Nevada Environmental Restoration Project

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National Nuclear Security Administration

Phase II Corrective Action Investigation Plan for Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nevada Test Site, Nye County, Nevada

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Environmental Restoration Project

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PHASE II CORRECTIVE ACTION INVESTIGATION PLAN FOR CORRECTIVE ACTION UNITS 101 AND 102: CENTRAL AND WESTERN PAHUTE MESA, NEVADA TEST SITE, NYE COUNTY, NEVADA

U.S. Department of Energy
National Nuclear Security Administration
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Las Vegas, Nevada

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Approved by: /s/ Bill R. Wilborn Date: 07/22/2009

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Approved by: /s/ Robert F. Boehlecke Date: 07/22/2009

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Federal Project Director
Environmental Restoration Project

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List of Acronyms and Abbreviations

1-D	One-dimensional
2-D	Two-dimensional
3-D	Three-dimensional
ALARA	As low as reasonably achievable
amsl	Above mean sea level
ASTM	American Society for Testing and Materials
bgs	Below ground surface
BLM	Bureau of Land Management
BN	Bechtel Nevada
°C	Degrees Celsius
CAB	Community Advisory Board
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
CD	Compact disc
CFR	*Code of Federal Regulations*
cm	Centimeter
CR	Closure report
DI	Deionized
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOE/NV	U.S. Department of Energy Nevada Operations Office
DOT	U.S. Department of Transportation
DQO	Data quality objective
DRI	Desert Research Institute
DTS	Distributed temperature sensor
EC	Electrical conductivity
EMI	Electric micro-imager

List of Acronyms and Abbreviations *(Continued)*

EPA	U.S. Environmental Protection Agency
ER	Environmental restoration
ET	Evapotranspiration
EV	Exceedance volume
FAWP	Field Activity Work Package
FEC	Fluid electrical conductivity
FEHM	Finite Element Heat and Mass Transfer code
FFACO	*Federal Facility Agreement and Consent Order*
FGE	Forced-gradient experiment
FMI	Formation micro-imager
FMP	Fluid Management Plan
ft	Foot
ft/d	Feet per day
FY	Fiscal year
gpm	Gallons per minute
GPS	Global Positioning System
HASP	Health and Safety Plan
HFM	Hydrostratigraphic framework model
HGU	Hydrogeologic unit
HST	Hydrologic source term
HSU	Hydrostratigraphic unit
ID	Identification
IDW	Investigation-derived waste
IE	Ion exchange
in.	Inch
K_d	Distribution coefficient
km	Kilometer
LANL	Los Alamos National Laboratory
LCBL	Life-cycle baseline
LLNL	Lawrence Livermore National Laboratory
m	Meter

List of Acronyms and Abbreviations *(Continued)*

m/d	Meters per day
MCL	Maximum contaminant level
MME	Modified Maxey-Eakin
MTC	Mass transfer coefficient
mW m^{-2}	Milliwatts per square meter
MWAT	Multiple-well aquifer test
N/A	Not applicable
NAD	North American Datum
NDEP	Nevada Division of Environmental Protection
NEM	Non-Electrostatic Model
NNSA/NSO	U.S. Department of Energy, National Nuclear Security Administration Nevada Site Office
NSTec	National Security Technologies, LLC
NTS	Nevada Test Site
NV/YMP	Nevada Yucca Mountain Project
OSHA	Occupational Safety and Health Administration
pCi/L	Picocuries per liter
PM-OV	Pahute Mesa-Oasis Valley
PPE	Personal protective equipment
QA	Quality assurance
QAPP	Quality Assurance Project Plan
QC	Quality control
RadCon	Radiological Control
REOP	Real Estate/Operations Permit
RMC	Reactive mineral category
RN	Radionuclide
RNM	Radionuclide migration
RPP	Radiation Protection Program
RST	Radiologic source term
RWP	Radiological Work Permit
SC	Surface complexation
SDWA	*Safe Drinking Water Act*

List of Acronyms and Abbreviations (Continued)

SISIM	Sequential indicator simulation
SNJV	Stoller-Navarro Joint Venture
SSM	Simplified source-term model
SWL	Static water level
TD	Total depth
TWG	Technical Working Group
UGTA	Underground Test Area
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
VOIA	Value-of-information analysis
WMP	Waste Management Plan
WPM-OV	Western Pahute Mesa-Oasis Valley

List of Stratigraphic Unit Abbreviations and Symbols

AA	Alluvial aquifer
ATICU	Ammonia Tanks intrusive confining unit
ATSM	Ammonia Tanks caldera structural margin
A20SM	Area 20 caldera structural margin
BA	Benham aquifer
BFCU	Bullfrog confining unit
BMICU	Black Mountain intrusive confining unit
BRA	Belted Range aquifer
CCICU	Claim Canyon intrusive confining unit
CFCM	Crater Flat composite unit
CFCU	Crater Flat confining unit
CHCU	Calico Hills composite unit
CHICU	Calico Hills intrusive confining unit
CHVCM	Calico Hills vitric confining unit
CHVTA	Calico Hills vitric-tuff aquifer
CHZCM	Calico Hills zeolitized composite unit
DRIA	Desert Research Institute recharge with alluvial mask
DRIAE	Desert Research Institute recharge with alluvial and elevation mask
DRT	Deeply rooted belted range thrust fault
DVA	Detached volcanics aquifer
DVCM	Detached volcanics composite unit
DVRFS	Death Valley Regional Flow System
FCA	Fortymile Canyon aquifer
FCCM	Fortymile Canyon composite unit
FCCU	Fluorspar Canyon confining unit
IA	Inlet aquifer
KA	Kearsarge aquifer
LCA	Lower carbonate aquifer
LCA3	Lower carbonate aquifer-thrust plate
LCCU	Lower clastic confining unit
LCCU1	Lower clastic confining unit - thrust plate

List of Stratigraphic Unit Abbreviations and Symbols
(Continued)

LFA	Lava-flow aquifer
LPCU	Lower Paintbrush confining unit
MGCU	Mesozoic granite confining unit
NTMMSZ	Northern Timber Mountain moat structural zone
PBRCM	Pre-Belted Range composite unit
PCM	Paintbrush composite unit
PLFA	Paintbrush lava-flow aquifer
PVTA	Paintbrush vitric-tuff aquifer
RMICU	Rainier Mesa intrusive confining unit
RMSM	Rainier Mesa caldera structural margin
SCCC	Silent Canyon caldera complex
SCCCSM	Silent Canyon caldera complex structural margin
SCICU	Silent Canyon intrusive confining unit
SCVCU	Subcaldera volcanic confining unit
SPLFA	Scrugham Peak lava-flow aquifer
SWNVF	Southwestern Nevada Volcanic Field
TCA	Tiva Canyon aquifer
TCU	Tuff confining unit
TCVA	Thirsty Canyon volcanic aquifer
THCM	Tannenbaum Hill composite unit
THLFA	Tannenbaum Hill lava-flow aquifer
TMA	Timber Mountain aquifer
TMCC	Timber Mountain caldera complex
TMCCSM	Timber Mountain caldera complex structural margin
TMCM	Timber Mountain composite unit
TMD	Timber Mountain dome
TSA	Topopah Spring aquifer
UCCU	Upper clastic confining unit
UPCU	Upper Paintbrush confining unit
USGSD	U.S. Geological Survey recharge with redistribution
USGSND	U.S. Geological Survey recharge without redistribution

List of Stratigraphic Unit Abbreviations and Symbols
(Continued)

VA	Volcanic aquifer
VCU	Volcaniclastic confining unit
VTA	Vitric-tuff aquifer
WTA	Welded-tuff aquifer
WWA	Windy Wash aquifer
YMCFCM	Yucca Mountain Crater Flat composite unit
YVCM	Younger volcanics composite unit

List of Symbols for Elements and Compounds

Ac	Actinium
Am	Americium
C	Carbon
Cl	Chlorine
Cs	Cesium
Eu	Europium
^{2}H	Deuterium
^{3}H	Tritium
He	Helium
I	Iodine
Mn	Manganese
Np	Neptunium
O	Oxygen
Pu	Plutonium
SO_4	Sulfate
Sr	Strontium
Tc	Technetium
Th	Thorium
U	Uranium

1.0 Introduction

Pahute Mesa, extending over Nevada Test Site (NTS) Areas 19 and 20 (Figure 1-1), was one of several areas used for underground nuclear testing. The Phase I corrective action investigation (CAI), hereafter referred to as the Phase I CAI, was directed by the *Corrective Action Investigation Plan* (CAIP) *for Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nevada Test Site, Nevada* (DOE/NV, 1999), hereafter referred to as the Pahute Mesa CAIP. Phase I modeling results are presented in the *Phase I Transport Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nevada Test Site, Nye County, Nevada* (SNJV, 2009), and supported by the *Groundwater Flow Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nevada Test Site, Nye County, Nevada* and the *Addendum to the Groundwater Flow Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nevada Test Site, Nye County, Nevada* (SNJV, 2006 and 2007). The Phase I transport model predicted potential migration of radionuclides (RNs) exceeding the *Safe Drinking Water Act* (SDWA) standard (CFR, 2009d) off Pahute Mesa within a 1,000-year time frame. This document summarizes the Phase I CAI and Phase I modeling results. This Phase II CAIP is an updating addendum to the Pahute Mesa CAIP (DOE/NV, 1999).

The Phase I modeling objective was to use flow and transport models to evaluate RN migration from underground nuclear tests at Pahute Mesa and generate forecasts of contaminant boundaries for the corrective action units (CAUs). A preemptive review subcommittee appointed by the Underground Test Area (UGTA) Technical Working Group (TWG) evaluated the Phase I model results and recommended modifying the Phase I objectives. The recommendation was made because the models had incompletely constrained parameter values and the TWG recognized that the contaminant boundary forecasts could be overly conservative and/or unrealistic. The U.S. Department of Energy (DOE), National Nuclear Security Administration Nevada Site Office (NNSA/NSO) and the Nevada Division of Environmental Protection (NDEP) agreed with the subcommittee recommendation and decided to change the objectives of the Phase I studies and initiate Phase II studies. The Phase I studies were refocused on model and parameter sensitivity and uncertainty analysis, and the identification of data needed to improve the Phase II model. The objective of the Phase II studies is to

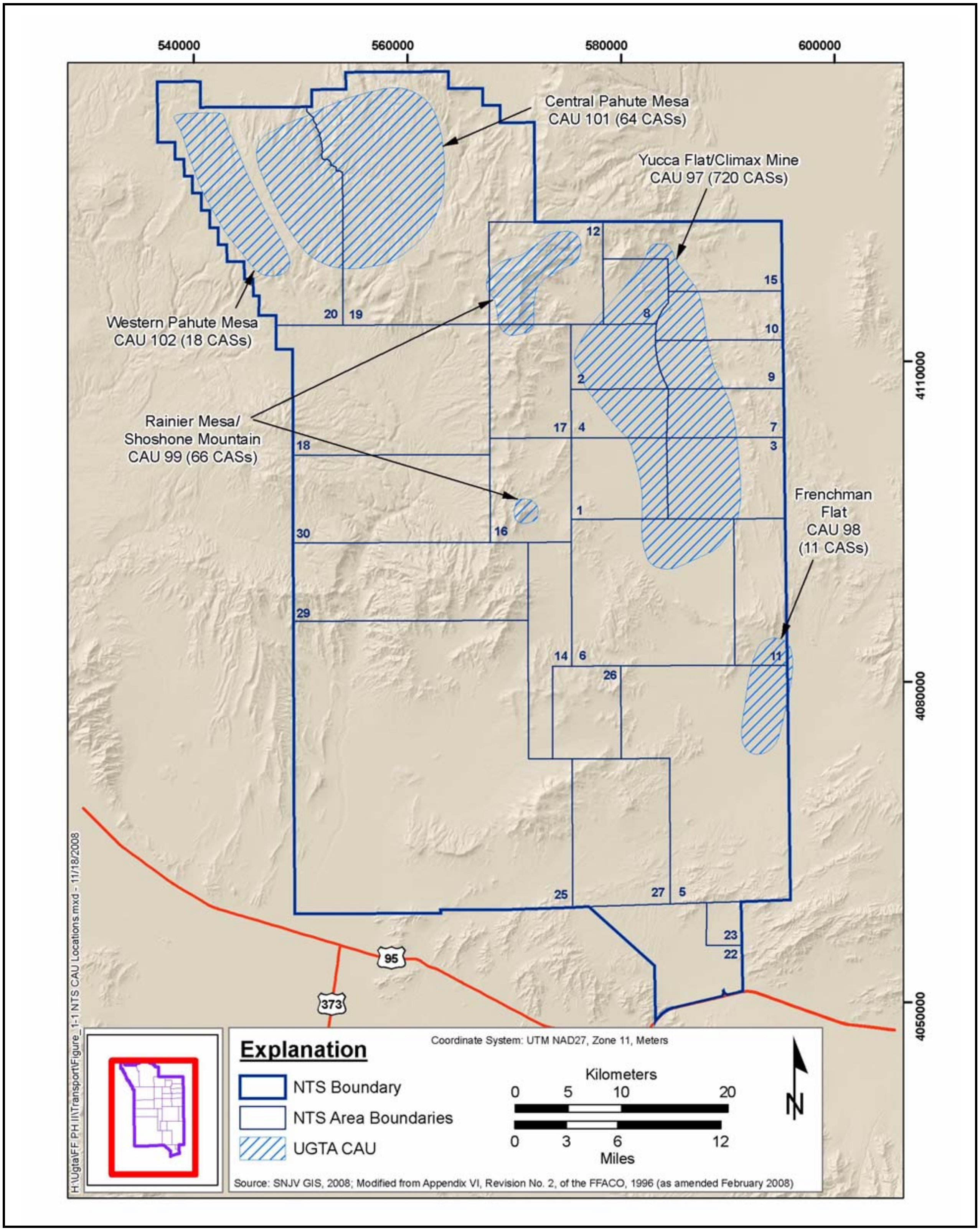

Figure 1-1
Location of the NTS Corrective Action Units

improve confidence in the reliability of model forecasts of contaminant boundaries, an important step in the successful implementation of the UGTA strategy.

The UGTA Project TWG Pahute Mesa Phase II CAIP *ad hoc* Subcommittee (hereafter referred to as the *ad hoc* Subcommittee) was formed to review the Phase I state of knowledge, flow and transport models sensitivity, uncertainty, and model results. They identified data needs, prioritized new data collection, and proposed further work to support Phase II modeling. Additional work includes new data collection, data analysis, and modeling activities for Central and Western Pahute Mesa CAUs 101 and 102. Work will be performed progressively, with iterative evaluation of new data and changes in uncertainty. Adequacy of Phase II work to define contaminant boundaries will be determined by mutual agreement of NNSA/NSO and NDEP, consistent with the revised UGTA strategy in Section 3.0 of Appendix VI of the *Federal Facility Agreement and Consent Order* (FFACO) (1996, as amended February 2008). The following subsections summarize the Phase I CAI results, FFACO Appendix VI changes affecting Phase II, and planned Phase II CAIP work. The organization and content of this document are outlined at the end of the section.

1.1 Purpose

This Phase II CAIP describes new work needed to potentially reduce uncertainty and achieve increased confidence in modeling results. This work includes data collection and data analysis to refine model assumptions, improve conceptual models of flow and transport in a complex hydrogeologic setting, and reduce parametric and structural uncertainty. The work was prioritized based on the potential to reduce model uncertainty and achieve an acceptable level of confidence in the model predictions for flow and transport, leading to model acceptance by NDEP and completion of the Phase II CAI stage of the UGTA strategy.

1.2 Scope

The Phase I CAI has been completed as specified by the requirements of the FFACO (1996, as amended February 2008). Because the CAI will go to Phase II, the contaminant boundaries have not been formally defined, and the adequacy of the model and data results have not been evaluated by NDEP and NNSA/NSO (see FFACO Appendix VI, Section 3.0).

Figure 1-2 shows the Phase I Pahute Mesa-Oasis Valley (PM-OV) model area. This area will remain unchanged in the Phase II studies. This Phase II CAIP provides plans for drilling and testing to acquire new data; summarizes data analysis activities of new and existing data to improve knowledge of parameter values for transport processes; and plans for the revision of the flow and transport models.

1.3 Summary of the Phase I CAI

The Phase I CAI began with the publication of the Pahute Mesa CAIP (DOE/NV, 1999), which included conducting field and laboratory studies designed to reduce existing uncertainties through data analysis and applied modeling studies. Field activities included geophysical surveys, well drilling and completion, and sampling and analysis of both clean and contaminated wells. Laboratory studies provided data and a better understanding of RN transport processes in groundwater. Data analysis methods included geochemical modeling, geophysical and geologic modeling, and CAU-scale groundwater flow and transport modeling. Table B.1-1 in Appendix B lists and briefly describes all data collection and analysis documents for the Phase I CAI. Table B.1-1 also lists other relevant, non-Pahute Mesa CAU-specific documents. The results of the investigations and analyses are summarized in Sections 3.0 and 5.0.

The Pahute Mesa CAIP (DOE/NV, 1999) identified a three-step process: data analysis, groundwater flow model development, and transport model development. The approach for flow and transport modeling was presented in the *Modeling Approach/Strategy for Corrective Action Units 101 and 102, Central and Western Pahute Mesa* (SNJV, 2004b). During the model development process, the TWG preemptive review process included periodic reviews and critiques with suggested revisions and improvements to the studies.

