regulations

The CWA (1996) and its implementing regulations govern the discharge of pollutants into the nation's surface waters from point and non-point (diffuse) sources. The State of Nevada regulations mandate that groundwater resources be protected in the same manner as surface waters under the CWA. The 1996 activities at PSA were covered under a Fluid Management Plan (FMP) (DOE/NV, 1996b). This plan addresses the on-site management of drilling-related fluids in both far-field and near-field drilling conditions. The FMP was negotiated with NDEP in lieu of a water pollution control permit (or National Pollutant Discharge Elimination System [NPDES] permit). This plan will be updated for any future drilling activities.

In addition, State of Nevada regulations dictate the conditions under which water wells, including monitoring wells, are drilled. While not enforceable on the NTS, these regulations must be followed when drilling monitoring wells outside of the NTS.

Safe Drinking Water Act (SDWA) and Related Nevada Water Control Regulations

The SDWA (1996) regulations serve to protect the nation's groundwater and to ensure that drinking water from public water systems is fit to drink. The Underground Injection Control (UIC) Program, established under SDWA authority, protects groundwater by regulating the underground disposal of liquid wastes. Because some experiments conducted in the CAI may involve the injection of fluids into an existing well, the applicability of the UIC program to such experiments should be considered on a case-by-case basis. Drinking water (at the tap) is regulated through the establishment and enforcement of drinking water standards, known as Maximum Contaminant Limits (MCLs). Drinking water standards are often used in support of other environmental statutes such as *Comprehensive Environmental Response, Compensation and Liability Act* (CERCLA) (1996) and the CWA (1996). In fact, the Nevada Drinking Water Standard (NAC, 1998b) regulations adopt the federal MCLs and form the basis for enforcement of the FMP.

Endangered Species Act (ESA) and Related Nevada Wildlife Regulations

The ESA (1997) and related Nevada wildlife regulations (NAC, 1998d) serve to protect the existence of threatened and endangered species and their critical habitat. Thirteen sensitive species (six mammals, one bird, four invertebrates, and two plants) are known to inhabit the areas around PSA, however, none have been found on the site. Pre-activity biological assessments/surveys must be conducted to determine if planned activities at a site will adversely affect the species present. Typically, the Desert Research Institute (DRI) performs such biological surveys for proposed activity sites on the Off-Sites.

National Historic Preservation Act (NHPA) and Related Nevada Historic Preservation Regulations

This law (NHPA, 1997) protects historic properties that are listed or eligible for listing on the National Register of Historic Places. Archaeological surveys conducted during the spring of 1996 at the existing well locations found no prehistoric sites. Any new drilling locations will be surveyed prior to surface disturbing activities. Cultural resource surveys are typically completed by the DRI for DOE/NV sites.

Federal Land Policy and Management Act (FLPMA)

The FLPMA (1996) governs the use of federal lands which may be overseen or managed by several agencies and establishes the procedure for applying to the U.S. Bureau of Land Management (BLM) for right-of-way reservations. Because the CAI activities will take place on lands, the acquisition of BLM right-of-way reservations may be necessary.

Comprehensive Environmental, Response, Compensation and Liability Act

The regulations promulgated under CERCLA (1996) establish a program which, among other things, directs the investigation and remediation of uncontrolled or abandoned hazardous waste sites as well as accidents, spills, and other releases of pollutants and contaminants into the environment. Within the CERCLA program, the National Oil and Hazardous Substances Contingency Plan outlines the actions for responding to emergency releases (spills) of both oil and hazardous substances on a national level. This law may be applicable to Off-Site locations if certain quantities (known as reportable quantities) of hazardous substances are spilled on site.

Resource Conservation and Recovery Act (RCRA) and Related Nevada Hazardous Waste Regulations

The RCRA-implementing regulations (RCRA, 1996; NAC, 1998a) govern the management of hazardous waste from generation to disposal, and RCRA requirements are applicable to all Off-Site activities which generate hazardous wastes. Potential requirements include those that address the generation, accumulation, and disposal of hazardous wastes. If such wastes are to be transported off of the sites, U.S. Department of Transportation regulations for the transport of hazardous waste generally apply.

3.0 Description of the Corrective Action Unit

3.1 Investigative Background

Investigations of the geology and hydrogeology of the PSA and the surrounding regions have taken place from 1960 to the present. These studies included geologic mapping, geophysical logging, analysis of soil and water chemistry (including major ions, metals, and both stable and radioactive isotopes), and hydrologic testing. Site investigation activities associated with the PSA have been summarized in the *Corrective Action Investigation Plan for Project Shoal Area, CAU 416* (DOE/NV, 1996a), and *Data Report, Project Shoal Area, Churchill County, Nevada* (DOE/NV, 1998b). Table 3-1 is a partial list of documents and a description of the studies covered in each.

Two analyses of the human health risk posed by migration of contaminants in groundwater from the Project Shoal cavity have been performed. Chapman et al. (1995) modeled potential migration of tritium away from the cavity and evaluated the risk of 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. The *Nevada Risk Assessment/Management Program* (1996) employed the same scenario and transport parameters identified by Chapman et al. (1995), but used a nuclear reactor computer code to calculate the source term. In addition to tritium, they considered the risk from cesium and strontium but found that the risk from these two contaminants is effectively zero.

The U.S. Environmental Protection Agency's (EPA's) Radiation and Indoor Environments National Laboratory, which monitors groundwater around PSA annually as part of the Long Term Hydrologic Monitoring Program, has consistently found tritium concentrations below the minimum detectable concentration (approximately 7 to 10 picocuries per liter). They concluded that, to date, migration into the sampled wells has not taken place and that no test-related radioactivity has entered area drinking water supplies (Chaloud et al., 1996).

3.2 Site History

The PSA is a 10.4-square kilometer (km^2) (4-square mile [mi^2]) area of land withdrawn from public domain by Public Land Order 2771 issued on September 6, 1962, as amended by Public Land Order 2834. A Special Use Permit issued by the Bureau of Land Management granted

Table 3-1
Partial Document List
(Page 1 of 2)

Author/Title	Year	Scope
Cohen, P., and D. Everett, *A brief appraisal of the ground-water hydrology of the Dixie-Fairview Valley area, Nevada*	1963	Regional groundwater hydrology and recharge in the Dixie-Fairview Valley area
AEC, "Project Manager's Report Project Shoal"	1964	Site demobilization
University of Nevada, *Final Report: Geological, Geophysical, Chemical, and Hydrological Investigations of the Sand Springs Range, Fairview Valley, and Fourmile Flat, Churchill County, Nevada*	1965	Geologic maps; an overview of the regional geology; site-specific geology based on drill cores, cuttings, and trenching; the results of airborne and surface geophysical surveys; the lithologic logs and borehole geophysical logs; hydrologic testing; regional flow system; potentiometric surface data; and groundwater chemistry
Hazelton-Nuclear Science, *Project Shoal Post-Shot Hydrologic Safety*	1965	Radionuclide transport, source term analysis, and cavity infill time
Gardner, M. C., and W. E. Nork, *Evaluation of the Project Shoal Site, Fallon, Nevada, for Disposition, Including Identification of Restrictions, Part I*	1970	Detonation type and products, climatology, geology, hydrology, cavity infill time, radionuclide transport, radioactivity distribution
AEC, *Site Disposal Report, Fallon Nuclear Test Site (Shoal), Churchill County, Nevada*	1970	Site demobilization
Glancy, P. A., and T. L. Katzer, *Water-Resources Appraisal of the Carson River Basin, Western Nevada*	1975	Regional groundwater hydrology
EPA, Offsite *Environmental Monitoring Report: Radiation Monitoring Around the United States Nuclear Test Areas,* Annual Report	1984 to 1993	Groundwater chemistry data
DOE/NV, *Long-Term Hydrologic Monitoring Program Project Shoal Site, Sand Springs Range, Churchill County, Nevada*	1984	Long-Term Hydrologic Monitoring Program
Chapman, J. B., and S. L. Hokett, *Evaluation of Groundwater Monitoring at Offsite Nuclear Test Areas*	1991	Evaluation of the Long-Term Hydrologic Monitoring Program

Table 3-1
Document List
(Page 2 of 2)

Author/Title	Year	Scope
Chapman, J. B., T. Mihevc, and A. Mckay, *Groundwater Flow Near the Shoal Site, Sand Springs Range, Nevada: Influence of Density Flow*	1994	Regional flow systems and regional isotopic and hydrochemical analyses
Chapman, J. B., K. Pohlmann, and R. Andricevic, *Exposure Assessment of Groundwater Transport of Tritium From the Shoal Site*	1995	Scoping calculations for tritium transport
NRAMP, *Nevada Offsites Integrated Risk Assessment Project Shoal Test Area, Churchill County, Nevada*	1996	Preliminary risk assessment covering surface chemical risk, risk from existing wells, and risk from drilling a well at the site boundary
DOE/NV, *Corrective Action Investigation Plan for Project Shoal Area, CAU 416*	1996a	Regional flow system, site history, potential contamination, description of proposed drilling operations
DOE/NV, *Data Report Project Shoal Area, Churchill County, Nevada*	1998b	Recent lithologic logs and borehole geophysical logs
DOE/NV, *Closure Report for CAU 416, Project Shoal Area*	1998a	Description of activities conducted to close the surface CAU 416
Pohll, G., J. Chapman, A. Hassan, L. Papelis, R. Andricevic, and C. Shirely, Evaluation of Groundwater Flow and Transport at the Shoal Underground Nuclear Test	1998	Local groundwater

the AEC the “rights” to an additional 260-km^2 (100-mi^2) area surrounding the 10.4-km^2 (4-mi^2) area of the site. This permit also allowed the AEC “Right of Entry” to an area of 1,040 km^2 (400 mi^2), which further surrounded and encompassed the PSA (AEC, 1970).

Project Shoal, part of the Vela Uniform Program, was a joint effort of the DoD and the AEC to study the effects of different geological media on seismic waves produced by an underground nuclear detonation and to determine if these seismic waves could be differentiated from seismic waves generated by naturally occurring earthquakes (DRI, 1988). The PSA, located in Churchill County, Nevada, was tentatively selected as the site for Project Shoal in 1961. After a year-long geologic exploration of the area it was confirmed as the chosen site in late 1962 and preparations for the test were begun.

The Shoal test consisted of detonating a nuclear device with a 12-kiloton yield, 367 meters (m) (1,204 feet [ft]) below the ground surface on October 26, 1963. The device was placed via a 3.7-m by 1.8-m (12-ft by 6-ft) shaft sunk in the granite to a depth of 402 m (1,320 ft). A 2.4-m by 2.4-m (8-ft by 8-ft) drift was mined to the east 320 m (1,050 ft) with a 9-m (30-ft) buttonhook raise at the end. The device was placed at the end of the buttonhook. Data collected from the post-shot drillback indicated that the shot cavity collapsed almost immediately following the test-producing a rubble-filled chimney 52 m (171 ft) in diameter and 109 m (356 ft) high with an 11-m (36-ft) void at the top (Korver et al., 1965).

The source term for this test is still classified; however, using the estimates from Borg et al. (1976), the combined inventory from the fission products and neutron activation has decayed to less than one percent of the original inventory. Residual radionuclides are most likely contained in the insoluble melt rubble at the bottom of the shot cavity.

There was no venting of particulate debris during or after the explosion although some radionuclides, mostly gases, may have been injected into fractures as far as 135 m (443 ft) from the shot point. Gaseous, short-lived radionuclides (iodine-131, xenon-131, and xenon-133) were liberated into the air during drillback operations or were brought to the surface on drill equipment. These radionuclides were trapped by filters and were subsequently mixed with clean soil and buried in the impoundment area (mudpit) beneath uncontaminated soil (Gardner and Nork, 1970). In 1996, the mudpit was characterized and no radiological constituents were found; however, mud with total petroleum hydrocarbon concentrations above the state regulatory limit were found. Under an approved Streamlined Approach for Environmental Restoration Plan, the mudpit was excavated and all of the materials were shipped to the NTS for disposal (DOE/NV, 1998a).

Deactivation of the site commenced on October 28, 1963. All vehicles, equipment, and surface structures (except for the head frame) were removed and the site was placed on “caretaker standby" status. A concrete slab was installed over the top of the shaft at that time. The decontamination and restoration activities were minimal because large areas of contamination were not found during or following the project. Some surface decontamination was required around the post-shot borehole and the mudpit for contaminated drilling debris. These contaminated materials were handled as described above.

In 1970 a radioactive material survey was conducted at the site. During this survey salvageable scrap and burnable debris was removed from the site. All of the salvageable scrap and debris along with the vehicles used to transport it were surveyed for radiological contamination. There were no radiological levels exceeding background levels for the area. A variety of soil and vegetation samples were collected for laboratory analysis (REECo, 1971). During this effort all boreholes on the site were plugged and abandoned (AEC, 1970).

An inspection of the site in 1995 revealed that the area around the shaft collar was eroding and that there was a 0.8-m (2.5-ft) diameter open hole leading into the open part of the shaft. A safety fence was installed around the hole and in 1996 the cover of the shaft was removed and the shaft was backfilled and plugged.

3.3 Corrective Action Sites

The PSA subsurface CAU 447 consists of two CASs, the emplacement shaft (CAS 57-49-01) and the underground test/detonation cavity (CAS 57-57-001). However, the emplacement shaft was backfilled and plugged in 1996 and will not be evaluated further. The underground test/detonation cavity is located at Nevada State Plane Coordinates North 493,828 (m) (1,620,170 ft), East 169,939 (m) (557,544 ft). The cavity consists of a rubble-filled chimney 52 m (171 ft) in diameter and 109 m (356 ft) high with an 11-m (36-ft) void at the top (Korver et al., 1965). The top of the chimney is 256 m (840 ft) below the ground surface.