Completion of the first step in the CAIP process was documented in a series of data compilation and analysis reports, including two compendium reports: the *Hydrologic Data for the Groundwater Flow and Contaminant Transport Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nye County, Nevada* (SNJV, 2004a) and the *Contaminant Transport Parameters for the Groundwater Flow and Contaminant Transport Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nye County, Nevada* (Shaw, 2003). Multiple hydrostratigraphic framework models (HFMs) were developed and documented in *A Hydrostratigraphic Model and*

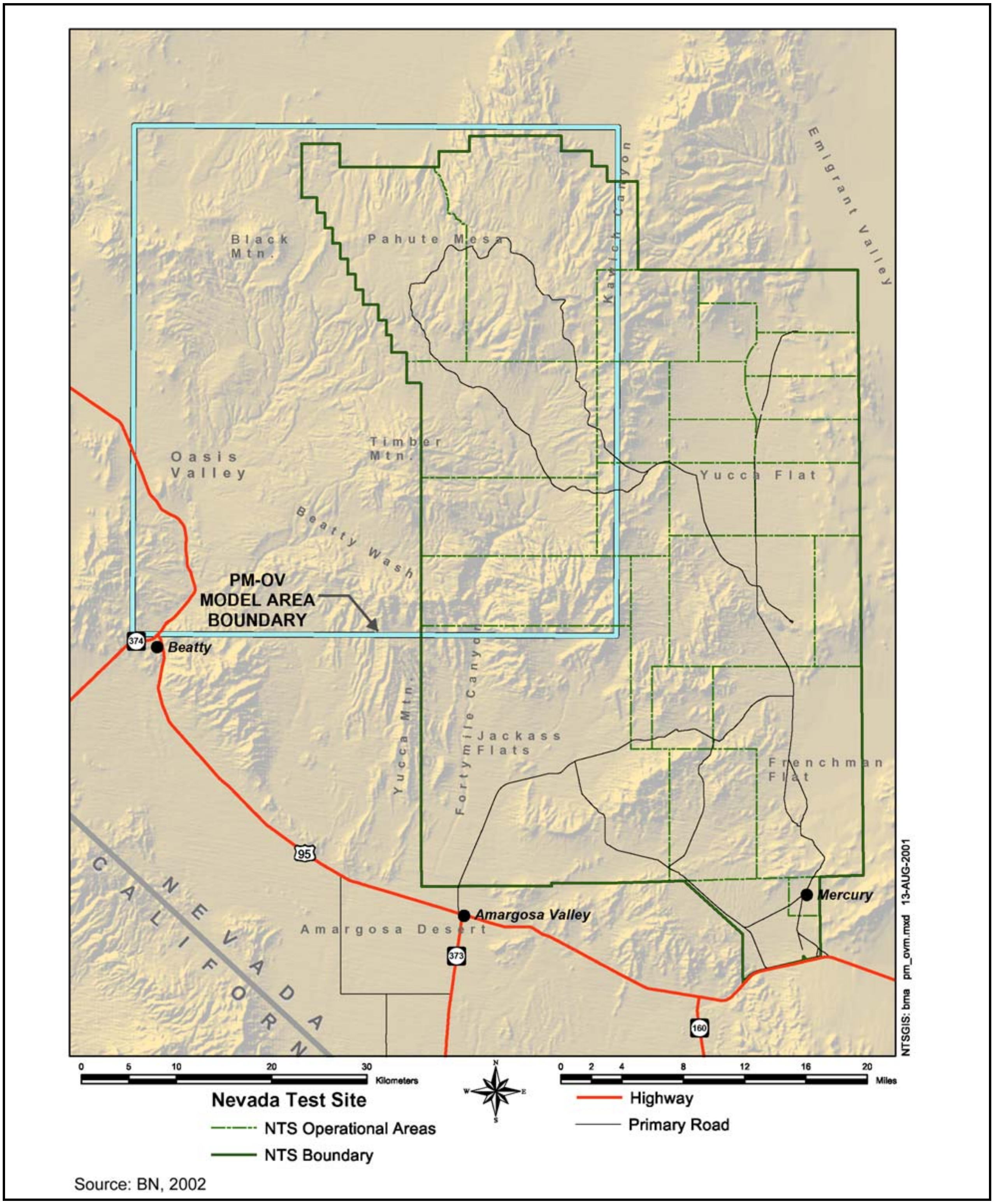

Figure 1-2
Pahute Mesa Model Area

Alternatives for the Groundwater Flow and Contaminant Transport Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nye County, Nevada (BN, 2002).

Completion of the second step was reported in the *Groundwater Flow Model of CAUs 101 and 102: Central and Western Pahute Mesa, Nye County, Nevada* and in the *Addendum to the Groundwater Flow Model of CAUs 101 and 102: Central and Western Pahute Mesa, Nye County, Nevada* (SNJV, 2006 and 2007).

Completion of the third step was reported in the *Phase I Transport Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nevada Test Site, Nye County, Nevada* (SNJV, 2009). During the development of the transport model, an additional iteration of flow model development was conducted with modified structural and hydrostratigraphic features to improve flow model calibration and better fit the observed groundwater geochemistry data. Consequently, the Phase I report covers both revisions to the flow model from step two and implementation of the transport model. The report also includes a critique of the results of flow and transport modeling embodied in the Pahute Mesa CAU studies and identifies data needs for development of defensible contaminant boundaries. A source-term model was also developed and is reported in *Unclassified Source Term and Radionuclide Data for Groundwater Flow and Contaminant Transport Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nye County, Nevada* (SNJV, 2004d), which integrates with the transport model.

1.3.1 Phase I CAI Accomplishments

The Phase I transport model (SNJV, 2009) is the culmination of the Phase I work and provides an overview of all elements of the CAU conceptual model incorporated in the transport model. The Pahute Mesa Phase I flow model and transport model integrate the component models (alternative HFMs, recharge model[s], alternative boundary conditions and fluxes, reactive mineral model, and simplified source-term model [SSM]), and transport parameter distributions used to predict the contaminant boundaries. Simulations using the flow and transport models evaluate the extent of predicted RN transport per the alternative models used for the contaminant boundary definitions and to assess the areas of greatest concern. In addition, the relative importance of the parametric and structural uncertainty of the model was assessed to guide prioritization of Phase II characterization and development work.

1.3.2 Phase I CAI Modeling Conclusions

The Phase I transport model (SNJV, 2009) presented the results of transport modeling studies and identified concerns and data needs for future data characterization and modeling studies of the Pahute Mesa CAU. The Phase I transport model simulated migration of RNs downgradient of Pahute Mesa and outlined areas where groundwater may exceed the SDWA radiological standards (CFR 2009d) for the Pahute Mesa CAU within the 1,000-year time frame. The dominant flow path for predicted transport was characterized by convergence of groundwater flow south-southwest off of Pahute Mesa, across the margins of the Timber Mountain caldera complex (TMCC) and Silent Canyon caldera complex (SCCC), and extending southwestward along the western flank of Timber Mountain to Oasis Valley. Uncertainty in the flow model also suggested secondary flow paths both east and west of the dominant flow path with somewhat less extensive RN transport. An overall assessment of uncertainty of flow and transport as a function of geologic, hydrologic, and flow and transport parameter uncertainty provides insight for an identification of characterization priorities for the Pahute Mesa Phase II CAI. The conceptual model (HFM, groundwater, hydrologic source term [HST]) uncertainty and parametric (flow and transport parameters) uncertainty affect the predicted transport (flow path and RN concentration with distance from the source underground tests).

1.3.3 TWG Pahute Mesa Phase II CAIP ad hoc Subcommittee Review

The *ad hoc* Subcommittee was formed to review the Pahute Mesa Phase I CAI status, determine Phase II data needs, and develop recommendations for Phase II data collection and analysis. Appendix C contains a summary of the subcommittee results. The reviewers included the UGTA NNSA/NSO Federal Sub-Project Director (or designee); subject matter experts from UGTA Project participants: Desert Research Institute (DRI), Lawrence Livermore National Laboratory (LLNL), Los Alamos National Laboratory (LANL), National Security Technologies, LLC (NSTec), and Stoller-Navarro Joint Venture (SNJV); a representative from NDEP; and two Community Advisory Board (CAB) members. Table C.1-1 contains the prioritized data needs. Recommendations for future data acquisition were focused on identifying locations for drilling and well installations related to model-predicted flow paths and RN transport. Specific approaches to testing and data collection were associated with each drilling location in addition to the standard data collection programs, including multiple-well aquifer tests (MWATs) and tracer tests. As discussed in Section 5.0, the groundwater flow and transport model results indicated a high probability of transport paths that extend from test sources on Pahute Mesa, converge in the Bench area (the area between the SCCC and TMCC; see Figure 5-1 for feature identification and Figure 5-2 for an illustration of the transport pathways), and move southward along the western margin of Timber Mountain dome (TMD). The focus for the Phase II investigation is on these flow and transport pathways and the hydrogeologic factors that control pathway convergence.

The first consideration for Phase II studies is to reduce uncertainty in the hydrologic framework and the flow and transport conceptual models; the secondary consideration is reduction in parameter uncertainty within the models. The *ad hoc* Subcommittee identified and prioritized locations for drilling and well construction, sampling, and testing to collect data (Table C.1-2) as well as additional data analyses using available data. These data will address uncertainties in the flow, source term, and transport modeling (see Section C.1.3) regarding the data needs identified in Table C.1-1; test basic assumptions of conceptual models; and evaluate adequacy of conceptual models.

1.3.4 Community Advisory Board Recommendations

The federally chartered Environmental Management Site-Specific CAB for NTS Programs is an appointed formal group of volunteers and liaison members organized to provide informed recommendations and advice to the NNSA/NSO Environmental Management Program. Attachment 1 of Appendix D contains letters from CAB members providing their review of the Phase I CAI work and recommendations for drilling new wells.

1.4 Revision of the FFACO Affecting the Phase II CAI

The Phase II CAI will conform to the 2009 revisions in Section 3.0 of Appendix VI of the FFACO (1996, as amended February 2008). Critical aspects of the revisions affecting the Pahute Mesa Phase II CAI include development of ensembles of contaminant boundary forecasts; iterative cycles of model refinements during all stages of the UGTA strategy; and the integrated use of modeling, monitoring, and institutional controls to reduce the risk of public exposure to contaminated groundwater. These revisions are discussed in Section 2.1.

1.5 Overview of Pahute Mesa Phase II CAIP

This section presents an evaluation of the current state of knowledge of the Pahute Mesa CAUs, and identifies data and model insights gained during Phase I studies. A review of Phase I CAI data and technical analyses is presented in Section 3.0 for data assessment and Section 5.0 for modeling. Section 5.0 includes summaries of conclusions from the model reports to support the proposed data collection and data analysis activities for the Phase II CAI (Section 6.0).

The Phase II CAI includes multiple approaches to data collection (including well drilling and testing), refined data analysis using newly acquired information, and model refinements using enhanced information. Yearly work tasks will be proposed for the CAI. Continuous review and assessment of the results will guide decisions for additional work. Changes to this Phase II CAIP will be made through memorandums of agreement between NNSA/NSO and NDEP or revisions to this document, as needed.

1.5.1 Characterization Activities

Phase II CAI characterization activities include drilling new investigation boreholes for geologic and hydrostratigraphic information; completing wells in these boreholes to access testing intervals; sampling groundwater; and conducting hydrologic measurements and tests. New borehole data will be incorporated in data analyses, in testing of conceptual models and model assumptions used in the Phase I flow and transport models. These collective activities are designed to reduce parametric uncertainty and increase confidence in the reliability of modeling results. Section 6.1.1.2 presents a prioritized list of 12 proposed drilling locations. The list is coordinated with proposed large-scale tests, MWATs, and tracer tests, all of which require two or more wells. Additional proposals for data collection and studies are also presented. The data acquisition approach will be iterative. The initial scope of data acquisition (Section 6.2) is based on the priorities assigned to data needs. Further data acquisition will be proposed as necessary as new data are acquired, integrated into the data analyses, and used to assess the potential reduction in uncertainty of the flow and transport models. These changes in data acquisition will be negotiated through memorandums of agreement between NNSA/NSO and NDEP.

1.5.2 Assessment of Data

The Phase II CAI will include further analyses of existing data; incorporation of new characterization data into Phase I analyses; new data analyses focused on improving the understanding of groundwater flow and contaminant transport; and resolving uncertainties associated with the forecasts of contaminant boundaries.

Descriptions of data analysis focus and objectives for new and existing data are presented in Section 6.2. New data will be integrated into the data analyses and used to assess the potential reduction in uncertainty of the flow and transport models on an ongoing basis. An iterative approach will be used to evaluate new data and help refine subsequent drill-hole locations.

1.5.3 Revision of Groundwater Flow and Transport Models

The refined conceptual models and parameter data from Phase II characterization will be used to revise the groundwater flow and transport models. The procedure to revise and refine the CAU groundwater flow and contaminant transport models is detailed in Figure 5-1 of the Pahute Mesa CAIP (DOE/NV, 1999).

1.5.4 Acceptance of Groundwater and Contaminant Transport Models

Model acceptance is required at two decision points in the UGTA strategy: (1) at the end of the CAI stage and (2) at the end of the Corrective Action Decision Document (CADD)/Corrective Action Plan (CAP) stage. Phase II CAI studies leading to model acceptance are based on the iterative process of model evaluation described in the Section 3.0 of Appendix VI of the FFACO (1996, as amended February 2008) and in U.S. Environmental Protection Agency (EPA) model guidance (EPA, 2009).

1.5.5 CAI Documentation

The Pahute Mesa Phase II CAI activities will be reported in data and analysis reports, documentation packages, CAU model reports, and the CADD as follows:

- Data reports will document the results of new characterization activities.
- Analysis reports will evaluate characterization and document the analysis of the data.

- An **updated** HFM will document the assessment of new geologic data and describe the resulting revised hydrostratigraphic model(s).
- **Updated** hydrologic and transport data documentation will document the assessment of new data in combination with existing data.
- **Updated** source term, flow, and transport model reports will document the results of the Phase II modeling process.

1.6 Document Organization

This Phase II CAIP has been organized following the format of the Pahute Mesa CAIP (DOE/NV, 1999). Additional subsections have been added to accommodate new subjects and information categories.

The Pahute Mesa CAIP (DOE/NV, 1999) documents the information and data that were available leading to the CAI. The completed Phase I CAI work is documented in reports listed in Appendix B. Links in the electronic text are provided to the referenced sections of the Pahute Mesa CAIP, which is included on the compact disc. This report is organized into the following sections:

- Section 1.0 - Introduction
- Section 2.0 - Legal/regulatory requirements
- Section 3.0 - CAU descriptions
- Section 4.0 - Data quality objectives (DQOs) summary
- Section 5.0 - Phase II CAI
- Section 6.0 - Phase II characterization activities
- Section 7.0 - Quality assurance (QA) requirements
- Section 8.0 - Duration and records/data availability
- Section 9.0 - References
- Appendix A - DQO development
- Appendix B - List and summary of major Phase I CAI documents

- Appendix C - *ad hoc* Subcommittee recommendations

- Appendix D - CAB correspondence on Pahute Mesa Phase I results and new well recommendations

- Appendix E - NDEP comments on CAIP draft

2.0 Legal/Regulatory Requirements

The FFACO (1996, as amended February 2008) is the regulatory driver for environmental restoration (ER) activities at the NTS. Appendix VI, Section 3.0, contains the ER strategy for the underground test areas (UGTA strategy). The FFACO was signed by the DOE, Nevada Operations Office (DOE/NV), the U.S. Department of Defense (DoD), and NDEP in 1996, and is updated periodically. The Phase I CAI (DOE/NV, 1999) was completed in accordance with the FFACO. During the Phase I CAI, the parties acknowledged that a Phase II CAI would be required, and the objectives of Phase I were revised to identify the issues and uncertainties in the models requiring additional information. Lessons learned from the Phase I CAI have been incorporated in Section 3.0 of Appendix VI of the FFACO. This section addresses the requirements pertaining to the Phase II CAI. Any additional changes that affect this CAIP addendum will be addressed through memorandum of agreement between NNSA/NSO and NDEP.

Central Pahute Mesa (CAU 101) and Western Pahute Mesa (CAU 102) are combined for the Phase II CAI, consistent with the Phase I CAI.

2.1 FFACO Requirements

This section summarizes the FFACO requirements (1996, as amended February 2008) and presents the revised UGTA corrective action strategy. The NNSA/NSO, through the UGTA Project, is responsible for completing corrective actions for five CAUs associated with historical underground nuclear testing. The UGTA Project CAUs are Frenchman Flat (CAU 98), Central and Western Pahute Mesa (CAUs 101 and 102), Yucca Flat/Climax Mine (CAU 97), and Rainier Mesa/Shoshone Mountain (CAU 99) (Figure 2-1). The CAUs were defined based on geography and hydrogeologic characteristics. This figure also shows the number of corrective action sites (CASs) for each CAU.

2.1.1 General Requirements

Corrective action investigations (CAIs) are conducted for the purposes outlined in the FFACO, Subparts II.1.b.ii and II.1.c, Subparts IV.14 and IV.15, and Appendix VI (FFACO, 1996; as amended February 2008).

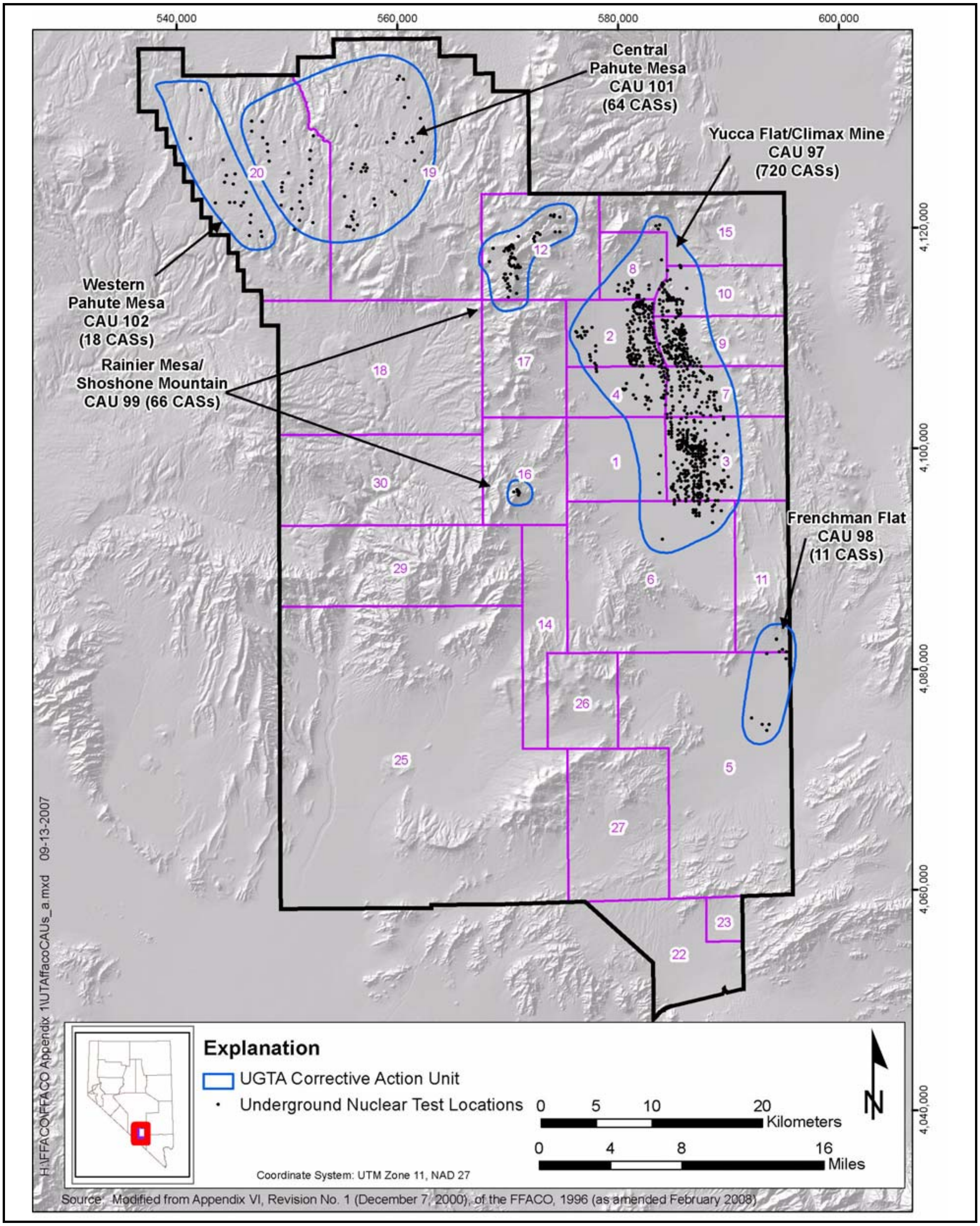

Figure 2-1
Underground Nuclear Test Locations Conducted at the NTS

> *II.1.b.ii. "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."*

Characterization and modeling activities designed to determine whether releases are migrating or could potentially migrate are described in Sections 5.0 and 6.0. Preliminary predictions of the nature and extent of contaminant migration based on the Phase I transport model (SNJV, 2009) are presented in Section 5.2.3. This model will be revised and refined during the Phase II CAI.

> *II.1.c. "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."*

A preliminary list of radioactive and hazardous constituents for the Pahute Mesa CAUs is provided in Section 3.5 by reference to the Pahute Mesa CAIP (DOE/NV, 1999) and Phase I CAI documents. These references will be updated based on the Phase II CAI.