3.4 Physical Setting

3.4.1 Study Area

The PSA consists of a 10.4-km^2 (4-mi^2) area in the Sand Springs Range, located near Fallon, Nevada, in Churchill County (Figure 3-1). Surface ground zero of the underground nuclear test is located at a land elevation of 1,594 m (5,230 ft) above mean sea level. The nuclear device was

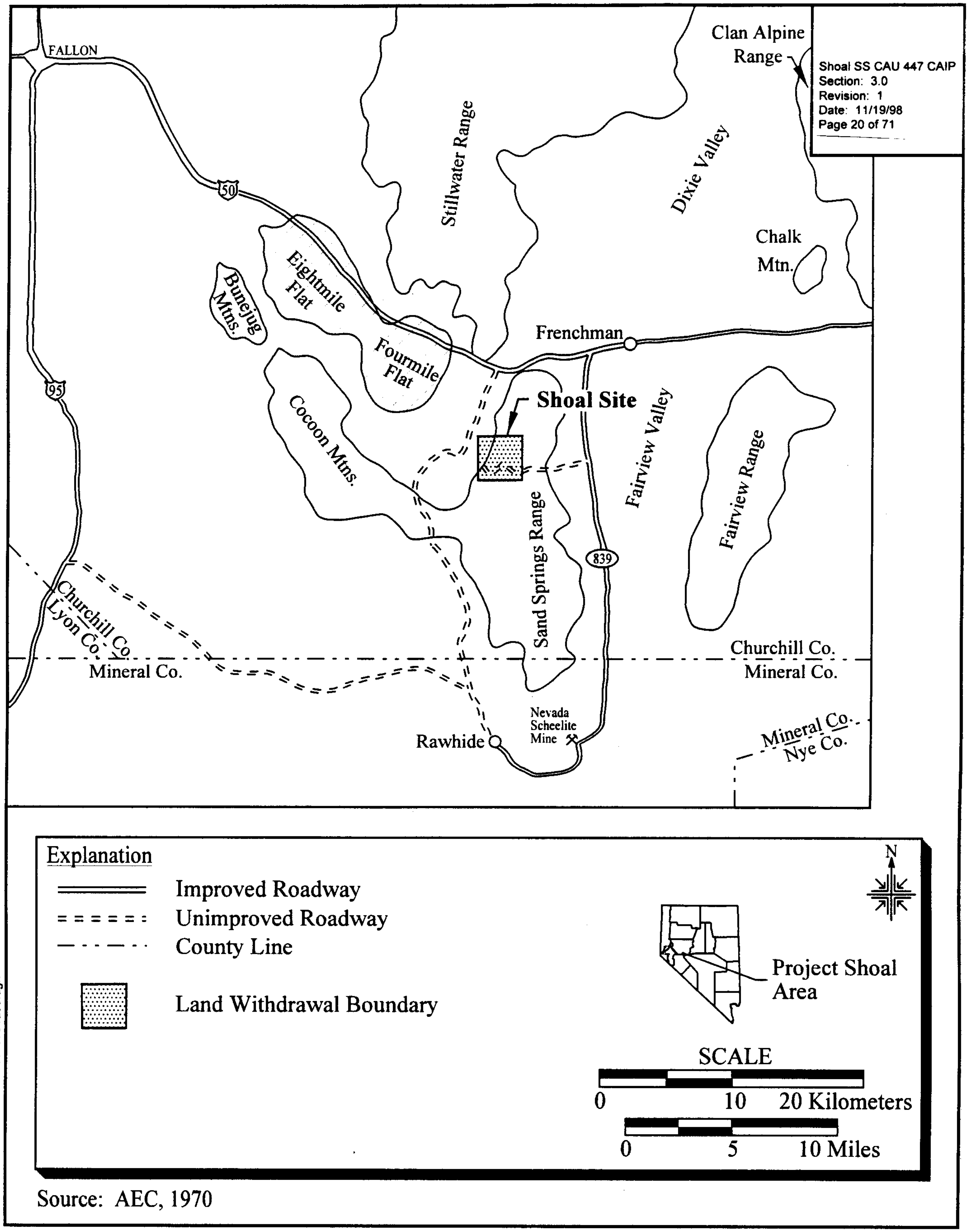


Figure 3-1
Study Location

emplaced 367 m (1,204 ft) below the land surface, at the end of a 305-m (1,000-ft) long drift mined east from a vertical shaft.

The Sand Springs Range is a north-south-trending range with a total relief between the range and valleys of about 500 m (1,640 ft). A major intermittent drainage course in Ground Zero Canyon leads east to Fairview Valley. No permanent water bodies or streams exist onsite. Sparse, low vegetation covers the area. The ground slopes steeply west to Fourmile Flat and east to Fairview Valley. Ground zero is near the crest on a minor intramountain plateau named Gote Flat, which is about 800 m (0.5 mi) wide. At a depth of 367 m (1,204 ft) below the land surface, the Shoal working point is nearly at grade with the adjacent valley floors.

The Shoal site is in a subhumid to semiarid region of Nevada's Great Basin. Annual rainfall varies from about 13 centimeters (cm) (5 inches [in.]) in the valleys to about 30 cm (12 in.) in the high mountain ranges (Hardman and Mason, 1949). Most precipitation in the mountain ranges occurs as snow. The annual precipitation estimate for the Shoal site varies between 20 cm (8 in.) (Gardner and Nork, 1970) and 30 cm (12 in.) (Hardman and Mason, 1949). Using the relationship between precipitation and recharge described by Maxey and Eakin (1949), an estimated 3 to 7 percent (0.6 to 2.1 centimeters per year [cm/yr] [0.2 to 0.8 in. per year]) of the annual precipitation will infiltrate and become groundwater recharge. Daily temperature fluctuations in excess of 50°F (28°C) can occur. Maximum temperatures exceed 100°F (38°C) in July and August, and minimum temperatures of 0°F (-18°C) occur in December and January.

3.4.2 Geology

The Shoal test occurred in typical Basin and Range terrain, consisting of fault-block mountains and valleys. The Sand Springs Range trends north-south with boundaries defined by nearly vertical northeast- and northwest-trending faults. The range is comprised of metamorphosed Paleozoic and Mesozoic marine sediments surrounding a central granitic intrusive body of Cretaceous age. East of the range, the Fairview Valley contains Tertiary and Quaternary alluvial and aeolian sediments as much as 1,765 m (5,791 ft) thick. Fourmile Flat is a pediment west of the Sand Springs Range consisting of alluvial fans, pediment sand and gravels, and aeolian and playa deposits. The Fourmile Flat sediment is underlain by a relatively shallow west-sloping crystalline basement. The unconsolidated deposits thicken westward to about 395 m (1,296 ft). Active tectonic history appears in many of the geologic features. The region's seismic activity, as evidenced by the 1954 Dixie Valley earthquake (Zones, 1957), was a desirable factor in siting the Shoal test. Intermittent faulting is present both in the high- and moderate-angle, northeast- and northwest-trending faults within the center of the Sand Springs Range.

3.4.3 Regional Hydrogeology

The Shoal test was conducted within the granitic uplift of the Sand Springs Range. The highland area around ground zero is a regional groundwater recharge area, with regional discharge occurring both in the Fourmile and Eightmile Flats area to the west of the range, and in the Humboldt Salt Marsh in Dixie Valley to the northeast of the range. Beneath the Sand Springs Range, groundwater occurs within fractured, predominantly fresh, granite. Groundwater occurs about 300 m (984 ft) below ground surface in the general vicinity of the test. Decreasing hydraulic potentials with depth were noted during site characterization studies (University of Nevada, 1965), supporting the interpretation of the range as a recharge area. A few high altitude springs discharging from perched zones in the granite can be found to the south in the range. In the adjacent valleys, groundwater occurs in alluvial material eroded from the highland areas, and hydraulic testing indicates much higher transmissivity than found in the granite (University of Nevada, 1965).

Granitic bedrock is relatively near the surface beneath a veneer of alluvium to the west of the Sand Springs Range, and hydrologic data are available from one well (H-3) completed in bedrock in that area (Table 3-2 and Figure 3-2). The water level in H-3 is about 99 m (325 ft) below land surface. Farther to the west, and in Fairview Valley to the east, bedrock occurs at greater depths and is not penetrated by wells. Discharge of water originating in the Sand Springs Range occurs at springs and by evapotranspiration along the edge of the salt pan in Fourmile Flat. Groundwater potentials beneath Fourmile Flat generally increase with depth, which is common in discharge zones. Data from Well H-2, completed in the alluvium between the range and the salt pan, suggests that a counterflow of dense, saline water may be moving back toward the range from the playa, driven by buoyancy forces, with fresh water moving from the Sand Springs Range confined to a thin lens at Fourmile Flat (Chapman et al., 1994).

The alluvium is much thicker in Fairview Valley, as compared to Fourmile Flat. Although three alluvial aquifers, separated by clay horizons, were identified in site characterization studies, it was concluded that the units act as a single hydraulic system (University of Nevada, 1965). The

Table 3-2
Summary of Wells Near the Shoal Site

Well	North (ft)	East (ft)	Total Depth (m)	Ground Elev. (m amsl)*	Water Table Elev. (m amsl)
HS-1	1622141.28	576875.65	213.06	1293.19	1201.71
H-2	1631585.00	543132.00	237.74	1224.38	1190.59
H-3	1627331.86	548884.86	146.30	1289.97	1189.91
H-4	1622285.67	576914.39	284.99	1292.94	1201.74
PM-1	1618717.83	556030.63	408.13	1633.13	1299.46
PM-2	1621842.43	558120.94	394.72	1620.79	1356.34
PM-3	1619192.76	559336.33	334.37	1563.65	1237.23
PM-8	1619967.78	557532.73	283.46	1596.48	1344.11
USBM-1	1619992.41	557949.92	452.90	1588.62	1312.16
ECH-A	1619292.70	558740.30	579.12	1572.43	n/a
ECH-D	1619975.70	556545.50	614.17	1593.78	1299.97
PS-1	1620168.00	557539.00	n/a	n/a	n/a
Shaft	1620150.00	556549.00	310.29	1610.99	<1300.58
GZ	1620137.00	557494.00	366.98	1593.98	n/a
HC-1	1621927.00	557360.40	405.38	1617.81	1293.90
HC-2	1620208.30	555447.80	369.42	1629.50	1292.70
HC-3	1618822.90	560114.70	338.30	1548.34	1192.70
HC-4	1619560.70	557188.00	377.95	1603.04	1285.50

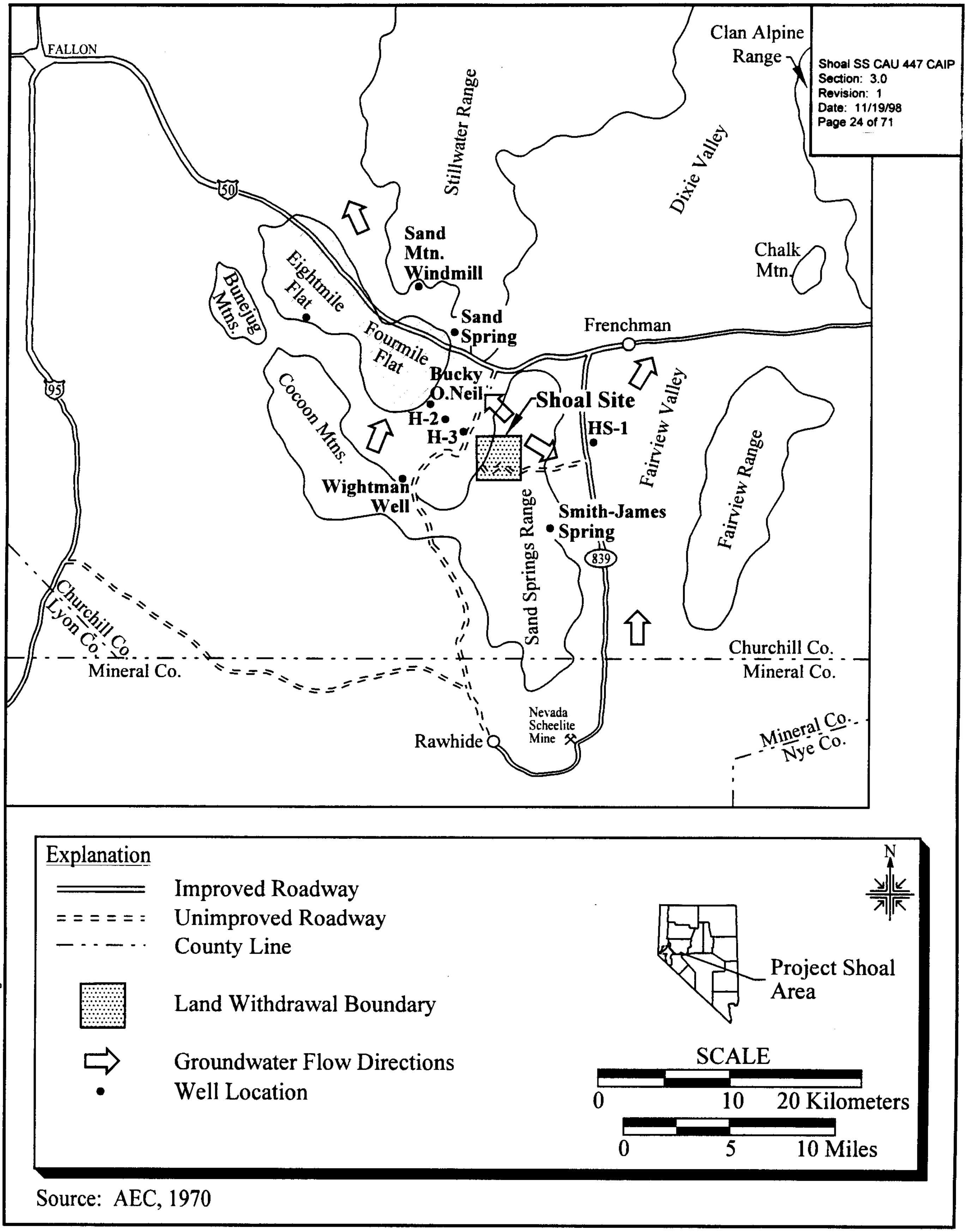
*asml - Above mean sea level
n/a - Not applicable
Note: Details of well drilling and completion can be found in University of Nevada, 1965, and DOE/NV, 1998b.

flow in Fairview Valley is primarily lateral with no vertical gradients. No discharge to the surface occurs in Fairview Valley. Groundwater in Fairview Valley moves northward to the regional discharge area in Dixie Valley. One monitoring well, HS-1, exists in Fairview Valley. This alluvial well was used as the supply well during drilling both in the 1960s and during the recent 1996 drilling. It also serves as a cattle ranching supply well during parts of the year. Another well, H-4, is located near HS-1 but is no longer accessible. Water level depths are 91 m (300 ft) in this area.

3.4.4 Local Flow System

3.4.4.1 Direction of Groundwater Flow

The University of Nevada (1965) conducted an extensive investigation to characterize the geology and hydrogeology of the PSA. They concluded that a groundwater divide may exist northwest of the test cavity and that the main component of lateral movement of groundwater



Source: AEC, 1970

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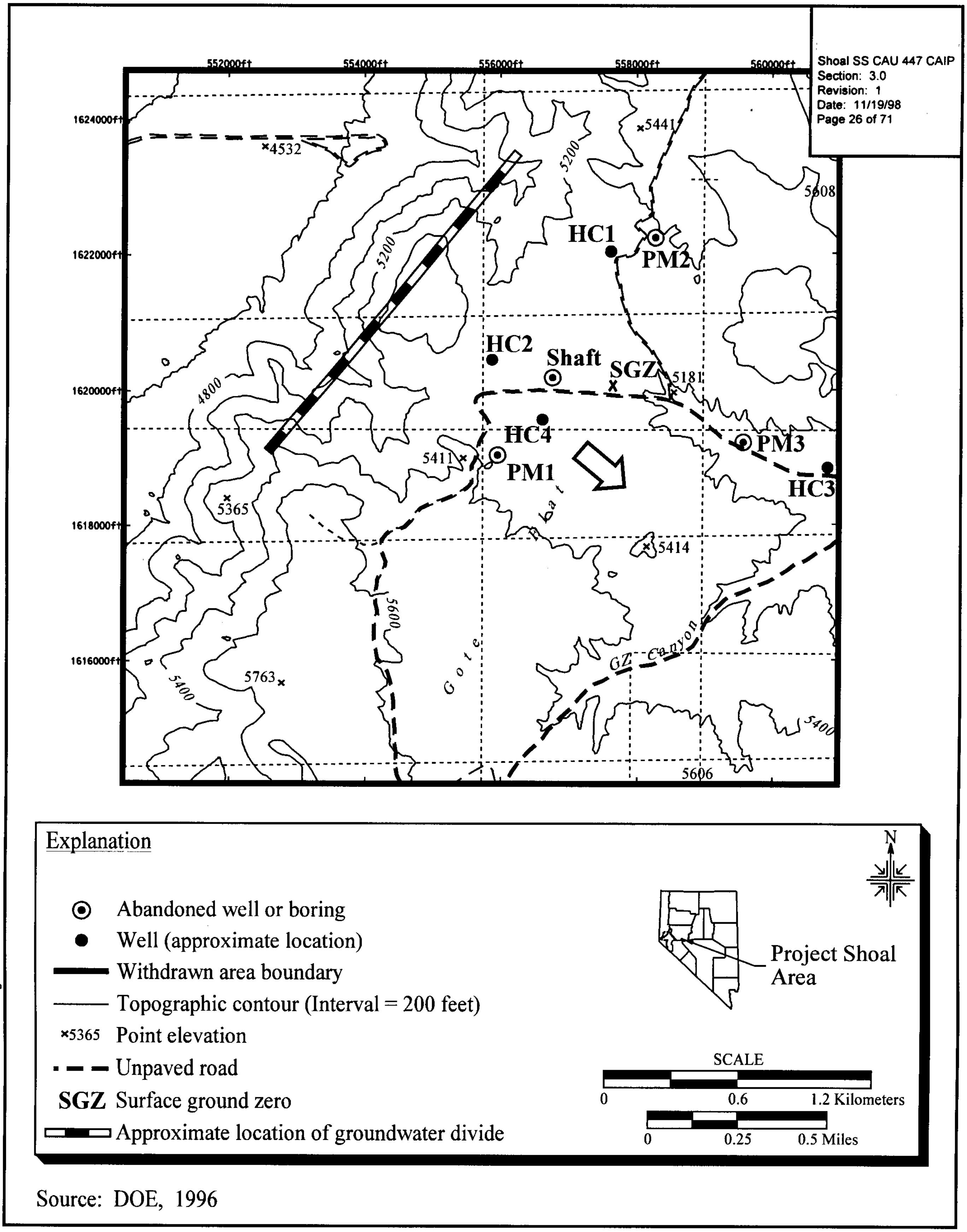
Figure 3-2
Study Location With Local Monitoring Wells and Regional Groundwater Flow Directions

from the cavity is southeast toward Fairview Valley. They also note that there is a large component of downward groundwater motion. The water levels observed during their study are highly uncertain due to the introduction of drilling and testing waters. The water levels in the wells fluctuate hundreds of feet due to the addition of drilling fluids and slug tests. Figure 3-3 shows the location of these monitoring wells for the local flow system.

A prime objective of the recent drilling effort (1996) was to determine with greater confidence the direction of groundwater flow from the nuclear test. Seven wells (PM-1, PM-2, PM-3, PM-8, USBM-1, ECH-A, and ECH-D) were installed during the 1960s site characterization work and provided some information regarding hydraulic properties, but all were plugged shortly after the Shoal test was completed. The original shaft was accessible until 1996, and a final videolog prior to filling showed no water saturation to a depth of 310 m (1,018 ft). Four new wells were installed in the fall of 1996 to characterize the subsurface hydraulic properties near ground zero.

The water levels determined from the new hydrologic characterization wells confirm the earlier conclusion of generally southeastward-directed groundwater flow from the test location. The wells were drilled with a minimal introduction of fluids and were completed within the first 100 m (328 ft) of the saturated zone. The groundwater flow divide lies to the west of an equipotential line described by the hydraulic head measurements at HC-1 and HC-2. From HC-1 and HC-2, there is a reduction in head of approximately 8 m (26 ft) at HC-4 (near the cavity location).

The hydraulic head measured at HC-3 varied dramatically and appeared to stabilize at an elevation of 1,217.1 m (3,993 ft), but subsequently dropped to 1,192.7 m (3,913 ft). This final value is approximately 10 m (33 ft) below the hydraulic head measured in the presumed downgradient valley well, HS-1. It is also below the water levels elsewhere downgradient in Fairview Valley and below that recorded for a stock well in Dixie Valley north of U.S. Highway 50 (University of Nevada, 1965). The Humboldt Salt Marsh, the probable regional discharge area for groundwater flow from Shoal, lies at an elevation of 1,025 m (3,363 ft) (Bateman and Hess, 1978), while Fourmile Flat lies between 1,186 (3,891 ft) and 1,201 m (3,940 ft). The borehole of well HC-3 apparently followed a major fault. Because of drilling difficulties the well could not be completed as intended. A 5-cm (2-in.) diameter piezometer was installed instead of



Source: DOE, 1996

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Figure 3-3
Generalized Groundwater Flow System and Well Locations at the Shoal Site

an open hole type completion that was done in the other HC wells. Because of this completion, hydraulic testing to investigate the anomalously low water level was not possible.

3.4.4.2 Hydraulic Properties

Four measurements of transmissivity in the granite aquifer were made within 1.6 km (1 mi) of the Shoal test, in Wells PM-1, PM-3, USBM-1, and H-3, by the University of Nevada (1965). They express no confidence in the interpretation of the test results because of the many differences between conditions in the granite and the idealized conditions under which the testing theory was developed. The University of Nevada (1965) concluded that the granite near the site has a transmissivity less than 3 x 10^{-5} m^2/s (2.8 x 10^{-6} ft^2/s) (original units were 200 gallons per day/ft). In addition, they state that the aquifer beneath the range has a lower transmissivity than that measured at Well H-3 west of the range.

Other workers have since provided interpretations of the hydraulic test results reported in University of Nevada (1965). Gardner and Nork (1970) report that the apparent hydraulic conductivity of the Sand Springs granite ranges from 10^{-6} to 10^{-5} centimeters per second (cm/s) (3.9 x 10^{-6} to 3.9 x 10^{-5} inches per second [in./s]). Using ranges of contributing thicknesses derived from well logs, Chapman et al. (1995) calculated a range in hydraulic conductivity for PM-1, PM-3 and USBM-1 of 4.7 x 10^{-6} to 1.1 x 10^{-4} cm/s (1.5 x 10^{-7} to 3.6 x 10^{-6} ft/s). Using the full saturated thicknesses of H-3 (46 m [151 ft]), they similarly calculated a hydraulic conductivity of 6.1 x 10^{-5} cm/s (2.4 x 10^{-5} in.), based on the aquifer test performed there.

Hazelton-Nuclear Science (1965) used an analysis of groundwater inflow into the shaft-drift complex to estimate the hydraulic properties of the granite. Using the Dupuit-Forchheimer equation, they obtained a hydraulic conductivity of 10^{-5} cm/s (10^{-7} ft/s).

Aquifer tests were performed in wells HC-1, HC-2, and HC-4 and are reported in detail in (Pohll et al., 1998). The hydraulic conductivity resulting from these fully penetrating tests ranges from 1.48 x 10^{-6} cm/s at HC-2 to 4.7 x 10^{-5} cm/s (4.9 x 10^{-8} to 1.5 x 10^{-6} ft/s) at HC-1. A numerical analysis of the HC-1 test resulted in a hydraulic conductivity value of 8.60 x 10^{-5} cm/s (2.8 x 10^{-6} ft/s).

In addition to borehole hydraulic testing, a program of discrete hydraulic conductivity measurements was undertaken at the hydrologic characterization wells, with the aim of understanding the hydrogeologic heterogeneity of the fracture system at Shoal. Stressed flowmeter testing determines the vertical distribution of hydraulic conductivity by either pumping or injecting fluid at a constant rate and measuring the vertical flow distribution. Although flowmeter testing is relatively simple to implement in the field, it has a limited lower resolution (it cannot quantify very low hydraulic conductivities). Stressed flowmeter testing was successfully carried out in wells HC-1 and HC-4. Measurements were made at 10-m intervals and are reported in detail in Pohll et al., 1998. Hydraulic conductivities ranged from 1.0×10^{-6} to 7.7×10^{-4} cm/s (3.3×10^{-8} to 2.5×10^{-5} ft/s). Measurements were attempted in Well HC-2, but the very low hydraulic conductivity of the well prevented equilibrium flow conditions from being achieved under either pumping or injection conditions.

3.4.4.3 Groundwater Velocity

Based on their observations during well drilling and testing, and during mining operations, the University of Nevada (1965) concluded that the rate of groundwater movement in the vicinity of the detonation site is low. They note that this conclusion is supported by the recovery tests, steep potentiometric gradients, and rapid increases in ion concentration downgradient. The rate of movement of groundwater in the granite was believed to be a fraction of that computed for the valley fill. The estimate of groundwater velocity in the alluvium was 10 meters per year (m/yr) (University of Nevada, 1965).

Using the data developed by the University of Nevada (1965), several estimates of groundwater velocity are available. Hazelton-Nuclear Science (1965) gave a range of fluid velocity at Shoal between 3 and 7 m/yr (10 and 23 feet per year [ft/yr]). Gardner and Nork (1970) estimate that the groundwater velocity ranges from 0.3 to 30 m/yr. Chapman et al. (1995) used a velocity of 3 m/yr (10 ft/yr) for flow eastward from Shoal. The work of Pohll et al. (1998), yielded conflicting estimates of groundwater velocity. The numerical groundwater model predicted a mean velocity (along the mean direction of flow to the southeast) of 5 m/yr (16 ft/yr), while hydrochemical evidence suggested a much slower velocity of 0.1 m/yr (0.3 ft/yr).

3.4.4.4 Hydrochemical Environment

The groundwater from wells at the Shoal site is part of the mixed-cation and mixed-anion chemical facies. Water quality is good, with total dissolved solids contents ranging from about 330 to 480 milligrams per liter (mg/L) (Pohll et al., 1998). The pH is near neutral (approximately 8 std units). Equilibrium solubility calculations indicate saturation with respect to calcite, aragonite, barite, chalcedony, quartz, and talc. This reflects a history of silicate hydrolysis and dissolution of carbonate minerals (probably from carbonate dust encountered during recharge). The granite is composed primarily of quartz and feldspar, which are undergoing dissolution and alteration.

Percent modern carbon contents for Wells HC-1 and HC-2 are 49 and 22, respectively, and result in calculated groundwater ages of 6,000 and 12,500 years before present, respectively. Despite this almost 5,500-year difference in age, the stable hydrogen, oxygen, and carbon isotopic compositions (Pohll et al., 1998) indicate that recharge occurred under similar climate and vegetative conditions. This implies that water in these wells was recharged under climatic conditions established after the end of the last pluvial period in the region, between about 12,000 and 14,000 years before present, based on water-level estimates for Lake Lahontan (Benson and Thompson, 1987).