> *IV.14. "Corrective action investigation (CAI) shall mean an investigation conducted by the 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."*

The CAI will 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 Pahute Mesa CAU. This Phase II CAIP describes the planned investigation activities, which include gathering field data (see Section 6.0) and CAU groundwater flow and transport modeling (see Section 5.0).

> *IV.15. "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 of 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."*

This document provides specific references for information used for planning investigation activities for the Pahute Mesa CAUs. This includes management, technical, QA, health and safety, public involvement, field sampling, and waste management information needed to conduct the investigation in compliance with established procedures and protocols. All information provided in this CAIP is based on the current state of knowledge, and results of the completed CAI will be reported in the CADD.

2.1.2 Revised UGTA Corrective Action Strategy

The UGTA corrective action strategy is discussed in Section 3.0 of Appendix VI of the FFACO (1996, as amended February 2008). The revisions to the UGTA strategy retain four stages (CAIP, CAI, CADD/CAP, and Closure Report [CR]). This section describes the changes in the CAI stage, covering activities described in the Phase II CAIP (see Figure 2-2).

The CAI stage steps have been refined with minor changes in step names; a data completeness step with a loop to auxiliary data assessment has been added after data evaluation and before development of CAU flow and transport models. Three new or modified decision steps are:

1. A joint assessment by NDEP and NNSA/NSO of the adequacy of model results and data completeness after completion of the flow and transport model.

2. An assessment of the achievability of the UGTA strategy before development of a revised CAIP.

3. A model acceptance after peer review and before the start of the CADD/CAP stage.

The following sections include definitions used in this Phase II CAIP. There are some minor wording modifications from Section 3.0 of Appendix VI of the FFACO (1996, as amended February 2008).

2.1.2.1 Boundary Definitions

Contaminant Boundary

A contaminant boundary is defined as the model-forecast perimeter and a lower hydrostratigraphic unit (HSU) boundary that delineates the extent of RN-contaminated groundwater over a 1,000-year time period. The contaminated groundwater is a volume (three-dimensional [3-D]) and is projected upward to the ground surface to define a (two-dimensional [2-D]) contaminant boundary perimeter. Contaminated groundwater is defined as water exceeding the SDWA radiological standards (CFR, 2009d). Simulation modeling of contaminant transport will be used to forecast the location of contaminant boundaries within 1,000 years and must show the 95th percentile of the model results (boundary outside of which only 5 percent of the simulations exceed the SDWA standards). An ensemble of contaminant boundaries from multiple model simulations will provide the basis for negotiations by NNSA/NSO and NDEP of a compliance boundary for each CAU.

The term *forecast* is used instead of *prediction* to denote the methods and uncertainty of evaluating contaminant boundaries. Transport modeling simulations are used to compute RN concentrations in time and space within a CAU. These 3-D concentration data are integrated into probabilistic forecasts of the likelihood of groundwater exceeding or remaining below the SDWA radiological standards (CFR, 2009d). Contaminant boundaries are not discrete *predictions* of the location or concentration of contaminants, but instead are spatial representations of the probability of exceeding SDWA standards.

Compliance Boundary

A compliance boundary negotiated between NDEP and NNSA/NSO represents a regulatory-based distinction between groundwater contaminated or not contaminated by the effects of underground testing. The ensemble of contaminant boundary forecasts for a CAU will provide the initial technical basis for negotiation of the compliance boundary.

The NNSA/NSO must demonstrate with an acceptable level of confidence gained through implementation of the UGTA corrective action strategy, that groundwater outside the compliance boundary meets the SDWA radiological standards (CFR, 2009d). The areas of potentially contaminated groundwater inside the compliance boundary are expected to require institutional controls to restrict public access. These controls may be legal restrictions on land use or access to groundwater, processes and procedures for monitoring compliance to restrictions, and maintenance of boundaries or deterrents to support restrictions.

The considerable depth to groundwater throughout most areas of the NTS effectively restricts surface exposure to contaminated groundwater. The NNSA/NSO and long-term stewardship organization will be responsible for establishing and ensuring compliance with the institutional controls. The compliance boundary may or may not coincide with individual contaminant boundary forecasts or ensemble contaminant boundary forecasts, but will be negotiated by NDEP and NNSA/NSO.
An initial compliance boundary will be established at the beginning of the CADD/CAP, and a final

compliance boundary will be established before developing the CAU closure report. The compliance boundary could change, subject to NNSA/NSO and NDEP negotiations, during the iterative process of model evaluation, model acceptance, and testing/corroboration of model forecasts through the monitoring and closure programs.

2.1.2.2 Revised Decision Process

The revised CAI decision process is shown in Figure 2-2. A three-step approach is used to establish adequacy of CAI data and model results.

First, NDEP reviews and approves the data used for modeling. Second, the flow and transport model is reviewed by NDEP and revised through comment resolution. Third, the results of flow and transport modeling, including sensitivity and uncertainty analysis, are reviewed by NNSA/NSO and NDEP to decide whether to use the model forecasts as a tool for regulatory decisions. If the data or model results are inadequate, NDEP and NNSA/NSO will evaluate model alternatives and assess whether the UGTA strategy is achievable, or whether a new cycle of data collection and modeling is necessary. If the results are adequate, a peer review is conducted, and the CAU model would be evaluated by NDEP for model acceptability.

2.1.2.3 Model Acceptance

Model acceptability is a process of building confidence in model results through verification, calibration, and model evaluation during the iterative stages of data gathering, model refinements, and monitoring. Model acceptance is decision dependent and is required at two stages in the UGTA strategy: (1) at the end of the CAI stage and (2) at the end of the CADD/CAP stage.

Model acceptance is defined as a joint judgment by NNSA/NSO and NDEP that sufficient credibility and reliability of model studies exist to use the transport modeling forecasts as the basis for regulatory decisions. Model acceptance consists of overlapping processes of model verification, calibration and evaluation:

1. *Verification* includes assessments to ensure the code is programmed correctly and algorithms are implemented properly, with no assumption or program errors.

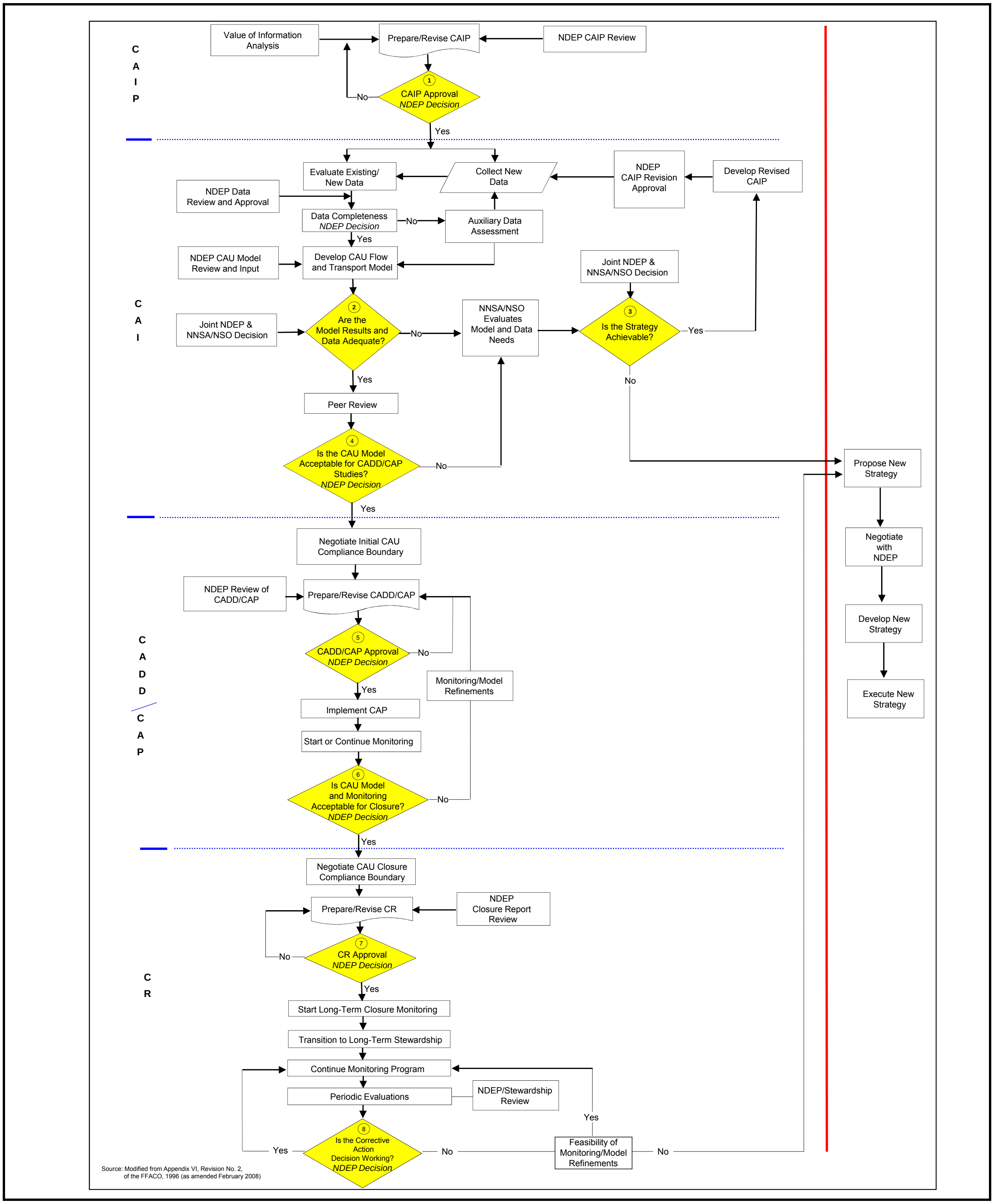

Figure 2-2
Revised FFACO Decision Process

2. *Calibration* is a demonstration that a model adequately estimates hydraulic properties within an acceptable range of error throughout a model domain (field-measured hydraulic heads and estimated boundary flows).

3. *Evaluation* is an iterative process of testing if model output makes sense using a range of model adequacy measures. Model evaluation for the UGTA strategy involves development of increased confidence in the reliability of model outputs through successive efforts to test and extend the model using multiple alternative approaches designed to assess the impact of uncertain model components. Successful evaluation of a model is achieved through a demonstrated inability to disprove a model for a range of modeling and monitoring studies (robust model). Model evaluation is consistent with and derived from guidance from the National Research Council (NRC, 2007) and EPA (2009).

2.1.3 Corrective Action Implementation and CAU Closure

After negotiation of an initial CAU compliance boundary, the CADD/CAP is prepared, revised through comment resolution, and approved or not approved by NDEP. Non-approval requires revision and resubmittal of the CADD/CAP. An approved CADD/CAP implements the CAP through monitoring initiation. The goals for the initial monitoring program are:

1. Continue model evaluation with an increased focus on assessing the reliability of contaminant boundary forecasts.

2. Test model output and contaminant boundary forecasts through additional drill-hole exploration and focused testing and sampling.

3. Develop an initial monitoring network that will transition to a long-term closure monitoring network. The CADD/CAP will include design criteria for initial monitoring wells.

Monitoring data will be used to refine model evaluations. Monitoring will continue at existing and/or new wells to gather data to increase confidence in the reliability of model results. This iterative process of monitoring and model refinements will continue until model acceptance decision by

NDEP at the end of the CADD/CAP stage (Figure 2-2). If the model is accepted by NDEP as a regulatory decision tool, the project will progress to the closure stage with the following goals:

1. Negotiate the final compliance boundary.

2. Prepare the CR, describing the development of a long-term closure monitoring program, the approaches and policies for land-use restrictions, and a design plan for transition of the UGTA Project to long-term stewardship. The CR will be reviewed through comment and resolution by NDEP and NNSA/NSO.

The results of long-term monitoring will be evaluated for consistency with the CAU conceptual models of flow and transport, remedial action strategy, and to ensure land-use restrictions are fully protective of human health and the environment. If the remedial action strategy remains consistent with monitoring results, the organization responsible for long-term stewardship will evaluate monitoring results for data changes, assess whether new information requires refinements in CAU modeling studies, evaluate requirements for new and/or replacement monitoring wells, and continue the monitoring program. If the monitoring results invalidate the remedial action strategy, the closure monitoring will be curtailed or suspended, and a new strategy evaluated (Figure 2-2).

2.2 Other Changes or Updates

2.2.1 Death Valley Regional Groundwater Flow System Regional Model

Regional models of groundwater flow within the NTS and the Death Valley Regional Groundwater Flow System of Nevada and California have been completed (DOE/NV, 1997; D'Agnese et al., 1997; Belcher et al., 2004). These regional models are used to establish boundary conditions, groundwater boundary flows, and the uncertainty in groundwater boundary flows for individual CAUs.

2.2.2 Specification of Bowen et al. (2001) Unclassified Inventory

Corrective action unit models will use the inventory and inventory uncertainty of Bowen et al. (2001) as the initial radiologic source term (RST).

3.0 Description of Corrective Action Units

The Pahute Mesa CAIP (DOE/NV, 1999) contained a complete description of the Pahute Mesa CAUs (101 and 102) based on available information at the time of publication. The Phase I investigation and analysis activities produced an extensive set of documents covering all aspects of the data compiled and analyzed for the Phase I CAI. A complete listing of these documents is provided in Appendix B of this document. In this section, the description of the CAUs will be updated by reference to the major documents that summarize new information, using the same subject breakdown and section designations as used in the Pahute Mesa CAIP (DOE/NV, 1999).

3.1 Investigative Background

The Pahute Mesa CAIP (DOE/NV, 1999) discusses the investigative background for the Pahute Mesa CAUs (Section 3.1 of the Pahute Mesa CAIP).

3.1.1 General Information

The Pahute Mesa CAIP (DOE/NV, 1999) presents general information (Section 3.1.1 of the Pahute Mesa CAIP).

3.1.2 Precipitation and Recharge

The Pahute Mesa CAIP (DOE/NV, 1999) discusses precipitation and recharge for the Pahute Mesa CAUs (Section 3.1.2 of the Pahute Mesa CAIP). Updated information is presented in *Hydrologic Data for the Groundwater Flow and Contaminant Transport Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nye County, Nevada* (SNJV, 2004a).

3.1.3 Topography

The Pahute Mesa CAIP (DOE/NV, 1999) discusses topography for the Pahute Mesa CAUs (Section 3.1.3 of the Pahute Mesa CAIP). The Pahute Mesa CAIP information for this topic has been updated with additional information published in *A Hydrostratigraphic Model and Alternatives for the Groundwater Flow and Contaminant Transport Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nye County, Nevada* (BN, 2002).

3.1.4 Geology

The Pahute Mesa CAIP (DOE/NV, 1999) discusses geology for the Pahute Mesa CAUs (Section 3.1.4 of the Pahute Mesa CAIP). The Pahute Mesa CAIP information for this topic has been updated with additional information published in *A Hydrostratigraphic Model and Alternatives for the Groundwater Flow and Contaminant Transport Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nye County, Nevada* (BN, 2002).

3.1.5 Groundwater

The Pahute Mesa CAIP (DOE/NV, 1999) discusses groundwater for the Pahute Mesa CAUs (Section 3.1.5 of the Pahute Mesa CAIP). The Pahute Mesa CAIP information for this topic has been updated with additional general information published in *A Hydrostratigraphic Model and Alternatives for the Groundwater Flow and Contaminant Transport Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nye County, Nevada* (BN, 2002), and with detailed information published in the *Groundwater Flow Model of CAUs 101 and 102: Central and Western Pahute Mesa, Nevada Test Site, Nye County, Nevada* and the *Addendum to the Groundwater Flow Model of CAUs 101 and 102: Central and Western Pahute Mesa, Nevada Test Site, Nye County, Nevada* (SNJV, 2006 and 2007).

3.1.6 Groundwater Chemistry

The Pahute Mesa CAIP (DOE/NV, 1999) discusses groundwater chemistry for the Pahute Mesa CAUs (Section 3.1.6 of the Pahute Mesa CAIP). The Pahute Mesa CAIP information for this topic has been updated with additional information published in the *Hydrologic Data for the Groundwater Flow and Contaminant Transport Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nye County, Nevada* (SNJV, 2004a); *Geochemical and Isotopic Interpretations of Groundwater Flow in the Oasis Valley Flow System, Southern Nevada* (Thomas et al., 2002); and *Geochemical Data Analysis and Interpretation of the Pahute Mesa - Oasis Valley Groundwater Flow System, Nye County, Nevada August 2002* (Rose et al., 2006).

3.1.7 Groundwater Radiochemistry

The Pahute Mesa CAIP (DOE/NV, 1999) discusses groundwater radiochemistry for the Pahute Mesa CAUs (Section 3.1.5 of the Pahute Mesa CAIP). The Pahute Mesa CAIP information for these topics has been updated with additional information published in the *Evaluation of the Hydrologic Source Term from Underground Nuclear Tests on Pahute Mesa at the Nevada Test Site: The CHESHIRE Test* (Pawloski et al., 2001); *Nevada Test Site Radionuclide Inventory, 1951-1992* (Bowen et al., 2001); and *TYBO/BENHAM: Model Analysis of Groundwater Flow and Radionuclide Migration from Underground Nuclear Tests in Southwestern Pahute Mesa, Nevada* (Wolfsberg et al., 2002). The radiochemistry information is summarized in the *Unclassified Source Term and Radionuclide Data for Groundwater Flow and Contaminant Transport Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nye County, Nevada* (SNJV, 2004d).

3.1.8 Contaminant Transport Parameters

The Pahute Mesa CAIP (DOE/NV, 1999) discusses contaminant transport parameters for the Pahute Mesa CAUs (Section 3.1.8 of the Pahute Mesa CAIP). The Pahute Mesa CAIP information for these topics has been updated with additional information published in the *Contaminant Transport Parameters for Groundwater Flow and Contaminant Transport Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nye County, Nevada* (Shaw, 2003) and the *Phase I Contaminant Transport Model of Corrective Action Unit 99: Rainier Mesa/Shoshone Mountain, Nevada Test Site, Nye County, Nevada* (SNJV, 2008a).

3.2 Operational History

The Pahute Mesa CAIP (DOE/NV, 1999) discusses the operational history for the Pahute Mesa CAUs (Section 3.2 of the Pahute Mesa CAIP). The Pahute Mesa CAIP information for these topics has been updated with additional information published in *United States Nuclear Tests, July 1945 through September 1992* (DOE/NV, 2000) and *Contaminant Transport Parameters for the Groundwater Flow and Contaminant Transport Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nye County, Nevada* (Shaw, 2003).

3.3 Corrective Action Sites

The Pahute Mesa CAIP (DOE/NV, 1999) discusses the CASs for the Pahute Mesa CAUs (Section 3.3 of the Pahute Mesa CAIP). The Pahute Mesa CAIP information for these sites has been updated with additional information published in the FFACO (1996, as amended February 2008) and the *Contaminant Transport Parameters for the Groundwater Flow and Contaminant Transport Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nye County, Nevada* (Shaw, 2003).

3.4 Physical Setting

The Pahute Mesa CAIP (DOE/NV, 1999) discusses the physical setting for the Pahute Mesa CAUs (Section 3.4 of the Pahute Mesa CAIP). The Pahute Mesa CAIP information for the following topics under this heading has been updated with additional information published in *A Hydrostratigraphic Model and Alternatives for the Groundwater Flow and Contaminant Transport Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nye County, Nevada* (BN, 2002). Background information is presented for the following topics:

- Climate
- Topography
- Surface water
- Geology

3.4.1 Hydrogeology

The Pahute Mesa CAIP (DOE/NV, 1999) discusses the hydrogeology for the Pahute Mesa CAUs (Section 3.4.5 of the Pahute Mesa CAIP). The hydrogeology of the investigation area incorporated in the Phase I flow and transport models is presented in the *Groundwater Flow Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nevada Test Site, Nye County, Nevada* and the *Addendum to the Groundwater Flow Model of CAUs 101 and 102: Central and Western Pahute Mesa, Nevada Test Site, Nye County, Nevada* (SNJV, 2006 and 2007), and in the *Phase I Transport Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nevada Test Site, Nye County, Nevada* (SNJV, 2009).

3.4.1.1 Regional Hydrogeology

The hydrology of the NTS region is described in the *Regional Groundwater Flow and Tritium Transport Model and Risk Assessment of the Underground Test Area, Nevada Test Site, Nevada* (DOE/NV, 1997). Updated information is presented in the *Death Valley Regional Model Ground-Water Flow System, Nevada and California-Hydrogeologic Framework and Transient Ground-Water Flow Model* (Belcher et al., 2004).

3.4.1.1.1 Regional Hydrostratigraphy

The Bechtel Nevada (BN) (2002) report and the Pahute Mesa CAIP (DOE/NV, 1999) discuss the hydrostratigraphy for the Pahute Mesa CAUs (Section 3.4.5.1.1 of the Pahute Mesa CAIP).

3.4.1.1.2 Groundwater

The Pahute Mesa CAIP (DOE/NV, 1999) discusses groundwater for the Pahute Mesa CAUs (Section 3.4.5.1.2 of the Pahute Mesa CAIP). The updated groundwater conceptual model of the investigation area incorporated in the Phase I flow and transport models is presented in the *Groundwater Flow Model of CAUs 101 and 102: Central and Western Pahute Mesa, Nevada Test Site, Nye County, Nevada* and the *Addendum to the Groundwater Flow Model of CAUs 101 and 102: Central and Western Pahute Mesa, Nevada Test Site, Nye County, Nevada* (SNJV, 2006 and 2007), and in the *Phase I Transport Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nevada Test Site, Nye County, Nevada* (SNJV, 2009).

3.4.1.2 Hydrogeology of the Investigation Area

The Pahute Mesa CAIP (DOE/NV, 1999) discusses the current understanding of the hydrogeology within the investigation area for the Pahute Mesa CAUs (Section 3.4.5.2 of the Pahute Mesa CAIP). The hydrogeology of the investigation area was incorporated in the Phase I flow and transport models is presented in the *Groundwater Flow Model of CAUs 101 and 102: Central and Western Pahute Mesa, Nevada Test Site, Nye County, Nevada* and the *Addendum to the Groundwater Flow Model of CAUs 101 and 102: Central and Western Pahute Mesa, Nevada Test Site, Nye County, Nevada* (SNJV, 2006 and 2007), and in the *Phase I Transport Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nevada Test Site, Nye County, Nevada* (SNJV, 2009).

3.4.1.2.1 Hydrostratigraphy

The BN (2002) report describes the hydrostratigraphy used in the alternative hydrostratigraphic models used for Pahute Mesa. The current understanding of hydrostratigraphy within the investigation area was incorporated in the Phase I flow and transport models and is presented in *Hydrologic Data for the Groundwater Flow and Contaminant Transport Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nye County, Nevada* (SNJV, 2004a), and the *Phase I Hydrologic Data for the Groundwater Flow and Contaminant Transport Model of Corrective Action Unit 99: Rainier Mesa/Shoshone Mountain, Nevada Test Site, Nye County, Nevada* (SNJV, 2008b). The *Groundwater Flow Model of CAUs 101 and 102: Central and Western Pahute Mesa, Nevada Test Site, Nye County, Nevada* and the *Addendum to the Groundwater Flow Model of CAUs 101 and 102: Central and Western Pahute Mesa, Nevada Test Site, Nye County, Nevada* (SNJV, 2006 and 2007), and the *Phase I Transport Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nevada Test Site, Nye County, Nevada* (SNJV, 2009) discuss the hydrostratigraphy incorporated in the flow and transport models.

3.4.1.2.2 Groundwater

The groundwater conceptual model of the investigation area incorporated in the Phase I flow and transport models is presented in the *Groundwater Flow Model of CAUs 101 and 102: Central and Western Pahute Mesa, Nevada Test Site, Nye County, Nevada* and the *Addendum to the Groundwater Flow Model of CAUs 101 and 102: Central and Western Pahute Mesa, Nevada Test Site, Nye County, Nevada* (SNJV, 2006 and 2007), and in the *Phase I Transport Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nevada Test Site, Nye County, Nevada* (SNJV, 2009).

3.4.2 Groundwater Chemistry

The Pahute Mesa CAIP (DOE/NV, 1999) discusses the groundwater chemistry for the Pahute Mesa CAUs (Section 3.4.6 of the Pahute Mesa CAIP). The Pahute Mesa CAIP information for these topics has been supplemented with additional information published in the *Hydrologic Data for Groundwater Flow and Contaminant Transport Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nye County, Nevada* (SNJV, 2004a); *Geochemical and Isotopic Interpretations of Groundwater Flow in the Oasis Valley Flow System, Southern Nevada*

(Thomas et al., 2002); *Evaluation of Groundwater Flow in the Pahute Mesa - Oasis Valley Flow System using Groundwater Chemical and Isotopic Data* (Kwicklis et al., 2005); and *Geochemical Data Analysis and Interpretation of the Pahute Mesa - Oasis Valley Groundwater Flow System, Nye County, Nevada August 2002* (Rose et al., 2006).

3.4.3 Groundwater Radiochemistry

The Pahute Mesa CAIP (DOE/NV, 1999) discusses groundwater radiochemistry for the Pahute Mesa CAUs (Section 3.4.7 of the Pahute Mesa CAIP). The Pahute Mesa CAIP information for the topics listed below has been updated with additional information published in the *Unclassified Source Term and Radionuclide Data for Groundwater Flow and Contaminant Transport Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nye County, Nevada* (SNJV, 2004d). This document includes updated information from the following programs:

- Hydrologic Resources Management Program
- Long-Term Hydrological Monitoring Program
- NNSA/NSO Annual Environmental Monitoring
- UGTA Project

3.4.4 Contaminant Transport Parameters

The Pahute Mesa CAIP (DOE/NV, 1999) discusses contaminant transport parameters for the Pahute Mesa CAUs (Section 3.4.8 of the Pahute Mesa CAIP). The Pahute Mesa CAIP information for the topics listed below has been supplemented with additional information published in the *Contaminant Transport Parameters for the Groundwater Flow and Contaminant Transport Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nye County, Nevada* (Shaw, 2003) and the *Phase I Transport Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nevada Test Site, Nye County, Nevada* (SNJV, 2009). The parameter information addressed by the Pahute Mesa CAIP and supplemented by the aforementioned documents includes:

- Matrix porosity
- Effective porosity
- Dispersivity
- Matrix diffusion parameters
- Matrix sorption parameters
- Fracture sorption parameters
- Colloid-facilitated transport parameters

3.5 Contaminants

The Pahute Mesa CAIP (DOE/NV, 1999) discusses contaminants for the Pahute Mesa CAUs (Section 3.5 of the Pahute Mesa CAIP).

3.5.1 Radioactive and Hazardous Substances Present

The Pahute Mesa CAIP (DOE/NV, 1999) discusses radioactive and hazardous substances present for the Pahute Mesa CAUs (Section 3.5.1 of the Pahute Mesa CAIP). The Pahute Mesa CAIP information for these topics has been supplemented with additional information published in the *Unclassified Source Term and Radionuclide Data for Groundwater Flow and Contaminant Transport Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nye County, Nevada* (SNJV, 2004d).

3.5.2 Potential Contaminants for the CAI

The Pahute Mesa CAIP (DOE/NV, 1999) discusses potential contaminants for the Pahute Mesa CAUs (Section 3.5.2 of the Pahute Mesa CAIP). The Pahute Mesa CAIP information for these topics has been updated with additional information published in the *Unclassified Source Term and Radionuclide Data for Groundwater Flow and Contaminant Transport Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nye County, Nevada* (SNJV, 2004d) and the *Phase I Transport Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nevada Test Site, Nye County, Nevada* (SNJV, 2009).

3.6 Conceptual Model of the CAU

The Pahute Mesa CAIP (DOE/NV, 1999) discusses the conceptual model for the Pahute Mesa CAUs (Section 3.6 of the Pahute Mesa CAIP). The conceptual model of contaminant release and migration as incorporated in the Phase I flow and transport models is presented in the *Categorization of Underground Nuclear Tests on Pahute Mesa, Nevada Test Site, for Use in Radionuclide Transport Models* (Pawloski et al., 2002); the *Unclassified Source Term and Radionuclide Data for Groundwater Flow and Contaminant Transport Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nye County, Nevada* (SNJV, 2004d); the *Groundwater Flow Model of CAUs 101 and 102: Central and Western Pahute Mesa, Nevada Test Site, Nye County,* *Nevada* and the *Addendum to the Groundwater Flow Model of CAUs 101 and 102: Central and Western Pahute Mesa, Nevada Test Site, Nye County, Nevada* (SNJV, 2006 and 2007); and the *Phase I Transport Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nevada Test Site, Nye County, Nevada* (SNJV, 2009). These documents discuss the following topics also described in the Pahute Mesa CAIP (DOE/NV, 1999):

- Release and discharge mechanisms
- Migration routes
- Contaminated media
- Exposure pathways
- Uncertainties

3.7 Preliminary Action Levels

The Pahute Mesa CAIP (DOE/NV, 1999) discusses groundwater for the Pahute Mesa CAUs (Section 3.7 of the Pahute Mesa CAIP). The Pahute Mesa CAIP information for this topic has been updated with additional information in the *Phase I Transport Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nevada Test Site, Nye County, Nevada* (SNJV, 2009).

4.0 Summary of Data Quality Objectives

Section 4.0 of the Pahute Mesa CAIP (DOE/NV, 1999) discusses DQOs for the Phase I CAI and presents the background for the Pahute Mesa CAU DQOs. This section presents a summary of DQO updates further detailed in Appendix A. The DQOs for the Phase II CAI are not substantially changed from the Pahute Mesa CAIP, but are updated to conform to revised guidance and regulatory/administrative changes since the publication of the CAIP. The purpose and objectives for the Phase II CAI remain as stated in the Pahute Mesa CAIP (DOE/NV, 1999).

4.1 Data Quality Objectives Approach

The EPA guidance for the DQO process was most recently updated in 2006 (EPA, 2006). While the DQO process and guidance has been refined, the DQO process established for the Pahute Mesa CAIP (Appendix A of DOE/NV, 1999), based on the 1987 and 1993 guidance (EPA, 1987 and 1993), is still appropriate and consistent. The DQO process for the Phase II DQOs is discussed in detail in Appendix A of this document relative to the EPA (2006) guidance.

The *ad hoc* Subcommittee met to review the state of knowledge of Pahute Mesa CAU hydrogeology and the status of flow and transport modeling at the conclusion of the Phase I CAI. The results of the *ad hoc* Subcommittee discussions were summarized in Section 1.3.3 and are further discussed in Appendix C. The nature and importance of uncertainties affecting the flow and transport models were evaluated, and the subject uncertainties were prioritized as data needs. The *ad hoc* Subcommittee meetings and conclusions provide the basis for updating the DQOs for this Phase II CAIP.

4.2 Data Quality Objectives Process

The DQO process is organized according to the seven-step method of the DQO guidance (EPA, 2006), which is discussed in detail in Appendix A. The Phase II revisions for each step are presented in Appendix A and address revisions to the NTS boundary, and Phase II data collection and analysis.

4.3 Relationship between Data Collection Activities and Conceptual Models

The characterization activities resulting from the DQO process will improve both the conceptual models used for Pahute Mesa flow and transport modeling, and knowledge of appropriate parameter values used in the models. Transport model predictions made with improved models and parameter values will lead to more reliable simulations of the migration flow paths and the location of the contaminant boundary. The relationships between the data collection activities and the conceptual models are documented in the relationships shown in Table C.1-1 among the broad topics of uncertainty, the specific statements for data needs, and the specific data collection activities in Table C.1-2.

5.0 Corrective Action Investigation

The focus of the Phase II studies is to reduce uncertainty and achieve increased confidence in modeling results. Several parameter- or process-specific models are used to support the numerical models that simulate groundwater flow and contaminant transport at the CAU scale. These supporting models operate within the framework of a CAU-scale model comprised of an HFM, hydrologic conceptual model, source-term model, transport conceptual model, and regional flow model. The first part of this section addresses the Phase I CAI results that are embodied in the flow and transport models and supporting models. The discussion focuses on the evaluation of conceptual models and results of Phase I modeling, and parameter characterization for sensitivity and uncertainty. This evaluation directly relates to the Phase II data collection activities and priorities. The latter part of this section discusses Phase II changes to the modeling approach and revisions to the CAU supporting models. These include refinements to the Phase I models based on Phase I modeling experience, additions to models based on new data analyses, and incorporation of new data to be acquired during Phase II. The Phase II data collection activities are described in Section 6.0.

Figure 5-1 provides reference for the discussions of geologic features and geologic structure. Plate 2 provides hydrostratigraphic information at the water table for the Pahute Mesa investigation area. This plate also shows the sequence of HSUs for the entire HFM in the legend. The basic concepts used to describe the hydrologic character of the rocks are the hydrogeologic unit (HGU) and the HSU. The HGU describes the rock character in terms of mineralogy, porosity and permeability. The HSUs are depositional stratigraphic units comprised of one or more HGU components. The HSUs used to construct the HFM for Pahute Mesa are identified on Plate 2. A complete discussion of the relationship of HSUs and HGUs can be found in the HFM document (BN, 2002).

5.1 Consideration of Uncertainty in Modeling

An important characteristic of the UGTA strategy is the emphasis on the quantification of uncertainty in both model development and evaluation of model results. This was emphasized in the recommendations of the external peer review of the Phase I Frenchman Flat CAI (IT, 1999). Formal uncertainty nomenclature is used throughout this report to identify and discuss important components of uncertainty. This nomenclature is derived from Morgan and Henrion (1990),

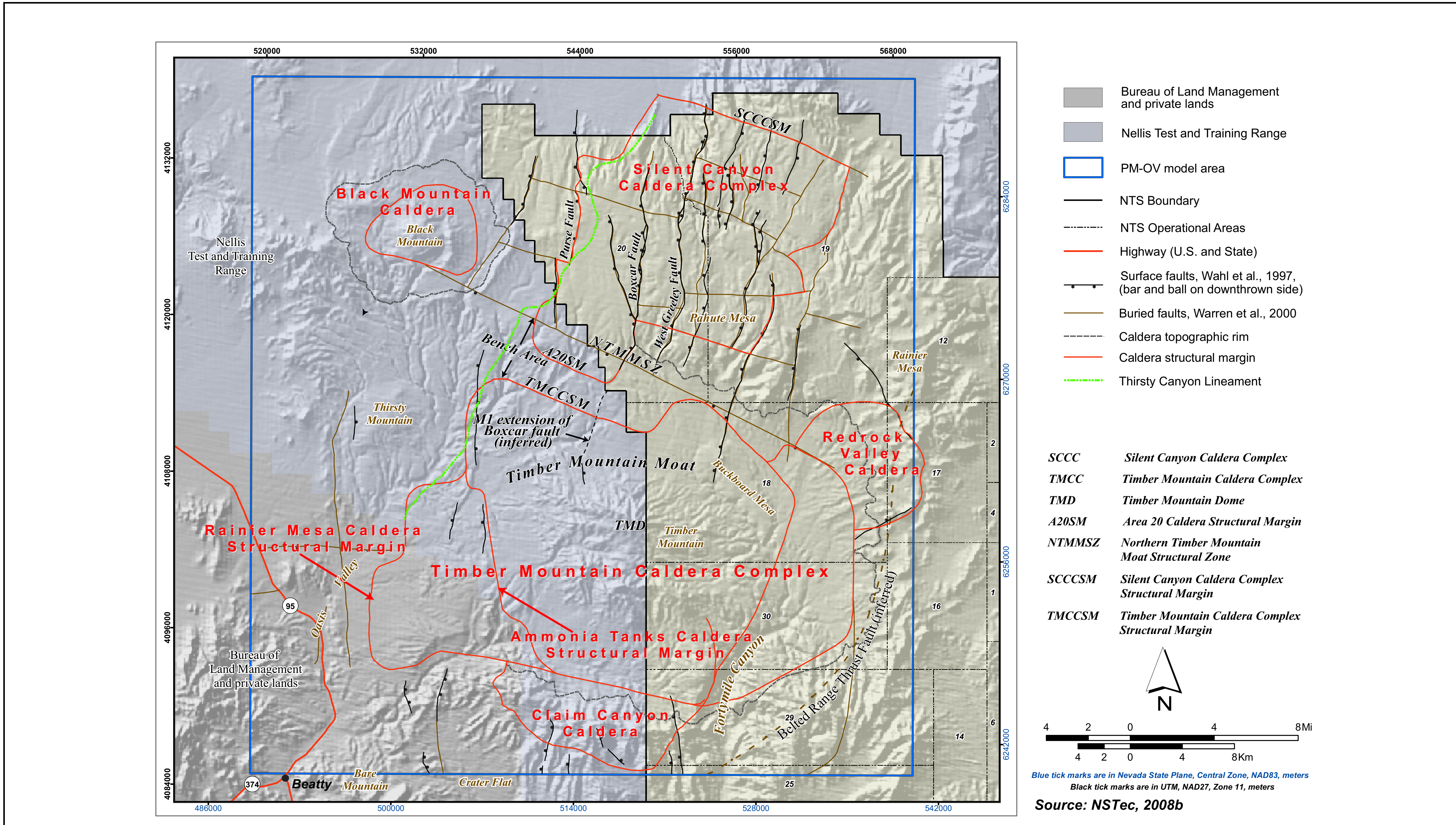

Figure 5-1
Shaded Relief Map of Structural Features of the Pahute Mesa Investigation Area

Cullen and Frey (1999), Wainwright and Mulligan (2004), and Krupnic et al. (2006); the recommendations of the Intergovernmental Panel on Climate Change (IPCC, 2004); and the National Research Council (NRC, 2007).

Uncertainty is divided into statistical and structural uncertainty. Statistical uncertainty includes variability and parameter uncertainty where variability can be viewed as a subset of parameter uncertainty and parameter uncertainty is often called knowledge uncertainty. Variability is the inherent heterogeneity of an empirical quantity across a population, and it cannot be reduced through additional research or data gathering (Krupnic et al., 2006). It can sometimes be quantified through model disaggregation, but this generally cannot be achieved for complex environmental problems with sparse characterization datasets. Parameter uncertainty, sometimes called epistemic uncertainty, is a lack of knowledge about a quantity due largely to limitations in measurements or data collection. Parameter uncertainty can be quantified through the use of probability density functions and Monte Carlo simulation, and it can be reduced through focused data collection.

Structural uncertainty refers to model, conceptual model, and decision or regulatory uncertainty. Model uncertainty can also be viewed as a form of information uncertainty. It is controlled largely by the selection and inherent assumptions in models used to mathematically represent the real world or real-world processes. Model uncertainty can merge with parameter uncertainty where models are used to produce parameters that are outputs of the models. Model uncertainty is difficult to address and has been assessed through intercomparisons of model results using different models to represent complex systems (e.g., Linkov and Burmistrov, 2003). Conceptual uncertainty, sometimes referred to as framework or scenario uncertainty, refers to model constructs that represent multiple permissive sets of alternative approaches or assumptions. It is sometimes referred to as a discrete form of uncertainty because it cannot easily be represented as probability density functions and often requires propagation of discrete sets or ensembles of model simulations using alternative model assumptions or model frameworks. Examples of conceptual model uncertainty applied in the Pahute Mesa modeling studies include alternative HFMs and alternative recharge models. Decision or regulatory uncertainty refers to the use of uncertain model outputs as a decision tool to solve regulatory or policy issues. The use of uncertain model predictions to define ensembles of contaminant boundaries for a CAU based on the implementation of the SDWA (CFR, 2009d) is a form of decision uncertainty for the UGTA Project.