There are significant chemical and isotopic differences between the water sampled at the Shoal site and analyses from well HS-1 in the downgradient Fairview Valley. For example, the concentration of chloride, which is not part of any major rock-forming minerals, decreases from values of 47.7 to 101 mg/L at the Shoal site, to 29.3 mg/L at Well HS-1. The stable isotopic composition of groundwater from Well HS-1 is also markedly depleted in the heavy isotopes as compared to groundwater at the site, and the radiogenic carbon content is very low (8.3 percent modern carbon), indicating a groundwater age in excess of 19,000 years. These differences between groundwater at the Shoal site and in the downgradient valley suggest that groundwater flow from the site area is either not a major contributor to the alluvial aquifers in the valley and/or that travel times are so long that temporal changes in water chemistry and isotopic content brought about by changes in recharge conditions caused by the end of the last pluvial period have not been transmitted to the valley aquifers yet. These interpretations require low-flow volumes from range to valley, together with low-flow rates.

3.5 Contaminants

Contaminants resulting from underground nuclear testing can be divided into two broad categories: radionuclides and nonradionuclides. Primary radionuclides can be attributed to three possible origins: (1) residual nuclear material which has not undergone a fission or thermonuclear reaction, (2) direct products of the nuclear reactions (fission products and tritium), and (3) activation products induced by neutron capture in the immediate vicinity of the explosion (Borg et al., 1976). In addition, radionuclide daughter products are produced by decay of many of the primary radionuclides. The relatively simple design and implementation of the Shoal test resulted in essentially no nonradionuclide contaminants.

The Shoal radionuclide source term is included in a classified inventory prepared by Los Alamos and Lawrence Livermore National Laboratories for nuclear tests conducted at locations off the NTS (Goishi et al., 1995). Calculations of the radionuclide production from Shoal are also presented in a nonclassified report by Hazelton-Nuclear Science (1965). Table 3-3 is a list of potential contaminants of concern.

Table 3-3
Potential Contaminants of Concern for Project Shoal Area Subsurface CAU

Nuclide	Half-Life in Years	Source*	Shot-Time Activity in Curies
Ce^{144}	0.78	f	6.7×10^4
H^3	12.3	a	3.0×10^4
Pm^{147}	2.7	f	9.7×10^3
Ru^{106}	1.0	f	6.4×10^3
Cs^{137}	30.0	f	2.2×10^3
Fe^{55}	2.6	f	2.0×10^3
Sr^{90}	28.0	f	1.9×10^3
Sb^{125}	2.7	f	8.0×10^2
Eu^{155}	1.7	f & a	4.7×10^2
Sm^{151}	90.0	a & f	4.2×10^2
Cd^{113m}	14.0	f	3.0×10^1
Gd^{153}	0.6	a	1.5×10^1

*f = fission product; a = activation product

NOTE: Table 3-3 includes device and neutron-activation produced non-gaseous radionuclides in quantity greater than 10 curies and with half-lives greater than one-half year. The amount of fission produced tritium is small relative to the total neutron activation production of tritium and does not alter the above figure significantly. (From Hazleton-Nuclear Science, 1965)

3.6 Conceptual Model of the CAU

Groundwater transport of radionuclides from the Shoal detonation is controlled by the ambient groundwater flow conditions and the geochemical environment that may act to inhibit the mobility of certain species. The groundwater flow system is apparently controlled by the fracture network within the granitic aquifer, the hydraulic properties of the fractures, the surface recharge, the mean hydraulic gradient, and the effective porosity of the bulk fracture material. A schematic showing the primary features of the physical flow system is given in Figure 3-4. The groundwater flow divide is assumed to be aligned with the topographic divide located in the northwest corner of the land exclusion boundary. The hydraulic head data from the local wells indicate a primary flow direction to the southeast. Recharge estimates for the Project Shoal site range between 0.60 to 2.14 cm/yr (0.23 to .84 in./yr) (Maxey and Eakin, 1949; Gardner and Nork, 1970). The recharge conditions are supported based on the water table beneath the range being higher than that in the adjacent valleys, and the observation of decreasing head with depth (downward vertical gradient) in well ECH-D (University of Nevada, 1965). The local flow system consists of surface recharge that infiltrates through the thin soil layer and enters the relatively deep (~335 m [1,100 ft] below ground surface) groundwater system. Once fluid reaches the groundwater system, it moves downward and laterally southeast toward Fairview Valley (Figure 3-4).

The groundwater flow system in the Sand Springs Range consists of a fractured granitic aquifer. The groundwater flow system is controlled by and restricted to fractures. The larger fractures are oriented primarily northeast-southwest and northwest-southeast, and the dip angles are moderate (30-40 degrees to the east or southeast) to steeply dipping (near vertical). The smaller fractures do not have a primary orientation. Analysis of the observed fractures suggests large fracture densities. Although the fractured system produces a highly heterogeneous groundwater flow system, it is assumed that it behaves like an equivalent continuous porous medium. Many researchers have used equivalent porous medium techniques to characterize fractured aquifer systems (Long et al., 1982; Tsang et al., 1996; Novakowski, 1990; Rehfeldt et al., 1992; Hsieh and Neuman, 1985; Schwartz and Smith, 1988). Long et al. (1982) report that an equivalent porous medium will exist for fractured rock when the fractures are relatively dense.

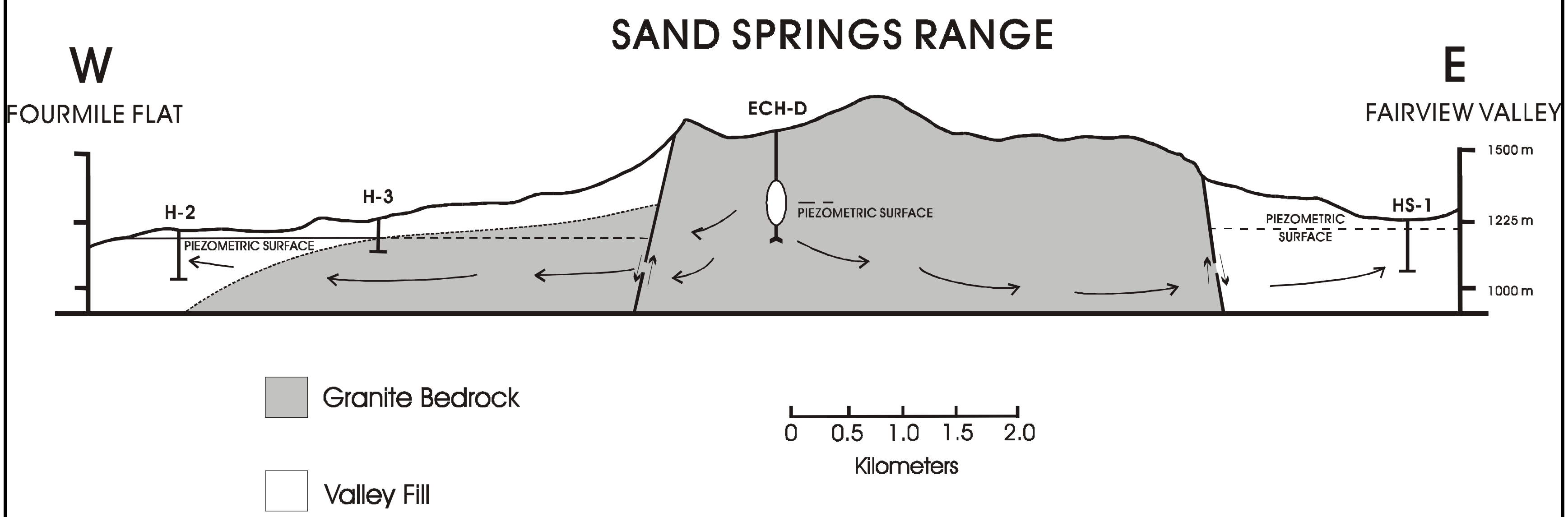

Figure 3-4
East-West Cross Section Near the Shoal Site Showing Idealized Groundwater Flow Directions
(From Hazleton-Nuclear Science, 1965)

The contaminants considered consist of the radionuclides produced by the Shoal test and the daughters created by radioactive decay. The nuclides are primarily located within the cavity created by the explosion, though it is possible that a relatively small proportion of the volatile nuclides might have been injected out into fractures generated by the explosion (a cracking radius of 159 m was predicted for the test; Beers, 1964). Within the cavity, nuclides are distributed according to their volatility among surface deposits and volume deposits in nuclear melt glass. Nuclear melt glass dissolution rates may be calculated using volcanic glass dissolution behavior as an analog. It is assumed that migration of radionuclides begins once the cavity has infilled with groundwater. Postshot drilling data confirm that the Shoal cavity and chimney were initially de-watered, as routinely occurs as a result of thermal and compressional forces, and bulking caused by collapse. Based on hydraulic properties and estimates of the post-shot water levels, it is estimated that reequilibration of the potentiometric surface (water-level recovery) will require about 10 years, after which time radionuclide migration can begin. Once released, some radionuclides will be subject to retardation due to reactions with the granite host rock.

3.7 Corrective Action Levels

The modeling objective for the PSA is to predict an acceptable contaminant boundary. This will be achieved through flow and transport modeling of contaminants from the underground test through the fractured granite aquifer. The contaminant boundary will be proposed as part of the CADD.

4.0 Summary of Data Quality Objectives, Processes, and Results

The Data Quality Objective 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 PSA subsurface CAS, and they support a course of action for investigating the PSA CAU. The DQOs are presented in Section 3.0 of the *Corrective Action Investigation Plan for the Project Shoal Area, CAU 416* (DOE/NV, 1996a).

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

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 the Shoal CAI. The ability to predict groundwater flow and transport requires the selection of the most appropriate computer codes such that all of the important flow and transport processes are incorporated. Computer codes will be evaluated based on the following capabilities:

1. Fully three-dimensional processes
2. Heterogeneous and anisotropic subsurface hydrologic properties
3. Flexible boundary conditions
4. Ability to handle unconfined aquifer conditions
5. Steady-state and/or transient conditions
6. Hydrologic sources and sinks (e.g., surface recharge)
7. Transport via advection, dispersion, adsorption, and matrix diffusion
8. Radioactive decay and daughter products
9. Minimal numerical dispersion
10. Capability for Monte Carlo simulations
11. Access to source code

There are additional considerations that relate to running large three-dimensional models of multiple datasets, including data formats, efficient data handling, pre- and post-processors, efficient numerical solvers, and compatibility with existing software and hardware. A previous groundwater modeling investigation by Pohll et al. utilized a variety of computer codes to simulate the groundwater flow and transport system. The spatial distribution of the fracture network was simulated using sequential indicator simulation algorithms (Deutsch and Journel, 1992). The three-dimensional model MODFLOW (McDonald and Harbaugh, 1988) was used to simulate the groundwater flow system (hydraulic heads and fluid fluxes). A particle tracking random walk method was used to calculate the transport of solutes. Radioactive decay was handled in a post-processing mode. These computer codes are well-suited to simulate the groundwater system at the PSA, although final model selection will consider previous experience as well as the factors listed above.

5.1.2 Model Discussion/Documentation

The groundwater modeling efforts will focus on the region near the PSA underground nuclear test. The previous model domain (Figure 5-1) was 1 km (0.6 mi) wide, 3 km (1.8 mi) long, and 2 km (1.2 mi) deep (beneath the uppermost groundwater elevation) such that solute transport could be calculated at the intersection of the model domain and the downgradient section of the land exclusion boundary. Due to the large uncertainty in the fluid velocities, the required extent of the new model domain is not known. After additional hydraulic data are collected, the model domain will be selected such that the simulated solute plumes will be contained within the model domain.

The approach will be to refine the previous modeling analysis such that the uncertainty in the simulated transport behavior will be reduced. The approach is to first define the subsurface heterogeneity through a variety of subsurface hydraulic and fracture characterization data. A combination of borehole logging data (geophysical and video) logs and geologic structure mapping are used to describe the geologic heterogeneity created by the fracture systems in the Sand Springs granite. The data are used to assign fracture classes to the subsurface and the statistical properties of the fracture classes. Because it is not possible to sample the fracture system at all points within the model domain, sequential indicator simulation methods are used to generate maps of hydrogeologic heterogeneity at unsampled locations.

The sequential indicator simulation methods provide the spatial distribution of fracture classes. The field hydraulic data are then used to convert the fracture classes to hydraulic conductivity values that are used in the groundwater flow model. Discrete hydraulic conductivity measurements are performed for each fracture class type to develop mean conductivities. Previous hydraulic testing revealed only minor variability within each fracture class. As new conductivity data are collected and possible increased heterogeneity found, variability of the hydraulic conductivity may be included in the simulation process.