5.2 Phase I Groundwater Flow and Contaminant Transport Models

The CAU-scale model that has been developed for Pahute Mesa was based on existing data as referenced in Section 3.0 of this document. The Phase I CAI was summarized in Section 1.3, and the DOE/NV review of the Phase I model was discussed in Section 1.3.3. This review identified further data needs (see Table C.1-1) and drilling locations to acquire data (Table C.1-2) to reduce uncertainty in the CAU model. New data acquisition proposals for the Phase II CAI are described in Section 6.0. This section provides an overview of the Phase I modeling, an assessment of sensitivity of the Phase I CAU model to uncertainties in the conceptual model and parameter values, proposed revisions and improvements and changes for the Phase II CAU modeling.

The following topics were discussed in Section 5.1 of the Pahute Mesa CAIP (DOE/NV, 1999) concerning selection of the flow and transport codes:

- Overview of modeling process
- Model selection
- Code attributes
- General attributes
- Groundwater flow model attributes
- Transport model attributes
- Desirable attributes
- Code identification and preliminary selection

Section 3.0 and Appendix A of the Phase I flow model document and addendum (SNJV, 2006 and 2007) present information on the applied selection process and the selected flow and transport code. Section 6.0 of the Phase I transport model document (SNJV, 2009) presents further information on the transport code.

These discussions will apply to Phase II modeling, which is proposed to use the same codes selected for Phase I, as developed in the Phase I flow and transport modeling documents.

5.2.1 Pahute Mesa CAU Model Structure

The Pahute Mesa CAU model comprises a group of interdependent models designed to predict the extent of contamination in groundwater due to the underground nuclear tests conducted within this CAU. The CAU model consists of a CAU groundwater model comprising two major components: a groundwater flow model and a transport model. The CAU groundwater flow model is supported by an HFM and a recharge model, and the CAU transport model is supported by a source-term model and a reactive mineral category (RMC) model. Within this document, the term "CAU model" refers to the Pahute Mesa CAU model as a whole, including all component and supporting models. Any single model that is part of the CAU model or any other type of model referred to in this document is explicitly identified. The reference to "Phase I" used as a qualifier for the CAU model or any of its component or supporting models, refers to the version completed under the Pahute Mesa CAIP (DOE/NV, 1999) and reviewed by DOE/NV.

The CAU model consists of multiple parts, including:

1. Flow model
   - Multiple equally weighted HFMs (structural uncertainty)
   - Multiple equally weighted recharge models (treated as structural uncertainty)
   - Alternative boundary conditions (structural uncertainty but also used as weighted calibration targets)
2. Transport model
   - Simplified source-term model
   - Monte Carlo simulations of transport where transport parameters are sampled as stochastic variables (probability density functions to represent statistical uncertainty)

Structural uncertainty is accounted for by creating flow models drawn from a matrix of alternative HFMs, recharge models, and alternative boundary conditions. After the initial calibration of the flow models, an independent check of the models was performed by comparing them to geochemical mixing models as a test of reasonableness. The screened set of calibrated models established the groundwater flow conditions that serve as input to the transport model. The calibration step was only used during the flow model phase of the flow and transport simulation sequence.

5.2.2 Groundwater Flow Model Development

The following topics were discussed in Section 5.1 of the Pahute Mesa CAIP (DOE/NV, 1999) and are updated with discussions in Sections 2.0, 4.0, and 5.0 of the Phase I flow model document and addendum (SNJV, 2006 and 2007):

- Groundwater flow data assessment
- Model setup
- Groundwater flow model calibration

5.2.3 Contaminant Transport Model Development

The following topics were discussed in Section 5.1 of the Pahute Mesa CAIP (DOE/NV, 1999) and are updated with discussions in Sections 3.0, 5.0, 6.0, 7.0, and 8.0 of the Phase I transport model document (SNJV, 2009):

- Contaminant transport data assessment
- Model setup
- Uncertainty and sensitivity analysis

The transport model developed for Phase I is not calibrated because there are no data with which to perform calibration. However, an objective for Phase II data collection is to acquire contaminant transport data that could be used for transport model calibration (see Table 6-2 of this document).

5.2.4 Summary of Phase I Flow and Transport Modeling

The Phase I flow model document and addendum (SNJV, 2006 and 2007) and transport model document (SNJV, 2009) present detailed discussions of the development and final configuration of those models. The discussion in this document is focused on the results of the Phase I modeling, lessons learned, and conclusions drawn from the models, which will be used to guide the Phase II CAI modeling.

Throughout groundwater flow and transport modeling, the elements of the models (conceptual models, HFM, supporting models, process models) and parameter values were adjusted to calibrate the flow models to available data. However, these data are insufficient to uniquely constrain the groundwater flow and transport models. Multiple configurations of the groundwater flow and transport models can non-uniquely match available observations, and the range of models yield transport predictions with great variability.

Initially, transport modeling was conducted after flow modeling, which revealed characteristics of the flow model performance that were not apparent when results for the flow simulation are viewed alone. During transport modeling, the flow model and the transport model were evaluated together, and the flow model was further developed. Simultaneous evaluation of the two models leads to a more complete understanding of the groundwater system and associated uncertainty of the conceptual model. Uncertainties regarding features of the conceptual models and processes represented in the existing models were identified and indicate important data gaps that warrant further investigation.

Periodic evaluation of modeling results by the TWG Pahute Mesa Modeling Preemptive Review Subcommittee and discussion of the achievable modeling certainty led to review of the Phase I CAU model by the *ad hoc* Subcommittee (Appendix C of this document) to guide selection of Phase II data collection activities. The following discussion (Sections 5.2.4.1 and 5.2.4.2) summarizes the major conclusions from the flow and transport model documents, including the sensitivity assessment of the models and associated uncertainties, and the reviews by the TWG subcommittees.

5.2.4.1 Conceptual Hydrogeologic Model

This subsection summarizes the major aspects of hydrogeologic interpretation of the Pahute Mesa model area flow system relative to the development of the flow and transport models. This discussion provides the basis for the subsequent summaries of sensitivities and uncertainties of those models and supporting models. For complete presentations of the details of the flow and transport models, refer to the Pahute Mesa Phase I flow model report and addendum (SNJV, 2006 and 2007) and the transport model report (SNJV, 2009).

The primary groundwater flow path southward from Pahute Mesa, starting in the area of the underground test locations on Pahute Mesa, can be described in terms of four distinct geologic subdomains: (1) the volcanic highland of Pahute Mesa, which overlies the buried SCCC and is the area where the underground nuclear testing was conducted; (2) an area referred to as the Bench, which is a distinctly different sequence of rocks that separates the SCCC and TMCC; (3) the down-dropped collapse caldera of the TMCC, including the Timber Mountain resurgent dome

(TMD) and the caldera moat zone; and (4) southward toward the Amargosa Valley and including the town of Beatty.

Groundwater flux through underground tests is predominantly derived from recharge and groundwater flow coming in from the northern boundary of the flow model, north of the SCCC. Groundwater flows from northwest to southeast in western Pahute Mesa, from northeast to southwest in eastern Pahute Mesa, and southwest in central Pahute Mesa. Groundwater flow is most pronounced in the welded-tuff aquifer (WTA) and the lava-flow aquifer (LFA) HGUs. The primary HSUs through which contaminated groundwater is thought to migrate off of Pahute Mesa are the Benham aquifer (BA) and the Topopah Spring aquifer (TSA). The Calico Hills zeolitic composite unit (CHZCM) is the most widespread HSU within the model that restricts flow off of Pahute Mesa. Based on geochemical mixing models for the distinctive groundwaters found in Areas 19 and 20, the flow paths of water from western and central Pahute Mesa appear to converge northwest of the TMCC then flow around the western margin of the TMD parallel to the western ring fracture zone of the TMD through the Timber Mountain composite unit (TMCM). This latter region was referred to as the “corridor” in the geophysical framework report of Grauch et al. (1999). Those same geochemical mixing models indicate limited flow along the east side of Timber Mountain.

The migration of contaminants from Pahute Mesa is strongly dependent upon continuity and connectivity of high- and low-permeability units. The Phase I groundwater flow model assigns uniform permeability for each HSU according to its average continuum properties. However, investigations at the CHESHIRE site found that the HSU in which this test was located (CHZCM), consisted of interfingered high- and low-permeability units that provided higher-permeability flow channels through the low-permeability HSU. The local presence of such interfingered high-permeability stringers and connectivity to high-permeability HSUs is not well known for other tests in the CHZCM. The Phase I model does not incorporate the level of detail required to simulate flow variation for high-permeability rocks embedded within low-permeability HSUs, and the source input to the transport model does not account for potential contaminant input through such paths. Further investigation of flow variability and source term are warranted.

The alternative HFMs used for the analysis offered two generalized scenarios relative to transport. Where high-permeability HSUs form a long, continuous, channelized flow path bracketed by lower-permeability units, simulated RN migration is more rapid, and RN concentrations remain high long distances from the source. Where there was not a continuous, channelized high-permeability pathway, the RN plume would spread laterally, and slower transport resulted in greater sorption and diffusion of RNs into the rocks. Predicted transport was enhanced by local faulting, the presence and continuity of high-permeability fractures and cooling joints in volcanic aquifers, and uncertainty in parameterizations used to represent fracture matrix interactions.

Two major north-south-oriented faults within the SCCC, the Purse and the Boxcar, have a pronounced impact on the water table head distribution. Measured heads in wells show as much as 100 meters (m) of head drop from the west side of the Purse fault to the east side. Head measurements for wells on the west side of the Boxcar fault indicate that head is about 40 m lower than on the east side. The water table in the structural block between the Purse fault and the Boxcar fault is substantially lower than in the adjoining upgradient blocks, and the head difference indicates that the faults may restrict transverse flow. The impacts of other faults on groundwater head are less well defined.

Another factor affecting flow through rocks within and between the subdomains is juxtaposition of HSUs across structural boundaries, resulting in uncertainty of flow path continuity and connectivity.

The Bench subdomain lies between the SCCC and the TMCC. The Bench subdomain is interpreted to be underlain by carbonate rocks (lower carbonate aquifer [LCA]) that extended through the region before the formation of the calderas of the Southwestern Nevada Volcanic Field (SWNVF), which is structurally truncated to the north and south by the bounding caldera structural margins. The carbonate structural block was subsequently covered by ash falls, ash flows, and lava flows from the caldera building events, bracketed by the debris of the caldera margins, and intersected by faults and fractures. The information defining this structural block is primarily derived from magneto-telluric and gravimetric geophysical surveys and boundaries are not well constrained. The Northern Timber Mountain moat structural zone (NTMMSZ), often referred to simply as the “moat fault,” is located along the southern margin of the SCCC. This structural zone appears to have a minimal effect on flow based on the minimal observed head difference between wells located on the north and south sides of the structure. The nature of this fault is unknown, and further characterization is warranted by its importance for modeled flow paths from tests.

The TMCC subdomain, located south of the Bench subdomain, is composed of a central resurgent dome (TMD) with a surrounding moat. The resurgent dome is composed of intracaldera densely welded tuff with well developed cooling joints. These rocks may have been subjected to intrusion by granitic rocks with migration of late stage pegmatitic and hydrothermal fluids which infilled and reduced the fracture permeability of the cooling joints. The juxtaposition of the lower-permeability Fortymile Canyon composite unit (FCCM) rocks against the TMCM promotes restricted flow through the relatively high-permeability TMCM near the contract between the rock units. Alternatively, this channelized flow may be an artifact of the permeability assignments for the two HSUs in the transport model. Interconnected lenses of higher-permeability fractured volcanic rocks may be present within the lower-permeability FCCM. The presence of these rocks could result in more distributed flow through the FCCM than allowed by the current model approach which assumes homogeneous permeability. These alternative interpretations are to be investigated as part of the Phase II studies.

The fourth subdomain is the southern extent of the modeled flow field where groundwater flows to discharge and is not included in total in the Pahute Mesa CAU model, but is truncated at the southern and western model boundaries and represented by boundary conditions. The groundwater that flows through the TMCM of the TMCC subdomain discharges into the alluvium south of the TMCC or continues toward the Amargosa Valley and Death Valley in a deeper carbonate aquifer. Discharge is calculated from spring discharge measurements and estimates of evapotranspiration (ET) based on plant type and population density. For the model to simulate sufficiently high head to account for the observed discharges, a depth-decay factor which reduces permeability with increasing depth, was applied to the permeability distributions for certain HSUs.

5.2.4.2 Flow and Transport Models

During the flow model calibration, multiple alternative HFMs were evaluated. Simulations using the different HFMs were compared on the basis of calibration targets (measured heads and spring flow estimates) and geochemical mixing targets at wells along the groundwater flow paths. The models that showed the best fit to the observed well heads and estimated discharge, and that reasonably matched the geochemical mixing targets were selected as alternative flow models for transport modeling. Groundwater ages were used for evaluating groundwater fluxes by comparing travel times between wells estimated from carbon-14 (^{14}C) age dating through inverse geochemical modeling.

Steady-state flow fields for each of the selected alternative flow models provided the groundwater flow paths along which transport of RNs were simulated. Simulation of transport was performed through particle tracking and a convolution-based particle tracking method was used to calculate the flux-averaged concentration in the groundwater model. The particle tracks through the model domain reveal that downgradient flow preferentially channeled from the test locations on Pahute Mesa (the SCCC subdomain) through interconnected high-permeability HSUs. Further, flow was focused into channelized flow paths by bounding low-permeability HSUs juxtaposed along structural boundaries. Review of the transport modeling concluded that the assignment of homogeneous permeability (high or low permeability) to HSUs, especially the thick composite HSUs, results in simulated flow through the model that may not be representative of expected or observed behavior for naturally occurring geologic units. The oversimplification resulting in such channelized flow, results in conditions that enhance transport through the model domain. Because hydrogeologic variability is excluded, the model predicts RN transport that is not observed in existing wells at or near predicted flow paths.

5.2.5 Modeling the Contaminant Boundary

The ultimate objective of transport modeling is to forecast the contaminant boundary, defined in Section 2.1.2.1. For Phase I transport modeling, the objective was changed to use the flow and transport models to evaluate data needs for the Phase II CAI. The effect of various model permutations on contaminant boundary predictions were determined using the concept of exceedance volume (EV). The EV is the volume of model grid nodes for which there is a 95 percent probability of exceeding the maximum containment levels (MCLs) for 1,000 years using multiple realizations of the model. The surface projection (map view) of the perimeter of the EV can be used to represent the contaminant boundary.

5.2.5.1 Sensitivity Analyses

Sensitivity of transport predictions to transport parameters and to flow model uncertainty were explored during transport modeling. The following sections summarize the CAU model development and flow and transport model sensitivity results included to provide information relevant to the understanding of the data needs (Table C.1-1) and the data acquisition tasks proposed in Section 6.0. A complete discussion of the sensitivity analysis can be found in Section 8.0 of the transport model document (SNJV, 2009).

5.2.5.1.1 Sensitivity to HFM Alternatives

The alternative HFMs provide multiple representations of the structural and hydrostratigraphic framework of HSUs and the assignment of hydraulic parameter values by HSU. There are two major components of uncertainty for the alternative HFMs. First, there is conceptual uncertainty associated with the spatial extent and contact configurations of volcanic rocks units in a complex caldera setting, and with the nature and geometry of structural boundaries and faults that disrupt the rock units. These represent a discrete form of uncertainty that is propagated through the transport model using multiple alternative representations of the HFMs and their structural setting. An additional consideration that may be important for the Phase II studies is the scale of the HFMs. The HFMs were developed for the Pahute Mesa modeling domain, whereas the results of transport modeling show that most of the important components of transport modeling occur in specific regions of the model domain (western Pahute Mesa, Bench area, and the constricted flow around the western margin of the TMD). Insight would be gained by further evaluating alternative HFMs for the areas of preferred pathways of RN migration as indicated by the transport modeling. Second, there is statistical (parametric) uncertainty in assigning permeability values for spatially variable HSUs and structural uncertainty (alternative conceptual models) in developing conceptual models of the controlling process that produced the spatial heterogeneity in permeability. Groundwater flow modeling was conducted on multiple conceptual models of the geologic structure to evaluate the effect of structural uncertainty. The available data are insufficient to characterize heterogeneity at scales smaller than HSUs across the model domain; thus, only the gross behavior of groundwater flow can be simulated, resulting in unrepresented processes at the sub-HSU level. Quantification of HSU heterogeneity and uncertainty across scale is to be addressed during the Pahute Mesa Phase II task.

Geologic uncertainty was represented by seven alternative HFMs, which include the original five alternative HFMs in the HFM document (Section 6.0 of BN, 2002). The identification of basin-scale preferential transport paths within subdomains of the TMCM led to reanalysis of flow model conceptualization. Two additional alternatives were developed from the Lower Clastic Confining Unit 1-Modified Maxey-Eakin recharge model (LCCU1-MME) HFM alternative (Section 3.0 of SNJV, 2009). The three flow models discussed later in this subsection encompass the uncertainty and illustrate the characteristics of modeled flow paths. Figures 5-2 through 5-4 illustrate contaminant transport predictions for each model showing the results for 1,000 realizations of the model, color-coded for first arrival time at model nodes of RNs exceeding SWDA standards (CFR, 2009d). The configuration of the surface projection of the EV indicates the general predicted flow paths along which contamination travels from the various source locations.

The LCCU1-MME flow model uses the preferred base HFM (the LCCU1 model) and recharge using the MME model. Figure 5-2 shows the extent of the predicted contaminant plume for any time of exceedance for source locations that originate from Pahute Mesa tests. Using this model, flow from northeast Pahute Mesa moves to the southwest toward the northwest perimeter of Timber Mountain. Flow from northwest Pahute Mesa is confined to the TSA and BA HSUs to the southeast by the Fluorspar Canyon confining unit (FCCU), and moves southeast to converge with flows from the northeast. The combined groundwater flow is channelized around the western flank of the TMD by the FCCM to the west, and in the upper TMCM due to reduced permeability with depth (depth decay). Flow restriction is through interconnected high-permeability units, further enhanced by bounding low-permeability units. To some extent, the apparent confinement may be attributed to the gross assignment of single permeabilities to HSUs in the model.

The Deeply Rooted Belted Range Thrust Fault-Desert Research Institute Alluvium (DRT-DRIA) model shown in Figure 5-3 has the same structure in the north model area as the LCCU1 model but raises the elevation of the low-permeability, pre-Tertiary basement in the model region. The uppermost pre-Tertiary rock immediately downgradient of Pahute Mesa is the (nonconductive) LCCU1 rather than the (conductive) LCA. The consequence is the focus of groundwater flow at shallower depths in the model, thus increasing flow velocity. Additionally, recharge from the DRT-DRIA recharge model is much greater than for the MME model. The reduced extent of the contaminant plume south of Pahute Mesa is attributed to dilution by increased recharge to groundwater from TMD.

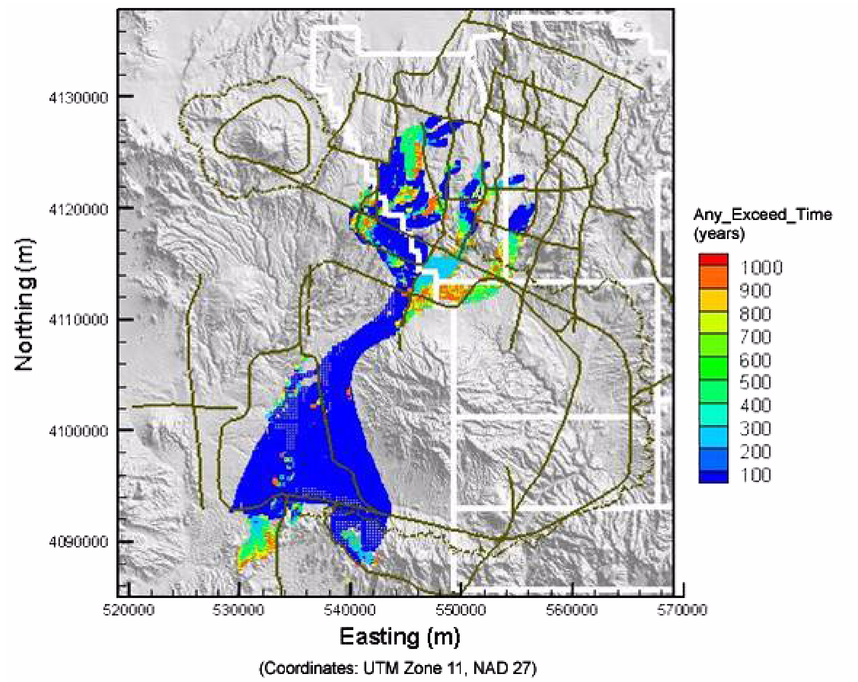

Figure 5-2
LCCU1-MME Surface Projection of the EV along Flow Paths
Source: Modified from SNJV, 2009

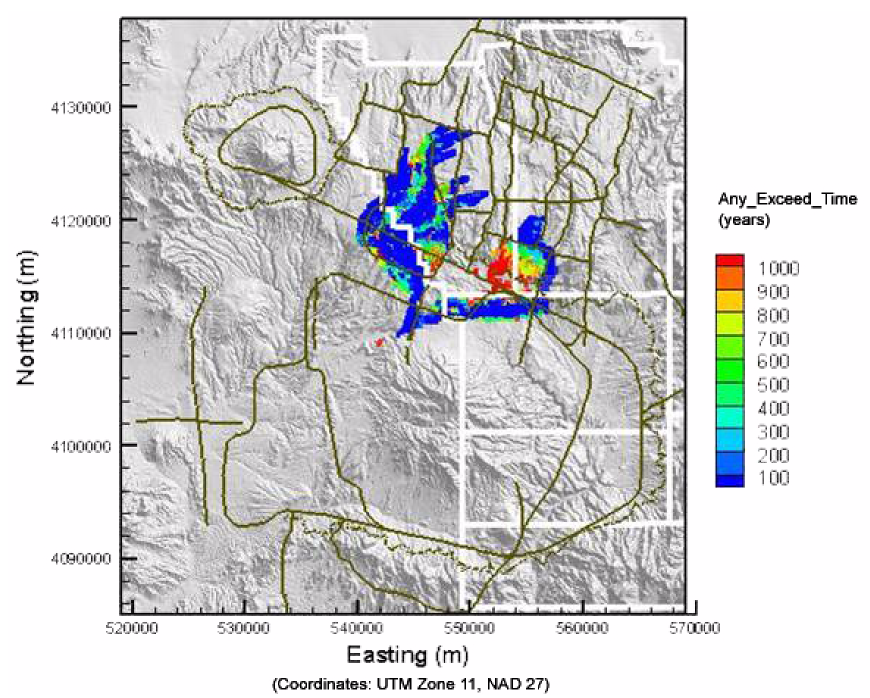

Figure 5-3
DRT-DRIA Surface Projection of the EV along Flow Paths
Source: Modified from SNJV, 2009

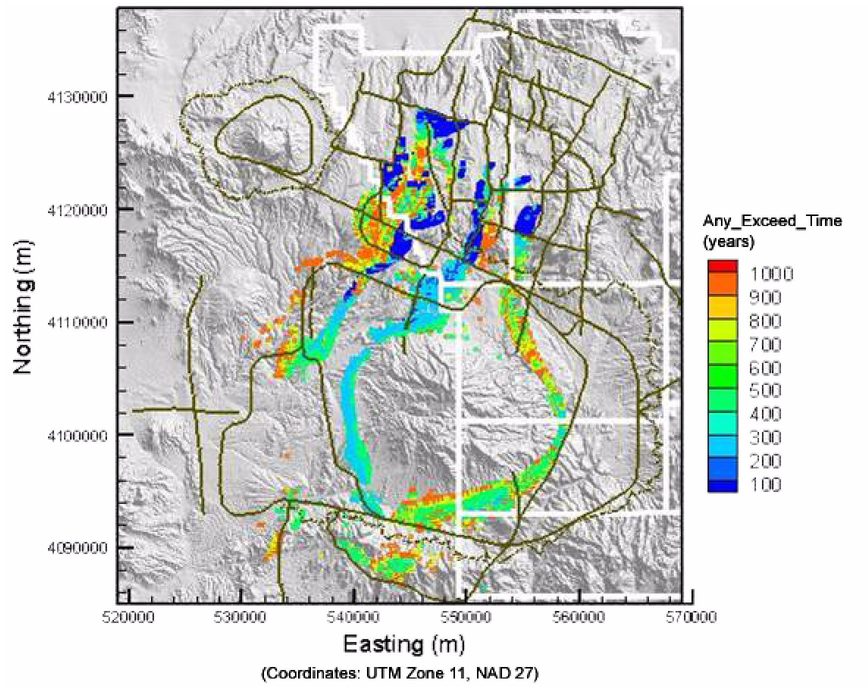

Figure 5-4
LCCU1-TMCM Surface Projection of the EV along Flow Paths
Source: Modified from SNJV, 2009

The LCCU1-MME-TMCM flow model used the LCCU1 HFM but with an alternative representation for the TMCM subcomponent HSUs to test the extent to which the flow field and contaminant distribution would change. The permeabilities of the TMCM, FCCU, and FCCM were adjusted to approximately the permeability of the TMCM. Figure 5-4 shows result for this flow model. Contaminants travel additional flow paths that do not all converge to the channelization of previous flow models. This increases the volume of rock through which flow occurs; increases the fracture-matrix interface area across which contamination can diffuse; and reduces the flow velocity, thereby increasing contaminant migration time.

All three models predict flow paths to the south that follow the northwest perimeter of the TMD. However, there is considerable variation between the models as to the extent of contaminant transport over 1,000 years and, in the case of the LCCU1-MME-TMCM model, the potential for additional flow paths from western Pahute Mesa toward the Thirsty Canyon Lineament and from central Pahute Mesa around the east side of Timber Mountain down Fortymile Canyon.

5.2.5.1.2 Transport Parameter Sensitivity

Sensitivity analysis of model output was performed on the model for 35 input parameters and contaminant output for each of the seven alternative HFMs. The model components identified through this analysis of transport predictions are:

- Mass transfer coefficient (MTC) for the WTA
- Effective porosity for the WTA
- Tritium (^3H) concentration from the TYBO underground test (southernmost source term)
- The plutonium (Pu) reduction factor to represent colloidal migration
- Effective porosity of the tuff confining unit (TCU)

Assessment of sensitivity to transport parameters for different HFMs revealed that the first three parameters were most important for transport through the four HFMs in which the results were most variable. These four HFMs were characterized by channelized, high-flux transport paths through welded tuffs and lava flows. The last two parameters were most important for transport through the three HFMs for which the results for transport parameters were characterized by lower flux/high dilution. Different HFMs identified different HSUs as most important with regard to transport. Transport predictions were also evaluated for sensitivity to the dispersion coefficient value. Increasing dispersion coefficient values resulted in faster movement of the contaminant front and increased extent of contamination. This result may be an artifact of the numerical model solution to the dispersion equation.

The results of the sensitivity analyses demonstrated that transport prediction is sensitive to flow model parameter uncertainty. The substantial and preferential transport simulated in the base HFM-derived models is explained by the interconnectivity of high-permeability HSUs. These interconnected high-permeability units are bounded by low-permeability units, resulting in converging flow paths. Transport predictions were also found to be sensitive to the depth-decay coefficient value for the flow model, which affects the vertical extent of flow paths and mixing volume.

5.2.5.2 Assessment of Uncertainties

Section 9.0 of the transport model document (SNJV, 2009) discusses flow and transport uncertainty relative to specific features and processes, rearranged in order of importance for the transport prediction. Table 5-1 lists the uncertainty categories and cross-references them to Table C.1-1 and Section C.1.3 of this document, relating the transport modeling conclusions with the *ad hoc* Subcommittee assessments.

Table 5-1
Uncertainty Categories

Uncertainty Categories	Data Needs (Table C.1-1)	Data Analysis (Section C.1.3)
Pahute Mesa Bench Complexity	1C	3, 4, 6, 12, 13, 14, 18, 20
Faults (hydrologic properties, effects)	1C, 1H	3, 4, 7, 10, 12, 14, 18
Heterogeneity (of composite units, spatial variability within HSUs)	1A, 1B, 1D, 1G, 3A	1, 2, 5, 8, 9, 10, 12, 13, 18, 19, 20, 23
Transport in Fractured Media - Fracture Properties, Fracture Pathways	1A	20, 23, 29
Depth Decay	1J	12, 13
Transport Calibration	1E	17, 21
Source Term (RST, HST at source locations)	1D, 3A, 3B, 3C	25, 26, 27, 28
Recharge	1F, 1I, 2C	15, 16
Specific Discharge (inflow, outflow, flow system)	1B, 1D, 1F, 2A, 2B	11, 12, 13
Boundary Flow (inflow division between volcanic and carbonate aquifers)	2A, 2B	11, 17, 20

Following is a discussion of these uncertainty categories with regards to how the various uncertainties interact and affect transport prediction.

Pahute Mesa Bench Complexity - Flow path convergence and confinement due to the HFM HSU configuration from Pahute Mesa onto the Bench subdomain immediately south of central Pahute Mesa and juxtaposition of low-permeability composite units of the Timber Mountain moat along the downgradient Bench boundary are shown in Figure 5-2. The majority of modeled flow paths from Pahute Mesa sources are constrained between the Purse fault and the Boxcar fault, and track southwestward into the Bench subdomain, where they converge along the axis of the Bench and then track to the southeast. The axis of the converged flow paths turn to the south toward Timber Mountain along the inferred extension of the Boxcar fault (M1 extension inferred). The Bench subdomain is a distinctly different arrangement of rocks between the SCCC and the TMCC. The Bench subdomain as defined in the Pahute Mesa HFM document (BN, 2002) was more restricted than the usage in this Phase II CAIP, where it specifically referred only to the structural Bench located between the common Ammonia Tanks and Rainier Mesa caldera structural margin (to the south) and the Area 20 caldera structural margin (A20SM) (to the north). Reference to the Bench subdomain is broadened in this Phase II CAIP to include the additional terrain from the A20SM northward to the NTMMSZ. The extra-caldera volcanic aquifers and confining units of the additional terrain are suspected to be underlain by moderately high basement of original sedimentary rocks. The lithologic units found in each caldera and across the Bench are not necessarily continuously deposited units but somewhat unique sequences of rock. In addition to eruptive cycles and deposition of volcanic rock from different depositional centers, structural offset along faults can further displace units at the Bench. The fault structures may constitute either conduits or barriers to flow, which may vary along strike of the faults. The arrangement and properties of the HSUs and faults in this area are primary controls on flow and transport to downgradient locations.

Faults - There is limited information about fault-zone hydraulics and transport dynamics in the Pahute Mesa system. The simulations conducted with the alternative flow models predict substantial migration away from Pahute Mesa (for tests from southern Area 20) without considering faults as potentially more conductive conduits for transport. Contaminant migration sensitivity to fault properties regarding their potential to enhance or retard migration was not thoroughly assessed. Information on faults in locations distant from testing areas is lacking.

Heterogeneity - An additional consideration regarding uncertainty of the HFM is the hydrologic representation of the two major composite units of the Timber Mountain moat: the FCCM and the TMCM. These thick composite units are undifferentiated as HSUs but have been observed to contain intervals of variable permeability (e.g., fractured welded tuffs) in drill holes. The flow model treats these composite units as massive, homogeneous, single-permeability units that, along with depth decay, result in converging, channelized flow paths. The introduction of heterogeneity or discrete layers that would provide alternative flow paths through these units could significantly affect the predicted flow.

Transport in Fractured Media - Transport in fractured media is controlled to a great extent by fracture properties. The fracture property distributions used for the sensitivity analyses reflect the limited field-scale information and substantial uncertainty. The fracture aperture distribution was developed using a theoretical relationship and the distributions of fracture porosities and fracture spacing based on data. Fracture aperture is the least constrained parameter for the transport model. Approximately 40 percent of the model realizations included fracture apertures greater than

1 centimeter (cm). Such large fracture apertures lead to simulations with minimized mass transfer from the fractures to the matrix as a result of small wetted-surface-area to fracture volume ratio. Observations of welded-tuff fracture apertures in boreholes, core, and in tunnels conflict with such larger apertures, as do estimates based on other properties. Considering the conflicting indirect evidence for actual fracture geometry and properties, fracture model parameters are uncertain.

Groundwater flow in fractured rocks occurs primarily in the fractures; however, the flow and transport models use equivalent porous media conceptualization that also incorporates a dual-porosity capability. There are significant limitations in using equivalent porous media properties to represent complex fracture networks. A uniform permeability value is assigned to all model nodes in an HSU, providing full continuity within that HSU, which is equivalent to fracture pathways that are fully connected and continuous. In reality, fractures comprise networks where the connectivity through fractured rocks is dependent on fracture density, length, and orientation variation. One of the primary issues is that the volume at which a continuum parameter is applied may be very large, but the effective parameters may vary with scale. Heterogeneity within HSUs is lost, and the effective field-scale permeability fails to represent complex processes at smaller scales. At smaller scales, flow may follow tortuous pathways in the fracture network. Such pathways would expose solutes to substantially greater surface area across which mass transfer may occur. Many realizations in the sensitivity analysis involve large fracture apertures, which lead to limited or no matrix diffusion, which, in turn, leads to limited or no matrix sorption of reactive species. Also, for larger apertures, colloid retardation is less than for smaller apertures. Fracture properties and effective retardation are highly uncertain.

Depth Decay - Depth decay conceptually reduces permeability with depth relative to the permeability distribution assigned to an HSU. The effect of depth decay on the flow model is to reduce the depth of penetration of flow paths and increase the proportion of the specific discharge higher in the flow system. Although depth decay is not well characterized, it has proven to be necessary to calibrate to head and discharge targets (SNJV, 2006 and 2007). Regarding transport predictions, depth decay affects the vertical spreading of contaminants and consequently modeled retardation. Depth decay may be an important uncertainty affecting plume evolution and, consequently, definition of the regulatory boundary. In the flow model calibration analysis, depth decay and anisotropy are highly correlated. However, they may have substantially different impacts on contaminant migration and simulated concentrations. This issue was not rigorously investigated in Phase I.

Transport Calibration - The transport modeling predictions cannot be calibrated or validated with presently available data. The Phase I transport modeling predicts that RNs are likely to have already migrated downgradient into the Bench subdomain and beyond. However, RNs have not been observed in the wells located in this area. Further, RN concentrations similar to the source-term concentrations used for transport modeling have not been observed near source locations. Consequently, both the transport predictions and the source term used for transport modeling are highly uncertain.

Source Term - A source-term model is used to provide the RN mass flux from individual nuclear test sites for input into the CAU-scale transport model. Source-term uncertainty is attributable to parameter uncertainty and to conceptual model or structural uncertainty. A source-term model of near-field processes was developed and calibrated to measurements for post-detonation conditions at and near the working point for two tests. An SSM that is computationally tractable was developed to use for specifying the source term for all the sources for transport modeling. This model abstracts the general features of a 3-D process model, incorporating parameter variability that describes the uncertainty in the parameter space, which is then reflected in the output distribution. The SSM is a one-dimensional (1-D) representation of a 3-D process model. As such, some processes that are 3-D in nature cannot be directly represented by the 1-D model. The fluid flux rate input to the SSM is derived from flux through the cavity calculated with the CAU-scale flow model. The various HFM models result in different fluxes, and in turn fluxes for each HFM model vary with the recharge model used. The source-term model used to specify the flow model source term uses the unclassified RN inventory.

An important factor that determines the source term applied to the flow system, constraining mass flux from the test cavity for each test site, is the connection to the flow system, as represented by the HSU assigned for the SSM. For those tests that are in or beneath the water table and are located in high-permeability rocks, assigned HSU properties promote substantial flux through the cavity. Alternatively, the test cavity may be located in a low-permeability HSU that connects to high-permeability rocks. Several variations of this situation can be conceptualized: (1) a test may be located within a low-permeability HSU containing high-permeability layers (heterogeneity), which provide connection to the high-permeability flow system; (2) a test may be located in a low-permeability HSU that is overlain by a high-permeability HSU beneath the water table, and the chimney rubble serves as a connection for groundwater flow (by heat-driven convection) and RN migration; (3) a test within a low-permeability HSU may be connected to an underlying high-permeability HSU by fracturing; and (4) the high volatility RNs could be dispersed in a vapor phase for both high- and low-permeability rocks and thereby removed from the aqueous source term. These different situations highlight the uncertainty of whether the Phase I SSM approach captures enough detail about the source locations to accurately account for the 3-D system dynamics relative to the resolution of HSUs.

Recharge - The recharge applied to the model may be a significant component of the water budget affecting the water balance and groundwater fluxes. Three different recharge models were applied to evaluate the sensitivity of transport predictions to uncertainty of recharge amount and distribution. In particular, recharge and the postulated recharge mound beneath TMD, adjacent to the primary groundwater flow path from Pahute Mesa, are significant controls on the flow paths. Uncertainties for the permeability of the TMD and recharge rates at TMD are substantial. Less recharge on the TMD than the assumed rate could significantly affect flow dynamics in the TMD area and therefore transport.

Specific Discharge - Specific discharge in the model domain is not a measurable parameter to which the flow model can be calibrated; rather, it is a simulation result based upon calibration of the flow model to groundwater heads, where large-scale permeability is estimated. Specific discharge within the model is important because it directly impacts groundwater flow velocity and consequently transport velocity and, in turn, impacts the effect of matrix diffusion.

Boundary Flow - Inflow and outflow across the lateral boundaries of the model constrains the calibration of the flow models. These values are estimated from the regional flow model (DOE/NV, 1997) and the Yucca Mountain site-scale flow model (Zyvoloski et al., 2003), which overlap the Pahute Mesa southern boundary. Radionuclide migration has been predicted primarily in shallow volcanic units, with little interaction with the deeper carbonate flow system. Inflows and outflows between the carbonate and volcanic systems along model boundaries have not been differentiated. The flow model was calibrated to net inflow, but small differences in the distribution of boundary flux between the volcanic and carbonate systems may lead to substantial flux changes affecting RN migration in the volcanics.

Boundary flows exert an effect on transport prediction uncertainty. This is reflected in a lack of supporting information from field observations of contamination that has led to the decision to develop this Phase II CAIP and identify uncertainties at the boundaries through acquisition of data that can be used to verify transport model predictions.