With the hydrogeologic variability in place, the next step is to construct the groundwater flow model. The purpose is to assign boundary conditions that replicate the natural groundwater flow system. This requires knowledge of the boundaries as inferred from hydrologic data. Data indicate that the Shoal site is in an area of active groundwater recharge, such that recharge along the upper model surface must be evaluated and applied within the groundwater modeling framework. The boundary conditions and hydraulic data can then be adjusted through a

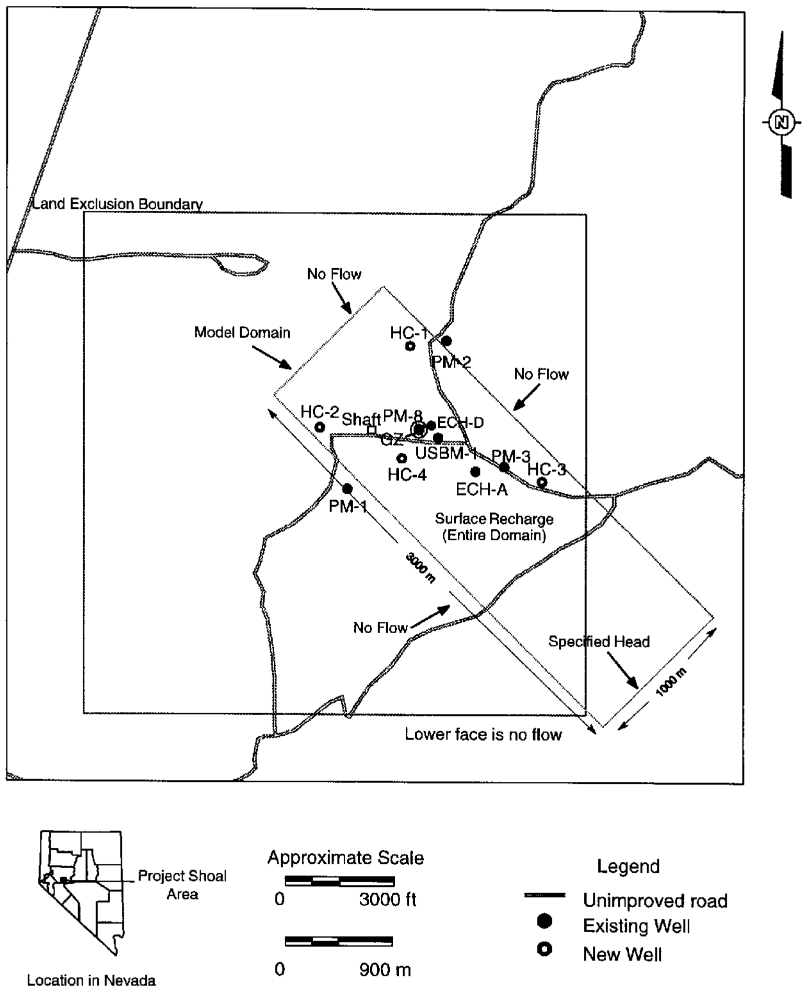

Figure 5-1
Current Model Domain and Boundary Conditions for the Groundwater Flow Model

calibration process to obtain a reasonable level of agreement between observed and simulated hydraulic head values (see Section 5.1.3).

The groundwater flow and transport model will be calibrated and documented to ensure that there is a correspondence between the model simulations and observed system behavior. The calibration process will be guided by the American Society for Testing and Materials (ASTM) standard guide for calibrating groundwater models. *The Standard Guide for Calibrating a Ground-Water Flow Model Application* (D5981-96 Standard Guide for Calibrating a Ground-Water Flow Model Application) (ASTM, 1997) is a guide and may be refined to match the specific needs of the project. For example, the guide does not discuss the calibration of stochastic models which, by definition, incorporate parameter uncertainty. The guide recommends the use of an objective function (a measure of model error) that quantifies the level of agreement (or disagreement) between observed and simulated system behavior. In the case of a stochastic model, many equiprobable realizations are performed and, as such, there is a distribution of simulated versus observed error. Because a stochastic model is proposed, the input parameter set will be adjusted such that the distribution of model errors (i.e., for all realizations) will be minimized.

The ASTM standard procedures that will be used include the guidance over the use of site-specific information (D5490), applying modeling to site-specific problems (D5447), defining boundary (D5609) and initial (D5610) conditions, performing sensitivity analysis (D5611), and documenting groundwater flow model applications (D5718) (ASTM, 1993a and b; 1994a-c; and 1997).

The final step is to calculate transport of contaminants of concern using a particle tracking random walk method. The release functions of the contaminants, as well as their retardation due to reactions with the aquifer matrix, will be included in the transport formulation.

Data identified in Section 3.4 will be used in the modeling steps as discussed above. A data decision analysis, described in Section 6.0, will be used to determine the possible benefit of augmenting the existing data during the Corrective Action Investigation.

5.1.3 Model Validation

The process of model validation involves following a modeling protocol - a series of steps which when followed builds support in demonstrating that a given site-specific model is capable of producing meaningful results. The steps of the modeling protocol are:

1) Establishing the model purpose
2) Developing a conceptual model
3) Selection of a computer code and code verification
4) Model design
5) Model calibration
6) Sensitivity and uncertainty analyses
7) Model verification
8) Predictive simulations
9) Presentation of model results
10) Postaudit

A more detailed discussion of most of these steps can be found in ASTM (1993a), Standard Guide for Application of a Ground Water Flow Model to a Site Specific Problem and in Anderson and Woessner (1992). Each of the steps will be discussed individually in the sub-sections below.

5.1.3.1 Model Purpose and Objectives

The objectives of the model guide the level of detail and accuracy required of the model. The model objectives can be summarized as follows:

a) Integrate a wide variety of data into a mass conservative description of contaminant migration in ground water from the PSA underground nuclear test. To the extent practicable, the model will honor observed data to a specified degree of confidence by following the calibration process described in Section 5.1.2. In the terms of ASTM (1995), Standard Guide for Subsurface Flow and Transport Modeling, the CAU model can be termed an aquifer simulator. This means the model will be used to assess the value of unknowns at specific locations and times. It also requires a high degree of correspondence between the simulations and the physical hydrogeologic system.

b) Simulate, as output, the concentration of individual contaminants downgradient of the underground test location over a time period of 1,000 years. All of the simulated contaminant concentrations will be evaluated in terms of significant health risk. A composite simulation will be performed with this subset of contaminants to define a contaminant boundary based on a 4 millrems per year (mrem/yr) composite dose.

c) Serve as a tool to evaluate impacts of future flow system changes on the migration of contaminants in the CAU.

5.1.3.2 Conceptual Model

The conceptual model defines the characteristics and dynamics of the hydrogeologic system. Section 3.6 of this document provides a description of the conceptual model. The elements of a conceptual model are defined in ASTM (1996), Standard Guide of Conceptualization and Characterization of Ground-Water Systems. All available data from PSA will be used to construct the conceptual model. Other non-site specific data may be included in the development of the conceptual model, particularly to provide additional constraints on parameter uncertainty.

5.1.3.3 Selection of a Computer Code and Code Verification

The computer code selection is the process of selecting the appropriate software that is capable of simulating the characteristics of the physical and chemical hydrogeologic system, as identified in the conceptual model to the degree required to meet the objectives. The code selection process is described in Section 5.1.1 of this document. Verification of the code, defined as the process of ensuring that the code algorithms are operating properly, is an important criterion of the code selection process. Typically, code verification is accomplished by comparing the model output to analytical solutions and in some cases results of other numerical models. To fulfill this requirement, only codes that have been thoroughly evaluated through a rigorous quality assurance process will be considered in the code selection process.

5.1.3.4 Model Design

Model design is the process of transforming the conceptual model into a mathematical form as described in Section 5.1.2. The process typically includes the data sets and the computer code. This step includes formulation of the model grid, selecting time steps, setting boundary and initial conditions, and preliminary selection of values for aquifer parameters. The natural heterogeneities at the PSA will be simulated via a statistical representation of the spatial distribution of hydraulic conductivity. This method requires parameterization of the statistical properties of the spatial heterogeneity and will provide numerous equiprobable realizations of spatial variability. Therefore, the model will provide predictions of the mean behavior and the uncertainty in the predictions.

5.1.3.5 Model Calibration

As defined in ASTM (1996), Standard Guide for Calibrating a Ground-Water Flow Model Application, model calibration is the process of refining the model 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 system. The model calibration process has been defined in Section 5.1.2. For the PSA flow model, the calibration targets will include hydraulic head targets as were used in the original flow model. Hydraulic head calibration targets will be revised as new data become available during the field characterization phase.

5.1.3.6 Sensitivity and Uncertainty Analyses

The sensitivity and uncertainty analyses are quantitative methods of determining the effect of variations in the parameter and boundary conditions (input parameters) on model predictions (output parameters). These analyses will follow ASTM (1994c), Standard Guide for Conducting a Sensitivity Analysis for a Ground Water Flow Model Application. The ASTM standard for sensitivity/uncertainty analysis is primarily intended for deterministic models, while the PSA model is constructed in a statistical framework so the sensitivity/uncertainty analysis for the PSA will have to be modified slightly from the general concepts of the ASTM approach. The uncertainty in model predictions may focus on the contaminant boundary location for the subset of the test related contaminants that are found to be critical in terms of health and safety (e.g., ^{3}H, ^{90}Sr, ^{137}CS). The uncertainty of the composite (4 mrem/yr) contaminant boundary will also be included in the sensitivity/uncertainty analysis.

The uncertainty in the model output is due to uncertainty in the mean parameters and the natural heterogeneity of the subsurface. The sensitivity analysis will determine how both of these uncertainties will propagate into model output uncertainty. The uncertainty analyses will include bounding calculations that are intended to capture 90 percent of the output uncertainty by choosing uncertainty ranges for the mean input parameters that extend from the 5 to 95 percent levels with the inclusion of the uncertainty due to the natural heterogeneity. This analysis will follow ASTM (1994c), Standard Guide for Conducting a Sensitivity Analysis for a Ground Water Flow Model Application to assess the sensitivity of the mean parameters. A Monte Carlo type approach will be used in conjunction with the sensitivity analysis to assess the uncertainty in the natural heterogeneity. Various combinations of the mean parameters (bounded by the 5 to 95 percent uncertainty) will be used in conjunction with a Monte Carlo analysis to assess the general uncertainty in the model output and to determine worst case scenarios of maximum contaminant boundary extent. The model output uncertainty resulting from model input uncertainty and natural heterogeneity will be summarized in tables and figures.

5.1.3.7 Model Review

A thorough review of the model will be performed to verify the modeling approach process and to determine if the modeling process can move forward to the verification phase. The model will be reviewed by three groups: (1) the DOE Technical Working Group Modeling Subcommittee, (2) DOE management, and (3) NDEP. These groups will be tasked with assessing model adequacy. The modeling peer group will be asked to attempt to identify fatal flaws in the model and to evaluate whether the modeling process has been applied correctly. In addition, the peer reviewers will be asked to assess the ranges of parameter uncertainty incorporated into the model and to verify that the range of parameter uncertainty is inclusive. In conjunction with the results of the peer review, DOE management and NDEP will determine if the modeling process can move into the model verification phase by not rejecting the model as presented. If either DOE or NDEP reject the model, DOE and NDEP will enter into discussions to determine how to proceed. If neither DOE nor NDEP reject the model, the model verification phase will begin.

5.1.3.8 Model Verification

Model verification is defined as the testing of predictions of the calibrated model against available data not used in the model production and calibration. Since there is a limited amount of steady-state hydraulic head data available at the PSA, transient head data from a tracer test may be used to verify the model. The model will be considered verified if the measured drawdown versus time is within the 5 to 95 percent bounds calculated from the tracer test model.

It may also be necessary for additional data to be collected for purposes of model verification. However, until the CAU modeling is complete, it is not possible to state what type of data should be collected and whether new wells will need to be installed. The new data collection types and locations will be determined from the model response to the uncertainty and sensitivity analyses. After completion of the model, a verification plan will be prepared and submitted to the NDEP for approval. This plan will identify what data are to be collected, where it will be collected, and the acceptable range of data uncertainty. Data representing both model inputs and model outputs will be collected. These new data potentially may include water levels, model parameters, geochemistry parameters, and contaminant concentrations. These data will be compared against the results of the model predictions consistent with the time period in which the verification data are collected. The data collected for model verification will be designed to provide positive comparison to model inputs and outputs and will be compared with the range of values corresponding to the 5 and 95 percent bounds of the specific parameter.

One of several approaches may be used to determine if the new data verify the model predictions. In the case of data for which the number of values are sufficient to determine a probability distribution (pdf), the new data will be shown to be consistent with the previously defined pdf by comparing mean and standard deviation values before and after inclusion of the new data. If the new data do not significantly change the mean and standard deviation, that parameter will be considered verified. In other cases, for which upper and lower bounds have been defined, the new data will be compared with the bounds. The new data will be considered to be verified if the results fall within the 5 and 95 percent ranges defined for that data.

If the data significantly modifies the pdf, or if it falls outside of the 5 and 95 percent ranges, the model will not have been verified. In this case DOE and NDEP will initiate discussions to identify the appropriate path forward.

5.1.3.9 Predictive Simulations

The stated purpose of the CAU model is to provide predictive simulations of radionuclide migration away from the underground test cavity for a period of 1,000 years. For each contaminant, the model will predict the concentration at each node in the model at each time step from 0 to 1,000 years. These data will be processed to calculate a contaminant boundary location. The contaminant boundary is defined as the maximum extent of the 4 mrem/yr composite dose which is made up of the sum of the doses from each of the contaminants.

Various combinations of the mean parameters (bounded by the 5 to 95 percent uncertainty) will be used in conjunction with a Monte Carlo analysis to assess the general uncertainty in the calculated maximum boundary extent. The uncertainty in the contaminant boundary will be presented from the calibrated model and from worst case scenarios as determined from an assessment of various combinations of the mean parameters and a Monte Carlo analysis. The simulated contaminant boundary will be presented in both areal figures and cross-sections within the model domain.

5.1.3.10 Presentation of Model Results

The model and results will be presented in the same level of detail as in the previous PSA model documentation package (Pohll et al., 1998). The documentation package will include descriptions of the numerical model, the model grid, boundary conditions, aquifer parameter assignments, model calibration, sensitivity analyses and presentation of results. The presentation of the transport simulation will include transport parameters, source term, the location of the 4 mrem/yr composite dose contaminant boundary for the 1,000 year time period and the uncertainty associated with these results. Additional results showing contaminant concentrations and the location of the contaminant boundary at selected times will also be presented. These times may include the verification period, the end of the 5 year proof of concept period, as well as other times that are of specific interest.

5.1.3.11 Postaudit

The final component of the validation process is the design of postaudit data collection to provide longer term verification of the model predictions. The postaudit data collection will be integrated as part of the Corrective Action Plan. The details of the postaudit will not be available until the CAP is written. Nonetheless, the general approach to the postaudit will be aimed at continued verification that the model output uncertainty is inclusive of actual future conditions.

The postaudit is designed to be the final stage of a thorough process of model validation designed to demonstrate that the contaminant boundary location has been bounded with reasonable assurance.

5.1.4 Define Contaminant Boundaries

One of the purposes of the modeling effort is to aid in the delineation of the aggregate maximum extent of contaminant transport at or above a concentration of concern and, in addition, express modeling uncertainty through inclusion of a confidence interval in the boundary determination. A method to calculate the aggregate contamination boundary is presented below.