5.2.6 Contaminant Boundary Forecasts

Probabilistic forecasts of preliminary contaminant boundaries were developed using the definitions and methods described in Section 2.1.2.1. These forecasts do not represent formal representations of contaminant boundaries but provide a basis for comparison of model-predicted transport over 1,000 years for alternative models (see, for example, Figures 5-2 through 5-4).

5.2.7 Model Evaluation

The process of model validation described in the Pahute Mesa CAIP (DOE/NV, 1999) has been replaced by a process of model evaluation that is designed to build confidence in model output leading to model acceptance by NDEP. Model evaluation and model acceptance are described in Section 2.1.2.3. After review and assessment of the Phase I CAI results, the TWG Pahute Mesa Modeling Preemptive Review Subcommittee concluded that there is insufficient confidence in the Phase I CAU model results to complete contaminant boundary forecasts. Phase II data collection and model revisions are required.

5.2.8 Supporting Models

As discussed in the introduction to this section, the CAU model is made up of component models and supporting models: the regional groundwater flow model, the HFM (and alternatives and sub-models), the Pahute Mesa flow model (with supporting recharge models), the Pahute Mesa transport model (with the supporting SSM), and additional supporting models. This section briefly discusses the major supporting models. Other supporting models were used for development of elements of the CAU model, and are discussed in the flow and transport model documents (SNJV, 2006 and 2009).

5.2.8.1 Regional Groundwater Flow Model

The UGTA regional groundwater flow model documented in *Regional Groundwater Flow and Tritium Transport Modeling and Risk Assessment of the Underground Test Area, Nevada Test Site, Nevada* (DOE/NV, 1997) was created to provide the necessary regional framework within which the CAU model operates. The regional model balances groundwater inflows and outflows on a regional scale to ensure that large-scale model flow is consistent with measured water levels, inflows, and outflows. This regional model was used for Phase I Pahute Mesa flow and transport modeling. Use of the UGTA regional flow model (DOE/NV, 1999) and adjustments to it for the Pahute Mesa flow modeling are discussed generally in Section 2.1 of the Pahute Mesa flow model document and addendum, and specifically in Section 6.4.2 (SNJV, 2006 and 2007).

Subsequently, the *Death Valley Regional Model Ground-Water Flow System, Nevada and California - Hydrogeologic Framework and Transient Ground-Water Flow Model* (Belcher et al., 2004), which encompasses the NTS, has been published, and the flow and transport models will be transitioned to this regional model.

5.2.8.2 Hydrostratigraphic Framework Model

The Pahute Mesa HFM was initially developed and documented in the Pahute Mesa HFM document (BN, 2002). The HFM was further developed during modeling in a number of ways. More detail was incorporated in a sub-HSU of the TMCM to support the Phase I groundwater flow model. Proposals for further development of the HFM model and associated sub-models are discussed in Section 6.2.1 of this document.

5.2.8.3 Recharge Models

Three approaches were used to develop alternative recharge models for the NTS area, which includes the Pahute Mesa flow model area. The three approaches are:

- Maxey-Eakin estimation techniques
- Net infiltration-recharge distributed parameter modeling
- Chloride mass-balance modeling

Five alternative recharge models were used to assess uncertainty for Phase I flow modeling. Each of the alternatives was assumed for at least one of the calibrated alternative models selected for transport simulation. The alternative recharge models are:

- MME - Modified Maxey-Eakin
- USGSD - USGS recharge with redistribution
- USGSND - USGS recharge without redistribution
- DRIA - DRI recharge with alluvial mask
- DRIAE - DRI recharge with alluvial and elevation mask

5.2.8.4 Source-Term Model(s)

The Pahute Mesa CAU model includes an SSM (see Section 4.1 of the transport model document [SNJV, 2009]) that is abstracted from a process model representation of the near-field source-term releases from the CHESHIRE test (Pawloski et al., 2001). Section 6.2.5 of this document discusses additional data analysis activities that would support improvement of the source-term conceptual model as well as refinement of the SSM.

5.2.8.5 Random Field Generator

Section 5.2.2 of the Pahute Mesa CAIP (DOE/NV, 1999) discusses application of random field generation to the representation of parameter heterogeneity within HSUs. This development was not applied to Phase I modeling but is proposed as a refinement for Phase II modeling. A proposal for development of conceptual heterogeneity models is discussed in Section 6.2.1 of this document, and the proposal for development of the numeric heterogeneity models is discussed in Section 5.3.2.6.

5.2.9 Evaluation of Phase I Flow and Transport Modeling

The TWG Pahute Mesa Modeling Preemptive Review Subcommittee periodically reviewed the results of the Phase I flow and transport modeling. In November 2007, the group determined that Phase I modeling was developed to the extent possible with available data (UGTA TWG, 2007). Additional drilling exploration with new data acquisition would be required to test the reliability of the model predictions, test and refine alternative conceptual models of the hydrogeological setting and features of the flow system, and increase data and potentially reduce uncertainty for topical areas of the model domain.

5.2.9.1 Flow Path Evaluation

The initial Phase I alternative flow models all produced concentrations of flow lines in the TMCM around the northwestern side of Timber Mountain with predictions of transport southward within the 1,000-year time frame. Models showing convergent flow paths on the northwest side of Timber Mountain approximate the constraints determined by geochemical flow path investigations as they incorporate isotopic mixtures west of the Purse Fault and east of the Purse Fault. Flow along flow paths further west were restricted by lower-permeability rock units. The LCCU1-MME-TMCM model was developed such that permeabilities were assigned across the TMCM and to the FCCM more uniformly, acting as a surrogate for formation heterogeneity. This resulted in more flow paths from Area 20 and predicts flow from Area 19 around the eastern side of Timber Mountain, in contrast with the other models. Shallow flow paths through Fortymile Canyon/Wash are interpreted from measured geochemical data to carrying isotopically heavier groundwater characteristic of surface recharge.

5.2.9.2 Flow Model Parameter Evaluation

Sensitivity of transport results to permeability parameters was evaluated, which indicated that flow paths and transport distances are sensitive to flow parameters. Specific concerns for flow modeling include the incorporation of depth decay. The uncertainty regarding depth decay is of concern due to the effect on predicted transport related to the effect of depth decay on the flow model. Depth decay reduces permeability with increasing depth, resulting in reduced vertical spreading of flow downgradient, which in turn results in greater predicted transport distance due to reduced spreading of contaminants in formations. The incorporation of depth decay is problematic due to the large uncertainty in the characterization of depth decay. There was general concern that the flow field is not adequately represented in the current Pahute Mesa model.

5.2.9.3 Transport Model Parameter Evaluation

Transport predictions are sensitive to matrix-diffusion parameters. Wider fracture aperture result in more rapid transport with little retardation due to matrix diffusion, and there is little dispersion with travel times. The fracture porosity determines the effective porosity for the WTA and LFA HGUs. Closely spaced fractures result in slower transport, also contribute little dispersion with travel times, and the system behaves similarly to a porous medium with the matrix porosity approximating the “effective” porosity of the fracture/matrix system. However, intermediate fracture spacings result in significant dispersion of travel times. Predicted transport was sensitive to longitudinal dispersivity values used in the flow model; increasing longitudinal dispersivity resulted in faster and more distant predicted contaminant transport. Scaling of MTCs, which embody the matrix diffusion process, is believed by some to be necessary when using a 1-D transport model (i.e., Phase I Pahute Mesa transport model) to simulate transport in fractured rock. Heterogeneous fracture network modeling with different flow geometries may provide insight. Alternately, use of travel time information based on ^{14}C or test-related RNs has the potential of determining “effective” parameters for the 1-D modeling.

5.2.9.4 Source-Term Evaluation

There is limited evidence for RN release from tests in the near-field and for RN transport downgradient from sources compared to predictions from the source and transport models. Near-field groundwater samples generally do not confirm the RN concentrations and, by extension, the RN mass used for the source terms in the transport model. Several explanations can be offered. Some tests may not be leaky, such as ALMENDRO and BULLION. This may be because the tests were conducted in low-permeability media and a permeability barrier was created by the compression of the rock for up to several cavity radii, or because the system has self-sealed due to localized post-test hydrothermal alteration of the rock. Also, vapor-phase transport up the chimney, as suggested by vadose-zone detections of ^{3}H above the water table, may remove some of the volatile RNs from the cavity environment. It was not uncommon to detect gaseous RNs at land surface days after tests, indicating that vapor-phase transport may be a common mechanism for removal of some of the RN inventory (specifically ^{3}H and ^{14}C) from the cavity. Additional characterization of the near-field environment may help explain the actual occurrences of RN transport, which conflict with model results, and improve simplified release and migration models.

With the exception of the BENHAM-TYBO example of contaminant transport, based on Pu source identification, significant contaminant plumes from Pahute Mesa sources have not been observed. The Phase I transport modeling predicted contaminant plumes extending downgradient substantial distances into areas where existing wells have not identified contamination. This may be because the existing wells are not located in appropriate places to sample contaminated groundwater given the uncertainty in the fracture-controlled flow paths, or that contaminant plumes have not migrated as predicted. Field observations of contaminant transport proximal to tests, in the immediate downgradient, and in the middle distance would provide a basis for evaluating the apparent discrepancy. Additional characterization of the near-field environment may help explain the actual occurrences of RN transport, which conflict with model results, and improve simplified release and migration models.

5.2.9.5 Fracture-Scale Transport Evaluation

Transport at a fracture network scale, considering the effects of heterogeneity, anisotropy, and scale, needs to be better understood. The Phase I transport modeling approach (1-D along path lines) inherently assumes a set of parallel fractures that are oriented along the flow path, which is calculated assuming homogeneous and isotropic rock permeability. More realistically, the natural system is comprised of non-parallel fracture sets that impose anisotropy on the rock permeability, which affects the flow field, and within which heterogeneity of aperture and orientation causes branching of flow and changes in velocity within the fracture network. With the current approach, a large number of the realizations simulate sets of parallel fractures that traverse entire HSUs, which transport RNs with little attenuation. Modeling HSU heterogeneity at a smaller scale would help correct this problem, including geostatistical heterogeneity modeling for porous media and fracture network modeling for fractured media. Fracture network models are criticized as non-unique, but heterogeneous porous media models are also non-unique. However, these models provide the best approach to understand transport processes. Fracture network models cannot practically be used at the CAU scale but could be developed at local scales for evaluating the effects of the fracture flow field and provide insight on better transferring a simplified process to the CAU model.

5.2.9.6 Additional Considerations

The TWG Pahute Mesa Modeling Preemptive Review Subcommittee reviewed the transport document (SNJV, 2009), which included considerations for Phase II modeling (UGTA TWG, 2008). These considerations included:

- Incorporating the RMC concept into the flow model, given that RMC subdivision contains more information on lithology and permeability than HSUs.
- Using the UGTA regional model (DOE/NV, 1997) for boundary conditions while other CAU models are using variants of the Death Valley Regional Flow System (DVRFS) model, resulting in inconsistency between different CAU models.
- Using different boundary fluxes among the CAU models for common borders, even when developed using the same regional model.
- Evaluating conceptual model uncertainty, which is explicitly based on HFM and recharge model differences, and uncertainty of boundary fluxes.
- Applying RN flux for tests located above the water table.
- Addressing uncertainty in flow-model parameters and dispersivity.

5.2.10 TWG Pahute Mesa Phase II CAIP ad hoc Subcommittee Review

The *ad hoc* Subcommittee evaluated presentations by the program participants including HFMs, geochemistry, source term, and flow and transport models. Important conclusions from the transport model include:

- More extensive RN migration than expected based on knowledge of the flow system, source-term and geochemical data from hot well sampling, and processes of RN transport and preliminary constraints on groundwater ages.
- A major identified cause of extensive RN transport was convergent groundwater flux along the western and southwest flanks of Timber Mountain and the presence of preferential migration pathways in higher-permeability welded tuff of the TMCM. The factors causing this convergent flux are present in all alternative HFMs.

- Radionuclide migration was highly sensitive to fracture matrix interactions and continuity in fractured rock represented in the model domain for pathways extending from Pahute Mesa toward TMD.

- Other important parametric uncertainties affecting RN migration include assumptions concerning the availability and release of RNs from the source term, release and mobility of colloidal Pu from the source, and the effective porosities of RMCs.

The *ad hoc* Subcommittee discussed the statistical and structural uncertainties affecting the model predictions of RN transport and identified data needs that could improve understanding the processes of flow and transport as incorporated in the flow and transport models (Data Need listed in Table C.1-1). These data needs were grouped into three major topical areas, including:

- Improvements in the understanding of flow and transport in fracture-dominated pathways leading south from Pahute Mesa toward TMD (see first column of Table C.1-1).

- Refinements in understanding of the groundwater inflow into and within Pahute Mesa.

- Refining and attempting to reduce the uncertainty in source term applied to the Pahute Mesa CAU transport model.

Each subcommittee member independently established priorities for data needs and refined assignments through group discussions at subsequent subcommittee workshops. The top five priorities in decreasing order from this evaluation are (see also the Priority and Description columns of Table C.1-1):

1. The flow models of Pahute Mesa show convergence of groundwater flow paths west of Timber Mountain, east of Thirsty Canyon, and along the approximate geologic contact between the TMCM and FCCM HSUs in the Bench area of the modeling domain. These areas are also strongly affected by faults associated with the Timber Mountain and SCCC calderas. Are the representations of these flow fields in the flow models realistic, and do the models provide reliable predictions of RN transport?

2. Groundwater flow through the TMCM and FCCM HSUs may be complicated and spatially variable. There are concerns with how the hydraulic properties of these units are represented in the flow and transport models.

3. Plutonium from the 1968 BENHAM test was found at the ER-20-5 site, 1.3 kilometers (km) from the test. The extent of RN migration immediately downgradient of drill hole ER-20-5 is currently unknown. Where and how fast are RNs migrating over time; what are the characteristics and extent of contaminant plumes in this critical area; and why were no RNs detected at drill hole ER-EC-6 approximately 4 km from the ER-20-5 site, as would be expected based on Phase I model predictions of transport?

4. What are the hydraulic characteristics of faults in critical migration pathways off of Pahute Mesa? Are these faults barriers or conduits for flow, and are the faults reasonably represented in the models of flow and transport?

5. What is the spatial variability of permeability for HSUs in the critical flow pathways leading off of Pahute Mesa toward TMD? Are these permeabilities correctly upscaled and represented in the flow and transport models?

The *ad hoc* Subcommittee used the combination of the identified data needs, major topical areas identified for flow and transport predictions, their prioritized data topics to develop and rank locations of drill holes for data collection (Table C.1-2), and proposed data analysis activities (Section C.1.3) for the Phase II CAI.

5.2.11 TWG Source Term Subcommittee

Kersting (2008) submitted the concerns of the TWG Source Term Subcommittee regarding the state of knowledge of the HST and information supporting the HST models to the *ad hoc* Subcommittee. Kersting (2008) addressed the importance of the source term to transport prediction, and specifically noted the discrepancy for ^{14}C between estimates of the near-field concentration for the HST used for transport modeling based on the Bowen inventory (Bowen et al., 2001) and actual measured concentrations. Because ^{14}C is a major determinant of the contaminant boundary, this discrepancy is significant. Kersting (2008) further noted that other high-mobility RNs (^{3}H, chlorine-36 [^{36}Cl], technetium-99 [^{99}Tc], and iodine-129 [^{129}I]) are not observed in the field as predicted by the transport model, to the extent of the available data. These concerns are similar to those presented in Section 5.2.9.4 of this document concerning the source term used for transport modeling.

5.2.12 NDEP Concern Regarding Fortymile Canyon/Southeastern CAU Boundary

The NDEP has identified particular concern regarding lack of information for the southeastern boundary of the Pahute Mesa CAU and possible groundwater flow from central Pahute Mesa (Area 19) around the eastern side of Timber Mountain, along Fortymile Canyon. The NDEP has indicated that data must be collected via some means (e.g., well installation, modeling, geophysics) to provide information concerning this possibility. Geochemical mixing targets in wells along the eastern side of the TMD indicate that groundwater has a high meteoric water component and limited contribution from Area 19 groundwater.

5.2.13 Community Advisory Board

The CAB for NTS Programs is an appointed formal group of volunteers and liaison members organized to provide informed recommendations and advice to the NNSA/NSO Environmental Management Program. The CAB has reviewed the Pahute Mesa information and Phase I modeling, and provided comments and recommendations for well drilling. Appendix D contains a cover letter and a technical summation submitted by the CAB concerning the siting of wells on Pahute Mesa.

5.3 Phase II Modeling

The modeling approach and structure used for the Phase I CAI will continue to be used during the Phase II modeling activities, and the models developed during Phase I will be further developed based on new data and analyses. This section discusses proposed revisions and improvements to those models.

5.3.1 Suitability of Current Numeric Models

The numeric modeling approach developed for Phase I flow and transport modeling was determined by the technical modeling team to be a suitable approach for predicting the regulatory contaminant boundary. However, the initial conceptual and parametric distribution within the groundwater flow and transport domain does not reproduce the observed or expected system response. Therefore, Phase II modeling is proposed to further develop those models as well as supporting models with the improvements listed in Section 5.3.2.

5.3.2 Proposed Revisions/Improvements to Current Models

Revisions and improvements proposed to further refine the conceptual model and reduce modeling uncertainty include, but are not limited to, the following:

- Re-evaluate role of major hydrostratigraphic and structural features.
- Refine model boundary conditions.
- Conduct simultaneous flow and transport simulation.
- Correct water table clipping.
- Develop sub-CAU scale heterogeneity model.
- Develop sub-CAU model of the Bench subdomain.
- Revise fracture parameter model.
- Develop discrete fracture models for upscaling.
- Revise the SSM.
- Reduce the number of RNs modeled.

The Phase II field activities are designed to collect information to fill data gaps identified from groundwater flow and transport model evaluation and review. For Phase II modeling, conceptual models will be improved and parametric distributions revised based on Phase II field data collection. Numerical and analytical models will be developed and revised concurrently with well drilling, development, and testing activities. This approach allows testing and refinement of applications that are necessary to effectively process the measured data and optimize model calibration and increase confidence that the contaminant boundary is a reasonable representation of future contaminant transport.

5.3.2.1 Re-evaluate Role of Major Hydrostratigraphic and Structural Features

The Purse and Boxcar faults located on Pahute Mesa appear to have a significant effect on the configuration of groundwater head and to act as transverse barriers to flow. The effect of other hydrostratigraphic and structural features is not as apparent from available head data, which are sparse. During review of the conceptual model, other features were identified that may have substantial effects on the flow system, which include the NTMMSZ (moat fault); the inferred southern extension of the Boxcar fault (M1 extension inferred); an area of CHZCM that extends above the water table at the intersection of the NTMMSZ and the Boxcar fault; the A20SM; the Timber Mountain caldera complex structural margin (TMCCSM), which includes the Rainier Mesa caldera structural margin (RMSM) and Ammonia Tanks caldera structural margin (ATSM); and juxtaposition of HSUs from the Bench to the FCCM/TMCM across the TMCCSM in the Timber Mountain moat west of Timber Mountain.

The physical and hydrologic nature of these structural boundaries as well as appropriate hydraulic properties will be incorporated into the flow and transport model using the flow model to determine how these geologic features affect calibration. In addition, Pahute Mesa Phase II drilling and hydraulic testing will specifically investigate major structural features to evaluate their hydrology. The additional information and hydrologic characteristics will be incorporated into the Phase II flow and transport models.