The groundwater model is used to create multiple equiprobable realizations of the contaminant migration. For each simulation, and at each time step, the concentration level is determined for each model grid cell. If the concentration exceeds the specified limit at any one vertical location, then a "hit" is recorded for that x-y location (areal perspective). Each of the x-y locations is scanned to determine if the threshold is exceeded. This process is repeated for all simulation times (typically less than 1,000 years). Because the simulations are performed in a Monte Carlo environment, the uncertainty in the boundary location can be calculated directly by simply counting the number of realizations whereby the x-y cell location exceeded the limit. For example, if 100 realizations are performed and the 50th percentile is of interest, then the boundary is drawn around all cells that have at least 50 realizations that exceed the limit. If the 95th percentile is of interest, then the boundary is drawn around all cells that have at least 5 realizations that exceed the limit. The process can be repeated for any confidence levels and/or cross sections.

A determination of the match between actual field conditions and the proposed contaminant boundaries relies on the degree of confidence in the flow and transport model. This confidence will be established through the validation process described in Section 5.1.3. As required by the FFACO (Appendix VI) the contaminant boundary is defined as the aggregate maximum contaminant extent. The boundary determination discussed above extends through the entire time period of concern (1,000 years), so that the boundary is not representative of any single point in time or single set of conditions that can be measured. Therefore, the assessment of the representativeness of the boundary to field conditions must rely solely on the degree of representativeness of the model, as determined through the validation process.

6.0 Field Investigation

This portion of the CAIP provides a framework for a data decision analysis to determine which investigation methods and data collection methods will minimize the model uncertainty. This process will lead to an addendum to the CAIP which will define the data collection methods. The first phase of the groundwater flow and transport modeling indicated that some parameters in the analysis of radionuclide transport from ground zero had unacceptable levels of uncertainty. The uncertainties were identified through a combination of model sensitivity analysis and identified ranges and associated uncertainties in input parameters. The range in resulting contaminant concentrations and mass flux at the downgradient land withdrawal boundary was used as a guide in determining the model sensitivity to the uncertainty in the parameter. Although the sensitivity analysis utilizes the numerical model, it is a qualitative method as it does not directly quantify the model uncertainty. That is, prediction uncertainty (i.e., variance) is not calculated directly from the input uncertainty. A quantitative assessment of the model prediction uncertainty will be performed as a part of the data decision analysis presented below.

Two characterization studies were conducted in the early 1960s (University of Nevada, 1965) and in 1996 (U.S. Department of Energy, 1998b) to quantify the subsurface hydrogeology. This information was used to construct a groundwater flow and transport model of the PSA. The details of the model construction, predictions and associated uncertainty are provided in Pohll et. al., 1998. Of the many parameters required to construct a numerical model, nine parameters were identified as uncertain in terms of the model's ability to predict solute migration:

1. Effective porosity - The pore space available for solute transport. The effective porosity is defined as the total porosity minus the porosity that is not connected to the groundwater flow system. At the Project Shoal Area, the effective porosity is primarily controlled by the size of the fractures in the granitic aquifer. The model assumes that the porosity is homogeneous throughout the model domain.

2. Hydraulic head - In the context of the groundwater model, this parameter relates to the specified hydraulic head at the downgradient model boundary. The HC-3 well is the closest well to this model boundary, but problems with the well installation led to large uncertainties in the water levels. The water level in HC-3 is lower than in Fairview Valley to the east, which indicates that this boundary condition is uncertain.

3. Recharge - This parameter describes the net amount of fluid infiltration that reaches the groundwater system. It is assumed that the recharge is constant over the entire surface of the model domain.

4. Hydraulic conductivity - The groundwater flow model assumes that there are three classes of fractures (#1: small/no fractures, #2: medium fractures, #3: large fractures). Each model grid point is assigned a fracture class and associated hydraulic conductivity (K_1, K_2, K_3) which represents the effective hydraulic conductivity due the ensemble of fractures contained in a 40 cubic meter zone. Field characterization of the hydraulic conductivity for each fracture class led to relatively certain estimates for the large and medium fracture classes, but limitations of the instruments introduced significant uncertainty in the estimated conductivity for the fracture class that contained little or no fractures (fracture class #1). To ensure adequate agreement between the observed and simulated hydraulic head values, a linear relationship is derived between the recharge rate and the value of the hydraulic conductivity for fracture class #1 (K_1). The linear relationship is derived by assuming that the ratio of recharge versus K_1 was constant. For example, if the recharge rate increases, then an associated increase in K_1 is required such that the simulated head values would not exceed the observed values. The groundwater model utilized in these numerical experiments allowed for variable hydraulic conductivity values within each fracture class. The distribution within each class is described by a ln-normal distribution with the mean being equal to K_1, K_2, K_3, as described above. The ln-variance of hydraulic conductivity is assumed to be a random variable. Therefore, there are two uncertain parameters relating to hydraulic conductivity. First is K_1, which is determined by the linear relation with recharge (another uncertain variable). Second is the ln-variance of hydraulic conductivity.

5. Fracture connectivities (i.e., correlation scales) - The spatial distribution of the fracture classes was simulated via a geostatistical algorithm. One of the critical parameters in this model is the correlation scale of the fractures which describes how the fracture classes persist along the strike and dip directions.

6. Fracture orientations (strike angle) - The geostatistical model requires that the angle of the strike be specified. The analysis of Pohll, et al., 1998 and University of Nevada, 1965 were in agreement on the north-east trending fractures, but there was less agreement on the north-west trending fractures. Pohll et al., 1998 identified an orientation N8W, while the University of Nevada, 1965 found the trend to be N50W. Therefore, the north-east strike angle was assumed to be a deterministic (*i.e.*, known with certainty) parameter and the north-west angle is treated as a random variable.

7. Fracture dip - Similar to the strike orientation, this parameter describes dip angle of the fracture classes. Pohll et al., 1998 reported moderate dip angles between 31E - 44SE, while University of Nevada reported a wider range of 40E - 90SE. The dip angle is

treated as a random variable and the dip angles for each strike orientation are assumed to be independent.

8. Glass dissolution rates - The solute transport model includes an algorithm to calculate the rate of nuclear glass dissolution. The model uses a dissolution rate coefficient which is highly dependent on the specific surface area of the melt glass.

9. Retardation - The dissolved radionuclides are subject to a variety of chemical reactions that can retard their movement relative to water. A linear isotherm was used to model the impact of sorption on solute migration. The retardation factor used by the transport model is parameterized by a distribution coefficient and the fracture aperture, each of which contain uncertainty.

The model sensitivity to each of these parameters was addressed by Pohll et. al., 1998, but the analysis was focused on sensitivity, not on the quantification of uncertainty. This report addresses through quantitative statistical analysis the uncertainty in the model predictions. Once the uncertainty is quantified, this information can be used help decision makers evaluate cost-effective information-collection options to reduce these uncertainties.

The numerical flow and transport model constructed for the PSA contains numerous input parameters. As noted above, there are nine uncertainty parameters. Therefore, there are nine random variables that describe the migration of solutes. Likewise there are many other parameters that are required to simulate migration, but these are considered deterministic variables (*i.e.*, not random).

To characterize the uncertainty in the model predictions, one needs to characterize the pdf's of each input random variable and then construct a relationship to determine how these uncertainties propagate through the model itself. The description of the input parameter pdf's is sometimes termed a prior probability. The prior probability is a description likelihood of obtaining a the true parameter estimate of a parameter given the current state of knowledge.

The prior distributions for nine parameters are determined from a combination of currently available data, literature assessment, and subjective analysis of possible ranges of values for a particular variable. The prior distributions represent the range of possible values that might be expected given the currently available information. The prior distributions do not represent the pdf of the population distribution.

If a uniform distribution is assumed to represent the prior probability distribution then the mean and variance can be calculated using the following expressions:

$$\mu = \frac{b - a}{2} \quad (1)$$

$$\sigma^2 = \frac{(b - a)^2}{12} \quad (2)$$

$$\sigma = \sqrt{\sigma^2} \quad (3)$$

where: a and b are the lower and upper bounds, respectively of the uniform distribution, μ is the mean, δ^2 is the variance, and σ is the standard deviation.

The change in uncertainty due to the collection of additional data is determined by first characterizing the posterior distribution of the input parameters. The posterior distribution is a description of the likelihood of obtaining the true parameter estimate for a particular data collection activity. There are a variety of methods to estimate the posterior distribution. One method utilizes Bayes theorem to calculate the posterior distribution based on the likelihood of various test outcomes (DOE, 1998d). This method assumes that additional characterization may produce outcomes that are similar or completely different that the prior distributions. For example, additional testing of effective porosity may indicate that the mean value is less than, greater than or equal to the original estimate. Another approach is to assume that the mean of the estimated parameter will not change significantly. In this case, the estimation of the posterior distribution is simplified, because one needs to estimate the certainty of the testing procedure about the mean. The latter method requires less subjective judgement on the uncertainty of each test activity, but it does not allow for dramatic changes in the input parameters following testing. The posterior distributions calculated for this analysis will utilize the latter method. This method provides an assessment of the collective input parameter uncertainty reduction for each field activity.

The posterior probabilities of the input parameters will be obtained from a group of hydrogeologists at DRI. The prior probabilities will be presented to the group. The group will then review the proposed field activities (see Section 6.1 for a description of the field activities). The group will provide a reliability factor for each parameter based on the individual field activity. The reliability factor is defined as a real number between 0 and 1 such that a value of one would indicate the field activity provides the true value of the parameter, while a zero would represent no information gain. The reliability factor is then used to calculate the posterior distribution as:

$$a_{post} = m - (1-R)\frac{(b_{prior} - a_{prior})}{2} \tag{4}$$

$$b_{post} = m + (1-R)\frac{(b_{prior} - a_{prior})}{2} \tag{5}$$

where: a_{post} and b_{post} are the lower and upper bounds, respectively of the posterior uniform distribution, a_{prior} and b_{prior} are the lower and upper bounds, respectively of the prior uniform distribution, R is the reliability factor ranging between 0 and 1, and m is the mean of the prior distribution. Therefore, the mean of the posterior distribution is assumed to be identical to the prior distribution (*i.e.*, the field activities will not produce significantly different mean values of the input parameters).

To reduce the individual biasing of the reliability assignment, the group of experts will meet to discuss the points of agreement and disagreement. After a thorough discussion on each of the field activities the group will be asked to come to a consensus on the most appropriate reliability factors.

There are two methods available to estimate the model output uncertainty. The method of Monte Carlo simulation samples from the input distributions, then a model simulation is performed. This process is repeated hundreds of times such that the output distribution can be characterized. The second order-second moment method uses a Taylor series approximation to estimate the output variance. This method utilizes the first and second derivatives of an output metric with respect to the input variables, which can be calculated numerically. The output variance is a function of the input variances and the first and second derivatives. A combination of both approaches will be used in this uncertainty analysis. The Monte Carlo method is used to calculate the output variances based on the prior and posterior distributions. Next, the second order-second moment method is compared to the Monte Carlo method for verification purposes. The second order-second moment analysis can be used to quickly re-evaluate the uncertainty analysis given another set of posterior distributions as the computational requirements are minimal.

The analysis of model uncertainty is performed within a Monte Carlo framework. The model uncertainty is calculated by sampling from the distribution (either prior or posterior) of the nine input parameters and then simulating the groundwater flow and transport model. A variety of output metrics can be calculated from the numerical model. The mean breakthrough time to the downgradient control plane and the peak concentration (any time during the simulation) at the control plane are used as the output metrics. The mean breakthrough time is an integral measure solute plume while the peak concentration is an extreme measure. The solute ^{137}Cs is used for all simulations because it is dependent on all of the input parameters. Other solutes (*e.g.*, ^{3}H and ^{90}Sr) could be used, but many are not dependent on the full suite of transport processes.

The Monte Carlo analysis is first used to calculate the model uncertainty based on the prior distribution of the input parameters. This analysis represents the current uncertainty of the model, which is also the maximum uncertainty of all numerical experiments. Next, the uncertainty reduction of each individual parameter is tested by reducing the input parameter variance to zero. This analysis represents the uncertainty of the model if a single parameter is known completely, but the remaining eight are not. Therefore, this allows the parameter's sensitivity to be ranked in terms of model prediction accuracy. The posterior distributions are then used to calculate the uncertainty reduction for each field activity. This analysis provides information on the relative merit of each activity's ability to reduce model uncertainty. The Monte Carlo analysis is then compared to the second order-second moment analysis to test its validity. The second order-second moment method can also be used to quickly reevaluate the uncertainty analysis given another set of posterior distributions as the computational burden is minimal (*i.e.*, it can be performed in a spreadsheet program).

The last step is to review the activities in terms of a cost-benefit analysis. The costs associated with each field activity will be determined in conjunction with the data decision analysis. The expected uncertainty reduction of the field activities versus estimated costs will be plotted. The activities that have the largest expected uncertainty reduction for a given cost are considered favorable. The set of activities that plot along the outer left edge can be considered the optimal activities in terms of cost versus benefit. Figure 6-1 summarizes the entire data decision analysis approach.

The data decision analysis will focus any data collection activities. Figure 6-2 shows the proposed decision process for the collection of additional data. The investigation will provide a detailed analysis of how the model uncertainty will be reduced as additional data are collected. This information will be used to decide how much additional data will be required for each of the eight parameters listed above. If additional data are required, then the most appropriate measurement technique will be identified.

6.1 Description of Field Investigations

Effective Porosity

Single-Well Withdrawal-Injection Test
The tracer is introduced into the groundwater system for a set time period followed by pumping from the same well and monitoring the tracer concentration versus time (Percious, 1969, Fried et al., 1974). Single well tests provide only limited information near the borehole.

Natural-Gradient Tracer Test
A tracer is introduced with little disturbance to the aquifer. The tracer is monitored at one or more points downgradient (Fried, 1976). Natural gradient tests are costly and may require long periods of time before the tracer moves a significant distance from the injection point.

Two-Well Recirculating Withdrawal-Injection Test
The tracer is injected into the aquifer at one well then it is pumped out of a second while recirculating through the withdrawal-injection system (Grove and Beetem, 1971, Pohll and Pohlmann, 1996, Claassen and Cordes, 1975). Recirculating tests distort the natural flow field and do not provide much information about *in situ* groundwater velocities.

Barometric Tests
The combined effects of barometric fluctuations and aquifer properties on the hydraulic head have been shown to be useful in the inverse sense to determine aquifer hydraulic properties (Furbish, 1991; Landmeyer, J.E., 1996). The method utilizes the temporal response in the surface barometric pressure changes within the aquifer.

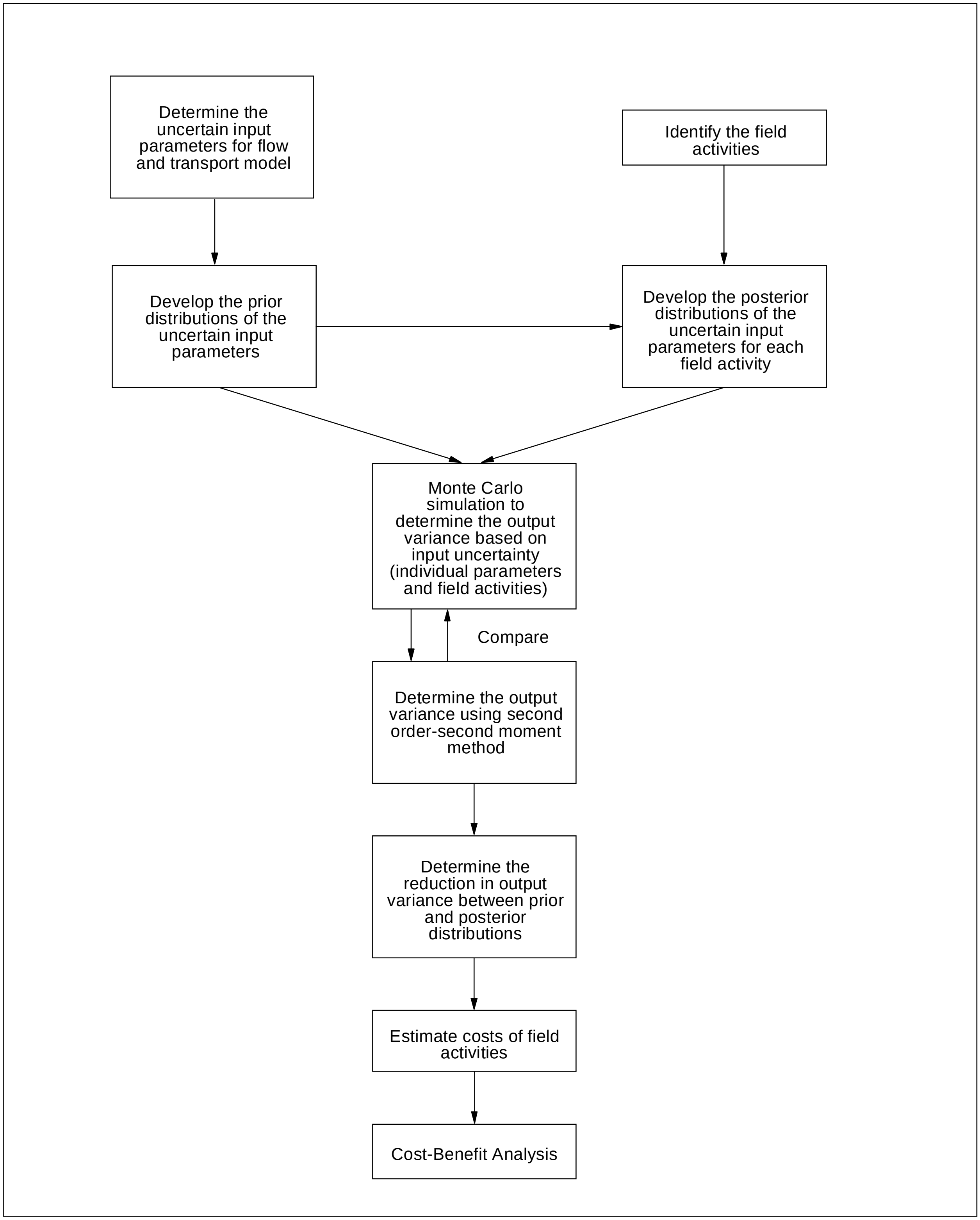

Figure 6-1
Summary of Data Decision Analysis

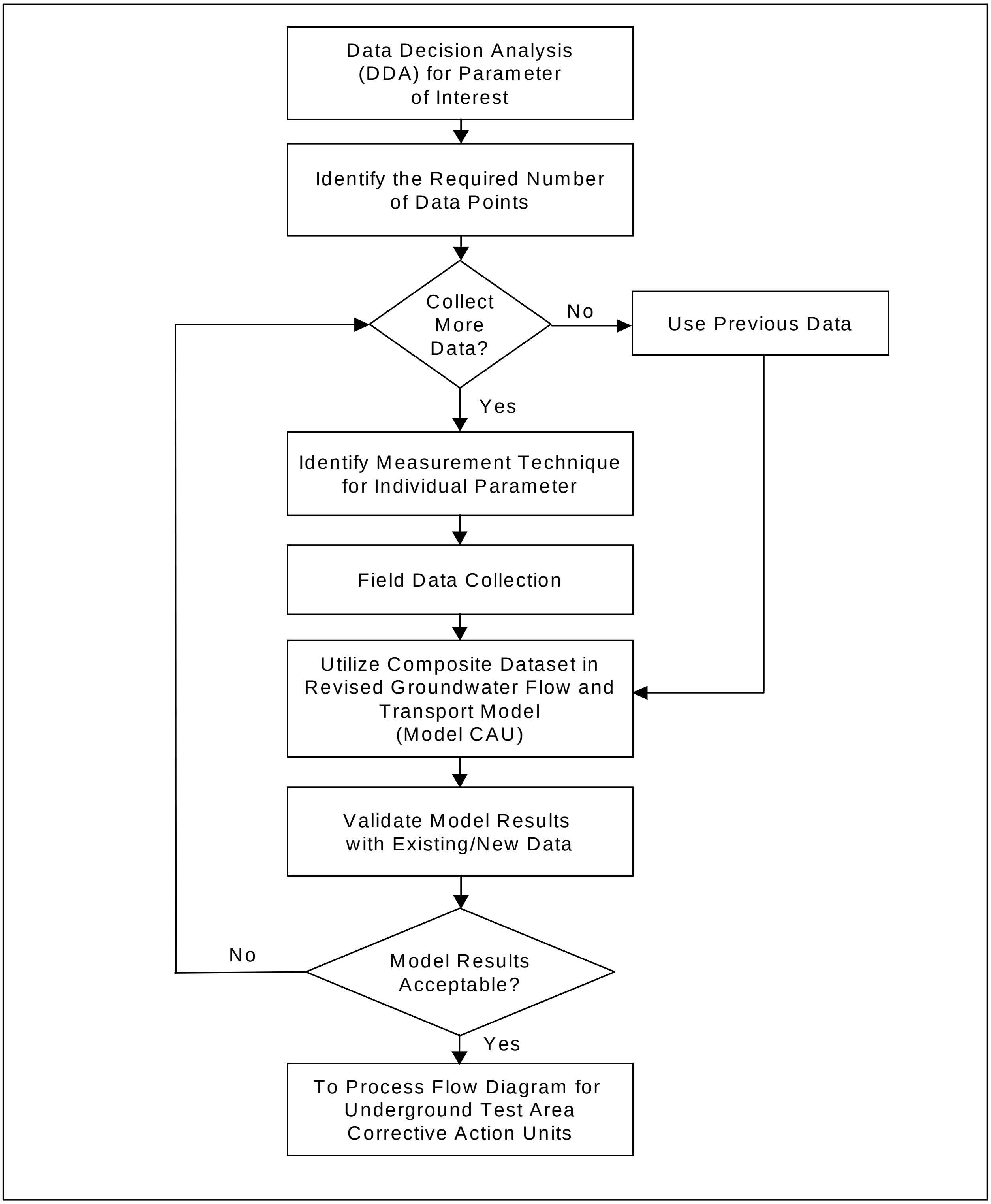

Figure 6-2
Process Flowchart for the Linkage of the Data Decision Analysis Within the Modeling Framework

Neutron Log

Neutron logs can be used to determine the total porosity in the saturated zone or moisture content in the unsaturated zone. Neutrons are emitted from a source and then a detector senses the number of neutrons returning. The porosity (or moisture content) is inversely proportional to the number of detected neutrons. It is very important to calibrate the neutron log for each site (Driscoll, 1986).

Gamma-Gamma Log

An active source of gamma radiation is lowered into the borehole along with a detector that is shielded so it counts only the back-scattered gamma rays. This tool is primarily used to infer formation density, but if the grain density is known, then total porosity can be determined (Driscoll, 1986).

Analogues

Published values of effective porosity, obtained using various testing methods, can be researched for similar hydrogeologic environments. A relatively large number of published values are available from fractured granitic rock as a result of nuclear waste disposal programs in European countries (Werner, 1996).

Hydraulic Head

Measurements in Wells, Including Vertical Gradients

Measurements of hydraulic head within the flow system provide an indication of the groundwater flow directions. It is important to install piezometers throughout the flow system such that vertical and horizontal head gradients can be calculated.

Hydraulic Conductivity (mean and variance)

Single-Hole Packer Testing

Single-hole packer tests can be divided into two categories: (1) injection tests and (2) slug tests. In an injection test, water (or air in the unsaturated zone) is injected under constant hydraulic head into a packed-off interval of the borehole and head and flow rate are monitored. In a slug test, the hydraulic head in the packed-off interval is instantaneously increased or decreased, and the subsequent head recovery is monitored (Hsieh et al., 1983).

Cross-Hole Packer Testing (Interference Testing)

Fluid is injected into a packed-off interval in one borehole, and the resultant hydraulic head variations are measured in packed-off intervals in adjacent boreholes. The objective of the test is to measure, on a field scale, the hydraulic conductivity tensor and the specific storage of a fractured rock aquifer (Hsieh et al., 1983).

Flowmeter Testing

The thermal flow meter is used to measure vertical flow at specified intervals in wells. *In situ* (non-stressed) flow measurements are made to quantify the flow rate between aquifers of differing hydrostatic heads. Measurements made while the well is being pumped or slugged are referred to as stress-flow measurements and are use to proportion the amount of water that flows out of or into the specific zone being tested (Paillet and Olson, 1991). The relative flow rates can be correlated to the relative conductivity of each discrete zone. The flow meter has a finite detection limit which limits its ability to estimate hydraulic conductivity in low permeability zones.

Recharge

Temperature Profiles

Measurements of the thermal profile from ground surface to the water table can yield information on the vertical fluid velocity due to surface recharge. The *in situ* temperature is measured at discrete intervals in the unsaturated zone. Analytical methods are used to determine the magnitude of the fluid velocity (Bredehoeft and Papadopulos, 1965).

Tracer Techniques

Use of environmental tracers in groundwater recharge investigations began in the 1960s with the tracking of tritium movement in soil water (Zimmerman et al., 1967). Use of radiotracers has since expanded to include carbon-14 (though there are complications due to geochemical reactions and diffusion of carbon dioxide gas; Thorstenson et al., 1983), and chlorine-36 (Phillips et al., 1988). The nonradiogenic isotopes of deuterium and oxygen-18 have also been used extensively in unsaturated zone studies (Barnes and Allison, 1983), as has the chloride mass-balance method (Allison and Hughes, 1978). All of these techniques basically track the movement of a known substance, either a dissolved solute or a part of the water molecule itself, through the unsaturated zone. Knowing the input function, the age of recharging water can be calculated directly with the radiogenic tracers, whereas the stable tracers can be used to determine flow characteristics that can be used to calculate recharge.

Vertical Hydraulic Head Measurements

Piezometer nests or multiple completion boreholes are used to measure the vertical hydraulic head gradient. Because the vertical head gradients are caused by surface recharge, one can infer the relative magnitude of recharge if the mean conductivity is known (Toth, 1963).

Vadose Zone Modeling

Vadose zone modeling can be used for hypothesis testing of various recharge and hydraulic conductivity relationships. Specifically, one would identify ranges of possible recharge rates and subsurface hydraulic conductivity values and test the flow system response under different combinations of each parameter (Jury et al., 1991).

Energy Budget/Turbulence Methods

One can use either energy budget (Bowen Ratio or Penman) or turbulence (Eddy-Correlation) methods to calculate the near surface water budget. Either method will yield an estimate of the bare soil evaporation and evapotranspiration which can be used to estimate the net surface recharge. The energy methods determine via direct or indirect measurements of the components of the heat balance, while the turbulence methods determine the turbulent fluxes of water vapor, momentum, and sensible heat from covariances (Brutsaert, 1982).

Fracture Connectivities

Surface Geophysics

Surface geophysical work offers the one mechanism for obtaining spatially distributed subsurface information and has been applied to a wide variety of problems with mixed results. There are two general options: seismic reflection and seismic refraction. Seismic reflection is frequently used for reservoir analysis in the oil and gas industry and is probably best suited to define the location and attitude of faults. Reflection is a well-established technique, requiring a contrast in acoustic response for the features of interest and relatively complex data processing and interpretation (Ayers, 1989). Seismic refraction is a simpler technique, but would provide less definition of faults. It can be used to map the depth to water under suitable subsurface conditions.

Horizontal Borehole With Borehole Scanner

Radio waves emitted from a borehole radar tool may be used to detect fractures. The logging tool is lowered into the well on 1 m increments. Fracture zones with minimum widths of 10 cm can be mapped up to a 150 m radial distance from the well (SwedPower/SKB, 1991).

Mining Drift Data

The Shoal test involved mining a 320 m long drift through the Sand Springs granite. Detailed photography of the underground workings, designed to provide data on the geologic characteristics of the granite, was conducted after washing down the walls of the drift. Mapping also accompanied the photography. Though a description of the photography and mapping has been found (Jerome, 1965), the results are more elusive and were apparently never published. It is likely that the records exist in an archive.

Fracture Orientation

Acoustic Televiewer Logs The acoustic televiewer uses a transmitter to paint the surrounding borehole walls with an acoustic signal and a receiver to record the travel time and characteristics of the returning signal. The travel time, amplitude and phase coherence are affected by the character of the surrounding rock. For fracture analysis, marked attenuation is interpreted as a fracture. When a planar feature, such as a fracture, intersects a cylindrical borehole, a sinusoidal trace results (Driscoll, 1986).

Oriented Video

Video logs can be oriented in non-cased wells by placing a magnetic diver’s compass to the back of the video camera light-head. However, in wells with excessive deviation the compass needle may not spin freely.

<u>Surface Geophysics</u>
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Glass Dissolution Rates

<u>Cavity Drillback</u>
A post-shot hole could be drilled into the Shoal cavity to obtain samples of the melt glass and samples of the associated groundwater. There are very few studies available that measure the presence of radionuclides in cavity fluids (Kersting, 1996), adding great uncertainty as to the availability of radionuclides to migrate in groundwater. The core samples could be used to evaluate glass composition and dissolution, and search for reaction products that may mantle surfaces. The groundwater would reveal the dissolved component coexisting with the solid phase and would represent what portion of the radiologic source term is available for transport.

<u>Lab Experiments</u>
Estimates of the release rate of contaminants from nuclear melt glass depend on estimates of the dissolution rate of that glass. In work done thus far, this dissolution has been approximated by the dissolution of volcanic glass. These approximations can be improved most by increasing confidence in the specific surface area (reactive surface area) of the actual puddle glass, and secondarily by refining the reaction rate constants. The rate constants can be improved using samples of Shoal melt glass to perform controlled dissolution experiments. Such techniques are well established (White, 1983), though the hazards and costs associated with working with highly radioactive material complicate this approach (Wolfsberg, 1978; Failor et al., 1983). The more important parameter, the specific surface area, is also the more difficult to measure. Standard laboratory techniques, such as Brunauer-Emmet-Teller (BET), can handle only very small particle sizes, whereas the question is the reactive surface area of a large mass of glass. Even with access to the cavity, research and development would be needed to carry out specific surface area measurements. Short of that, examination of analogues, both natural and man-made, is the only possibility.

Retardation

<u>Lab Experiments</u>
Equilibrium sorption experiments (either batch and/or column) can be performed to estimate the partitioning of an ion between the solution and the solid under equilibrium conditions. Many sorption experiments have been performed on granite materials, but the results are

specific to the site mineralogy and hydrochemistry (Stenhouse and Pottinger, 1994; Frick et al., 1991; Werner, 1996; Failor et al., 1982; Beall et al., 1980). It is important to design the lab sorption experiments using local granite and fluid with hydrochemical characteristics similar to the Shoal site.

7.0 Quality Assurance

This CAIP for CAU 447 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/NV, 1998c). All additional data collection procedures will be under the guidance of current DRI and/or IT Corporation standard operating procedures.

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 as described in this plan, up to and including the preparation of the CADD, is projected to be 2 years and 10 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 CAIP is available in the DOE public reading rooms located in Las Vegas and Carson City, Nevada, and from the DOE Offsites Project Manager. The NDEP 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

NDEP Comment Review Sheet

NEVADA ENVIRONMENTAL RESTORATION PROJECT
DOCUMENT REVIEW SHEET

1. Document Title/Number Corrective Action Investigation Plan for CAU 447: Project Shoal Area, NV, Subsurface DOE/NV - 513
2. Document Date July 1998
3. Revision Number Rev. 0
4. Originator/Organization DOE/IT
5. Responsible DOE/NV ERP Subproject Mgr. Monica Sanchez
6. Date Comments Due
7. Review Criteria NDEP review of document
8. Reviewer/Organization/Phone No. Sigurd Jaunarajs/NDEP
9. Reviewer's Signature

10. Comment Number/ Location	11. Type[a]	12. Comment	13. Comment Response	14. Accept
		The document, when resubmitted, will be deemed Substantially Deficient pursuant to Subpart VIII.3.b of the FFACO, if it remains inadequate in development of sections 5.1.3 and 5.1.4 in the CAIP, (which have been previously agreed to in the Annotated Outline for the UGTA Corrective Action Investigation Plan, dated March 25, 1998), as indicated below. • The portion of the CAIP that is asserted to be so lacking it is factually non-existent (Criteria A), involves the proposed model validation procedure. The plan does not outline the validation process, nor specify the decision criteria to be applied to assess model validation. Additionally, the requirement to demonstrate that the model-predicted contaminant boundaries are reasonably representative of field conditions has not been met.	Sections 5.1.3 and 5.1.4 changed so that this question is answered, see detailed comments # 8 and # 9.	
		The Department of Energy must submit revised due dates for subsequent documents within 30 days following the CAIP deadline. Failure to submit the revised due dates for the subsequent documents will cause the NDEP to establish the due dates without DOE input.	The DOE understands that they have to provide the dates within that time period and will do so after the deadline has passed.	

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Reviewer/Organization Sigurd Jaunarajs/NDEP

10. Comment Number/ Location	11. Type[a]	12. Comment	13. Comment Response	14. Accept
General 1.		An area of continuing concern involves the requirements to assess the validity of model results and show that the model-predicted output is reasonably representative of actual field conditions. As has been stated previously, the type of new data to be collected for validation does not need to be specified in this CAIP. What is required, is an outline of the process that will be followed, along with some decision criteria that will be applied, to validate the results. Different from the validation process, yet closely related to it, is the requirement to define contaminant boundaries that are reasonably representative of actual field conditions. Confidence in model-predicted contaminant boundaries can be established by validating the model results *only if that validation procedure includes some reference to actual field conditions involving the contaminant*. The point of this requirement in Section 5.1.4 of the Annotated Outline for UGTA CAIP is that the CAIP must present some method of demonstrating that the model reasonably approximates real conditions and that the model isn't simply a hypothetical construct (see detailed comments 8 and 9).	This concern is answered in the detailed comments.	
2.		Constructing a flow and transport model for the PSA prior to preparing this CAIP presents a dilemma in terms of how much detail from the *results* should be presented in this *plan*. In most instances, the work of Pohl et al., 1998 is referenced and presented with an appropriate level of detail. In a couple of cases, however, more detail is required in order to follow the progression of scientific reasoning from Pohl et al. Document to the plan presented here. Portions of the text where this link is inadequate have been pointed out in the detailed comments that follow.	This concern is answered in the detailed comments.	

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Detailed Comments 1. Page 2		In the second paragraph, a bit more detail explaining Figure 1-2 is needed. Our understanding is that following approval of this CAIP, a data decision analysis will be performed, followed by a CAIP addendum, followed by the acquisition of additional data, followed by a second phase of modeling runs. If this is the case a few sentences could be added to lead the reader through the flow chart.	Section changed to read "After NDEP has approved this CAIP; a data decision analysis will be completed to determine what data should be collected to refine the groundwater model. Once this has been determined an addendum (or technical change) to the CAIP will be prepared followed by the acquisition of the additional data. The data is then collected and entered into the model and a second phase of modeling runs will be completed."	
2. Page 4		In Figure 1-2, does the line leading from Acquire Additional Data to Model CAU require an arrow? Additionally, shaded boxes are difficult to discern in the copy we received.	An arrow was added to the specified line. The only shaded box on the figure is the key, the shading was removed.	
3. Page 5		In Section 2.1.1.1 in the third sentence, the word "although" should read "through".	Changed as indicated.	
4. Page 7		In the last complete sentence on this page, the numeral "2" inadvertently appears.	The "2" was removed.	
5. Page 25		In the last paragraph, the difficulties with well HC-3 are discussed. What is planned for this well and for gathering data at this critical downgradient location? Will this be reviewed as part of the Data Decision Analysis?	HC-3 is slated for only water-level monitoring. Efforts to adequately purge the well of drilling fluid last fiscal year were unsuccessful, based on bromide levels in pumped water. The difficulties arise from the small diameter access tubing and the limited water column, and the lack of adequate well development before the tubing was installed. The impact of the uncertainties caused by this well were included as part of the Data Decision Analysis, concerning the uncertainty in hydraulic head at the down gradient model boundary.	

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10. Comment Number/ Location	11. Type[a]	12. Comment	13. Comment Response	14. Accept
6. Page 30		The final two paragraphs in Section 3.5 seem a bit out of place in this discussion on contaminants. The point that is alluded to is that the limited measurements and instrumentation for the PSA test precluded detailed information on contaminants from being gathered. To reinforce this point, a sentence in the 3rd paragraph could be modified to read, "The result is that no test rack... were apparently used for Shoal which precluded detailed information on contaminants from being gathered."	The two paragraphs will be deleted and the following sentence: "The relatively simple design and implementation of the Shoal test resulted in essentially no nonradionuclide contaminants," will be inserted at the end of the existing first paragraph in the section. The purpose of the discussion of limited instrumentation for the Shoal test was to support the contention of the absence of large quantities of potentially hazardous materials.	
7. Page 31		The discussion of the release/discharge mechanisms in the 3rd paragraph of the conceptual model could be a little more detailed. It is understood that no hard data exist on the potentiometric surface in the shot cavity. Does the current conceptual model assume a filled in cavity and when is it assumed to have filled? Does the model account for radionuclides injected into surrounding fractures at the time of detonation? The discussion on this in Pohl et al., 1998 could be summarized.	The discussion in the paragraph will be expanded as follows: "The contaminants considered consist of the radionuclides produced by the Shoal test and the daughters created by radioactive decay. The nuclides are primarily located within the cavity created by the explosion, though it is possible that a relatively small proportion of the volatile nuclides might have been injected out into fractures generated by the explosion (a cracking radius of 159 m was predicted for the test; Beers, 1964). Within the cavity, nuclides are distributed according to their volatility among surface deposits and volume deposits in nuclear melt glass. Nuclear melt glass dissolution rates may be calculated using volcanic glass dissolution behavior as an analog. It is assumed that migration of radionuclides begins once the cavity has infilled with groundwater. Postshot drilling data confirm that the Shoal cavity and chimney were initially de-watered, as routinely occurs as a result of thermal and compressional forces, and bulking caused by collapse. Based on hydraulic properties and estimates of the post-shot water levels, it is estimated that reequilibration of the potentiometric surface (water-level recovery) will require about 10 years, after which time radionuclide migration can begin. Once released, some radionuclides will be subject to retardation due to reactions with the granite host rock."	

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8. Page 39		Section 5.1.3 does not sufficiently describe the validation process being proposed. This section must outline the process by which model predictions of the location and concentration of contaminants will be assessed. The second requirement of this section, a data assessment to determine if additional data are needed to improve model predictive capability, is addressed in Section 6.0 with regard to hydrologic data.	All of section 5.1.3 Model Validation was rewritten and expanded.	
9. Page 40		In reference to the last paragraph in Section 5.1.4; the representativeness of the proposed contaminant boundaries to actual field conditions relies on the degree of confidence in the flow and transport model, *which in turn is established in part through a process validation and correlation of model output to field measurements*. As specified in Section 5.1.4 of the Annotated Outline for UGTA CAIP, the portion of the plan in which a process for defining contaminant boundaries is outlined must also include a discussion on how those contaminant boundaries will be assessed to be reasonably representative of field conditions. This discussion might conceivably include a plan for comparison of model predicted results with field data.	A determination of the match between actual field conditions and the proposed contaminant boundaries relies on the degree of confidence in the flow and transport model. This confidence will be established through the validation process described in section 5.1.3. As required by the FFACO (Appendix VI) the contaminant boundary is defined as the aggregate maximum contaminant extent. The boundary determination discussed above extends through the entire time period of concern (1,000 years), so that the boundary is not representative of any single point in time or single set of conditions that can be measured. Therefore, the assessment of the representativeness of the boundary to field conditions must rely solely on the degree of representativeness of the model, as determined through the validation process.	
10. Page 41		The first paragraph states that the first phase of modeling indicated that some parameters had unacceptable levels of uncertainty. How was this determined? Was a qualitative assessment made or were levels of uncertainty calculated with a quantitative method? Some discussion of this is warranted in the CAIP, without having to render a complete reiteration of the modeling results as presented in Pohl et al., 1998.	Chapter 6 Field Investigation was entirely rewritten and this comment was addressed.	

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11. Page 45		How will the required number of data points be identified (in reference to Figure 6-3)? The curve relating model uncertainty and number of samples (Figure 6-2) does not lead to a single number of samples required for a particular parameter. One option is to choose the number of samples found where the slope of the uncertainty curve flattens out. Please discuss how you will use this curve to select the appropriate number of required samples of reach parameter.	Chapter 6 Field Investigation was entirely rewritten and this comment was addressed.	
12. Page 45		Does Figure 6-3 represent the data decision process for individual parameters or all parameters collectively? It stands to reason that an analysis of all parameters collectively, may reveal that collection of additional data for a single particular parameter may produce the same reduction in model uncertainty as collection of additional data for several different parameters. Please discuss how using this statistical approach, you will consider the merits of additional data collection for all parameters collectively, as opposed to just individually.	Chapter 6 Field Investigation was entirely rewritten and this comment was addressed.	

[a]Comment Types: M = Mandatory, S = Suggested.
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