5.3.2.2 Refine Model Boundary Conditions

The groundwater flow model requires specification of head and/or flow at the boundaries of the model and at internal discharge points of the numerical model, termed boundary conditions. The Pahute Mesa CAU model accounts for regional inflow and outflow across all four lateral edges, internal flow from precipitation recharge, and internal discharge at Oasis Valley. This was particularly uncertain for the Pahute Mesa CAU model because the model boundaries do not coincide with natural hydrologic boundaries. Boundary conditions for the Phase I Pahute Mesa flow model were primarily derived from the regional flow model simulation, adjusted to incorporate applicable data, but generally are not defined by head measurement. The Phase I boundary conditions reflect potential overestimation of fluxes along the model boundaries that is an artifact of the regional model conceptualization and the coarser resolution of the regional grids. The Phase II flow model boundary conditions will be derived from DVRFS model coordinated with the other CAU flow models. Reassignment of boundary conditions that allow the flow model to better honor the measured heads at observation wells near the model perimeter will be considered, which may provide better simulation of appropriate boundary fluxes.

5.3.2.3 Evaluate Depth Decay and Anisotropy

During Phase II modeling, uncertainties regarding depth decay and anisotropy will be further evaluated for both flow modeling and transport modeling. These factors directly affect the modeled flow and secondarily affect contaminant migration as a result of modeled spreading of contaminants and, consequently, modeled retardation.

5.3.2.4 Conduct Simultaneous Flow and Transport Simulation

The Phase I Pahute Mesa flow model was built first and calibrated independent of the transport model, which then uses the calculated groundwater fluxes from the flow model to determine transport paths. During transport modeling, simulation of particle tracks based on the flow paths and calculation of the flux-averaged solute concentration revealed irregularities that were not directly apparent from the flow model results. During Phase I Pahute Mesa transport model development, some of these discrepancies were investigated to evaluate the changes to the flow model that would improve the calibration of the model and accuracy of the predictions. Key among the observed transport model results that require further investigation is the effect that large, homogeneous HSUs have on contaminant transport. Phase II modeling will concurrently simulate groundwater flow and transport such that the behavior of the flow field can be evaluated relative to transport modeling before selecting the flow field alternatives.

5.3.2.5 Correct Water Table Clipping

The Phase I groundwater flow model cuts off ("clips") the upper surface of the water table at 1,500 m above sea level. At some locations, the water table is above this elevation. Radionuclide mobilization in the upper, higher-permeability units may not be captured in those areas where the water table is "clipped." This condition could result in exclusion of alternative flow paths along which RNs are migrating. Use of the moving water table approximation in Finite Element Heat and Mass Transfer code (FEHM) would help solve this problem. This situation will be evaluated and corrected as necessary.

5.3.2.6 Develop Sub-CAU Scale Heterogeneity Model

Heterogeneity is a positional property of the rocks through which flow and transport occur, referring to the variability of properties at multiple scales, in the case of the flow model for effective permeability assigned to each HSU. Heterogeneity can be represented at the nominal scale of the grid blocks as an averaged value defined by a group of grid blocks or as a sub-grid size representation. The first representation of the heterogeneity used in the Pahute Mesa flow and transport model uses variable size grid blocks to characterize local complex geological structures and groups of grid blocks for homogeneous representation of individual HSUs. When groundwater flow and transport results are viewed together, transport is shown to be sensitive to both flow and transport heterogeneity. However, for high-flow velocities, transport parameter heterogeneity may be insensitive in any form. High-flow grid blocks in volcanic rocks result where data are sparse and the assembled grid blocks represent kilometer-scale HSUs. For those HSUs that are characterized as high-permeability rocks, the path becomes a conduit for more rapid flow and contaminant migration. This fast migration also reduces diffusion and adsorption from the fractures to matrix which, in turn, contributes to transport parameter insensitivity. Lower-permeability rocks are also represented as homogeneous blocks that, when adjacent to the high-permeability rocks, confine flow through the higher-permeability units. This effect results in higher velocities through the permeable rocks due to constricted flow.

Hydrostratigraphic units are not homogeneous but exhibit sub-HSU, grid-scale variability that includes layering and interfingering of both high- and low-permeability rocks. This structure had significant effect on the results of the CHESHIRE study by Pawloski et al. (2001) and the BENHAM-TYBO study reported by Wolfsberg et al. (2002). To adequately represent the nature of the flow and transport through such HSUs, it may be necessary to incorporate some degree of sub-HSU scale heterogeneity into the large homogeneous HSUs, or otherwise derive equivalent effective properties. A range of possible permeabilities for sub-HSU heterogeneity can be sampled from the probability distribution for each HSU and assigned based on geostatistical metrics (correlation length and juxtapositional relationship).

Approaches to integrating heterogeneity of properties into the Phase II models that may be used include:

- **Sequential indicator simulation** (SISIM) was used to upscale the sorption coefficient (K_d) through incorporation of spatial variability for the Phase I Pahute Mesa transport model. The model grid was subdivided into smaller grid blocks that were more representative of the scale at which measurements were recorded, and multiple realizations of the K_d fields were generated. This approach could also be used for incorporating permeability field variation within each of the HSUs. The method is particularly relevant to Pahute Mesa HSUs because it captures the hydraulic discontinuity between fracture and matrix permeability within a grid block, which incorporates the discontinuity at the larger HSU scale.

- **The pilot-point method** (Doherty, 2003) could be used to assign spatial variability in the permeability field. Although the locations of pilot points are qualitatively assigned, a quantitative assignment for optimal placement of pilot points within HSUs is possible using numerically derived sensitivities to permeability (e.g., Lavenue and de Marsily, 2001).

Implementation of the pilot-point method within Pahute Mesa HSUs may incorporate scales of spatial correlation, as well as the pilot-point permeability, as fitting parameters during flow model calibration.

- **A transition probability-based geostatistical method** (Carle, 1999; Dai et al., 2007a and b) would be a third approach to define permeability heterogeneity within HSUs. This approach can be used to simulate multiple categorical zones within a single HSU while honoring available borehole data. The zones may be categorical classes of permeability (e.g., low, medium, high), stratigraphic layers, or some other relevant hydrogeologic characteristic. The strength of the transition probability method over other geostatistical methods is that the juxtapositional tendencies of HSUs as observed in the field (or in theory) can be reproduced, and also that the models of spatial variability and their parameters can be understood in terms of standard geologic descriptions and observations. This allows better incorporation of subjective as well as observed geologic knowledge into the models of spatial variability.

5.3.2.7 Develop Sub-CAU Model of the Bench Subdomain

The Bench subdomain that lies between the SCCC and the TMCC is very important for modeling flow and transport from Pahute Mesa. The Bench is particularly complex because it represents a transitional zone between the adjacent caldera complexes that have each experienced multiple caldera formation events. The lithologic units found in each caldera and across the Bench are not necessarily continuously deposited units but represent unique hydrostratigraphy in each area. In addition to eruptive cycles and deposition of volcanic rock, structural offset along faults displace HSUs juxtaposing HSUs at interfaces across structure, which affects continuity of permeability along flow paths. The arrangement of the HSUs and faults is a primary control on flow and transport to downgradient locations.

A sub-CAU model of the Bench subdomain is proposed to allow greater detail to be modeled. Specific concerns are juxtaposition of lithologic units across faults and structural boundaries; the distribution and connectivity of permeable HSUs; and location and hydraulic properties of faults that may provide or prevent communication between HSUs vertically, transversely, and longitudinally, determining flow paths. This model could also incorporate heterogeneity within HSUs for both flow and transport properties.

5.3.2.8 Revise Fracture Parameter Model

Fracture aperture, spacing, and porosity are model parameters that substantially affect flow through fractured rocks and the transfer of contaminant mass between fractures and the matrix for which there are little data directly characterizing parameter values. For Phase I modeling, these related parameters were calculated based on some data and relationships between the parameters for the parallel plate conceptual model of transport in a fracture. Fracture aperture was calculated from sampled distributions of measured porosity and fracture spacing in boreholes, which produced large apertures that are an artifact of the method and not necessarily representative of expected ranges.

An alternate approach calculates the aperture, keeping the permeability fixed and varying the fracture spacing. Porosity is then calculated using the previously calculated aperture and associated fracture spacing, providing a range of apertures that are tied to the permeability. This approach, discussed in Section 5.0 of the Phase I Pahute Mesa transport model document (SNJV, 2009), will be used to recalculate fracture aperture and porosity as it relates to fracture-matrix mass transfer for the Phase II model HGUs and RMCs. As with spatial variability of permeability, which was calculated for each of the HSUs using geostatistical approaches, the porosity distribution can be calculated for the RMCs. Porosity variability introduces variability in the mass exchange between fractures and the rock matrix within an HSU that will correlate with permeability variations in the flow model.

The current approach assumes a continuum model to represent the fracture distribution. Additional approaches to better describe the fracture system may be explored. Other alternative approaches that may be investigated include a fracture network modeling approach and use of ^{14}C travel time data to calibrate transport parameters.

5.3.2.9 Develop Discrete Fracture Models for Upscaling

Fractured volcanic rocks are the primary media for groundwater flows through and downgradient from Pahute Mesa. Fracture connectivity, spacing, and aperture substantially determine actual groundwater flow paths, flow velocities, and contaminant mass transfer that occurs between the fracture and rock matrix. The Phase I models do not account for variability of the fracture system within individual HSUs. This is represented by homogeneity assigned at the HSU level and signifies a lack of information about the variation of fracture properties at the HSU level. Fracture properties (e.g., orientation, aperture width, fracture roughness, fracture connectivity, flowing fractures) have generally been measured only at the borehole scale and are not well characterized for any local site, much less at the HSU-scale. An approach to account for fracturing variability at the sub-HSU scale may be identified and evaluated for application regarding modeling feasibility and data requirements. Once the range of fracture properties is defined and the method to represent fracture variability is chosen, the range of flow and transport behavior may be evaluated through stochastic modeling from which uncertainty and sensitivity can be assessed.

Discrete fracture network models could be developed at the local scale and used for assessing effects of fracturing variability. In particular, discrete fracture network modeling could be used for evaluation of upscaling from the scale of data to the grid-block scale, and then to the scale of transport. Parameters requiring evaluation for upscaling include flow parameters (e.g., hydraulic conductivity and storage) and transport parameters (e.g., effective porosity, MTC, and K_d).

5.3.2.10 Revise the SSM

The contaminant mass flux used for the CAU-scale transport modeling is derived from a 1-D SSM of local-scale flow and transport through the test cavity and adjacent disturbed rock. The 1-D model is derived by fitting an analytical solution to the mass flux calculated using a 3-D process model for the CHESHIRE test site. The generalized model is applied to all other Pahute Mesa tests. Calculation of the source term using this approach is less labor intensive and more computationally efficient than building a 3-D simulation for each Pahute Mesa test, and data are unavailable for most of the test sites to validate a test-specific SSM. However, several potentially important 3-D processes are not represented with the Phase I SSM. This oversight can lead to an overestimation of the source-term concentration that is then applied during the numerical modeling activity. Additional analysis will be conducted to incorporate the necessary processes, how to generalize source-term knowledge, and how to represent source-term uncertainty.

5.3.2.11 Reduce the Number of Radionuclides Modeled

The importance of individual RNs in the transport modeling is dependent upon the contribution that each makes to the total dose at the contaminant boundary. For Phase I transport modeling, RNs were assigned to three groups corresponding to SDWA (CFR, 2009d) standards categories: alpha emitters, beta emitters, and uranium (U) isotopes. The importance of each RN group depends on the total inventory, half-life, and sorption coefficient that each RN within the group contributes to the total exceedance. Those RNs that possess a short half-life, high sorption coefficient, or low inventory are less likely to persist as a dose risk. For the Phase I Pahute Mesa transport modeling, the RNs that were incorporated were ^{3}H, ^{14}C, ^{129}I, ^{36}Cl, ^{99}Tc, ^{241}Am, ^{237}Np, ^{90}Sr, Total Pu, and total U. These RNs will be further evaluated during transport modeling for importance in determining the contaminant boundary.

Section 3.5.2 of the Pahute Mesa CAIP (DOE/NV, 1999) specified seven RNs, identified by the TWG, that were judged most likely to affect regulatory compliance metrics within the 1,000-year period. These RNs were ^{14}C, ^{129}I, $^{239/240}$Pu, ^{137}Cs, ^{90}Sr, ^{3}H, and ^{238}U. Additional RNs of concern (^{36}Cl, ^{237}Np, and ^{99}Tc) were included in Phase I transport modeling. The Pahute Mesa CAIP (DOE/NV, 1999) states that the list of potential radioactive contaminants that will be included in simulations of the contaminant boundary for Pahute Mesa may be modified based on the findings of the CAI. A formal evaluation and selection process using the transport model, based on running all RNs in the inventory for one source to show relative migration extent, could provide justification for the elimination of specific RNs. The TYBO or BENHAM tests are likely candidates because they were high-yield tests in high-permeability rocks near the southwestern end of Pahute Mesa and therefore pose the highest risk of contributing contaminant mass to the contaminant boundary.

5.3.3 Model Acceptance

As discussed in Section 2.1.2.3, model acceptance will be based on overlapping processes of model verification, calibration, and model evaluation through the iterative processes of data gathering and model refinements. The model evaluation process is proposed to replace model validation. Verification refers to evaluations to ensure the model code is programmed correctly and the algorithms are implemented with no assumption errors or program bugs. Calibration refers to 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 simulation and observations of the groundwater flow system. Model evaluation involves developing confidence in the reliability of model outputs through efforts to test and extend the model.

A successful model evaluation is achieved through an inability to disprove a model. Model confidence increases with successful verification, calibration, and model evaluations.

5.3.4 Contaminant Boundary Forecasts

The contaminant boundary per Section 2.1.2.1 will be forecast using the CAU flow and transport model, and a resulting ensemble of model forecast contaminant boundaries will serve as the basis for negotiating the compliance boundary.

6.0 Phase II Characterization Activities

The primary goal of the Phase II characterization activities is to obtain data that would increase confidence that the flow and transport model results can be used effectively to forecast CAU contaminant boundaries required to implement the UGTA strategy. The objectives for the data characterization are to test conceptual models of flow and transport, address data requirements that could reduce the uncertainty of parameters required for the modeling studies, and continue the process of model evaluation. Successful completion of the Phase II studies would lead to completion of ensembles of contaminant boundary forecasts, provide supporting information required for negotiation of the compliance boundary, and allow initiation of the monitoring program leading to the CAU closure report. Descriptions of support activities for drilling and other field characterization are provided in this section of the report.

6.1 Characterization Activities

The Pahute Mesa Phase II CAI includes proposals for extensive investigation, characterization, and data analysis, including:

- Hydrogeologic field investigation program
  - Drilling and well construction
  - Coring (contingent)
  - Well development and single-well testing
  - Geochemical sampling
  - Water-level monitoring
  - Multiple-well aquifer tests
  - Single-well and cross-hole tracer tests
  - Hydrophysical logging
  - Temperature profiling
- Geologic and geophysical studies
- Hydrology studies
- Isotope- and geochemistry-based studies
- Transport parameter studies
- Source-term studies

These are discussed in more detail in the following subsections.

6.1.1 Hydrogeologic Field Investigation Program

The hydrogeologic field investigation program includes drilling new boreholes and completing new hydrogeologic investigation wells, collecting and evaluating data, testing the individual wells, and performing large-scale testing of groups of wells.

6.1.1.1 Objectives

The objective of the field investigation program is to institute a second phase of data collection designed to test assumptions of the component models, improve the quality of parameter data used in models, and increase confidence in the transport model results used to predict contaminant migration boundaries. This includes collecting data to reduce uncertainties of the HFM, flow, source term, and transport models; and investigating RN migration along predicted flow paths that could be used to verify flow path and calibrate transport predictions. Specific data collection objectives are based on the data needs identified by the *ad hoc* Subcommittee (Table C.1-1), bolstered with additional considerations identified in reviews discussed in Section 5.0.

6.1.1.2 Proposed Well Locations

Table 6-1 presents location information for the 12 highest priority wells identified in the technical review of Phase I CAI results by the *ad hoc* Subcommittee, summarized in Section 5.2.10 and Appendix C. One contingency well (ER-20-11) is also included to address high-priority objectives if the Priority Wells 1 and 2 (ER-20-7 and ER-EC-11, respectively) do not meet intended objectives. The planned contingency well is discussed at the end of this section. The Phase I CAI drilling program was largely an exploratory program with wells located in areas where there was limited geological and/or hydrological data or control. In contrast, the Phase II drilling program was developed after development of geologic, flow, and transport models, and evaluation of the results of model predictions of RN transport where the model implements the current state of knowledge and uncertainty in processes of flow and transport. The Phase II drilling program represents a transition from an exploratory program to a focused program using model results to identify key program issues and uncertainties. The ultimate goal of Phase II data collection is to develop confidence that the transport model provides a reliable tool for predicting the 1,000-year extent of contaminant boundaries.

Table 6-1
Proposed Drilling Locations

Well Name	Priority	UTM NAD 27 Zone 11 (m)		Elevation amsl (ft)	Target HSU(s)	Planned Depth (bgs ft)	TD Elevation (bgs ft)	Predicted Depth to Water (bgs ft)	Predicted SWL amsl (ft)	Penetration below SWL (bgs ft)
		Easting	Northing							
ER-20-7 [a]	1	546,219	4,118,430	6,209	TSA	2,500	3,709	2,016	4,193	484
ER-EC-11 [a]	2	544,839	4,116,703	5,657	BA, TCA, TSA	3,500	2,157	1,477	4,180	2,023
ER-20-8 [a]	3	546,675	4,119,269	5,849	BA, TCA, TSA	3,700	2,149	1,650	4,199	2,050
ER-20-11 [b]	(4/5)	To be determined		N/A	BA, TCA, TSA	N/A	N/A	N/A	N/A	N/A
ER-EC-12 [c]	4	545,059	4,113,972	5,520	BA, TCA, TSA	3,650	1,870	1,335	4,185	2,315
ER-EC-13 [c]	5	540,184	4,113,512	5,170	FCCM, TMCM	3,000	2,170	1,036	4,134	1,964
ER-EC-14 [c]	6	543,815	4,110,254	5,210	FCCM, TMCM	3,400	1,810	1,046	4,164	2,354
ER-EC-15 [c]	7	542,675	4,115,325	5,360	BA, TCA, TSA	3,200	2,160	1,195	4,165	2,005
ER-20-9 [c]	8	548,635	4,114,414	5,670	BA, SPLFA, PLFA	3,000	2,670	1,444	4,226	1,556
ER-EC-16 [c]	9	540,866	4,109,976	5,040	FCCM, TMCM	2,900	2,140	880	4,160	2,020
ER-20-10 [c]	10	546,679	4,120,324	6,275	TCA, TSA	3,000	3,275	2,090	4,185	910
ER-20-4 [c]	11	549,676	4,116,493	5,740	BRA	3,100	2,640	1,495	4,245	1,605
ER-EC-3A [c]	12	545,909	4,101,849	6,000	TMCM	2,500	3,500	1,735	4,265	765

[a] Global Positioning System (GPS) coordinates, elevation of staked location.
[b] This contingency well is proposed for the second drilling campaign if RNs are not found at Wells ER-20-7 or ER-EC-11.
[c] Coordinates of map location, not staked.

amsl = Above mean sea level
bgs = Below ground surface
ft = Foot
N/A = Not applicable
SWL = Static water level
TD = Total depth

The coordinates listed in Table 6-1 are based on locations plotted onto a topographic map, except for the first three wells and ER-20-4 (an existing well site), as noted, which have been staked and located by GPS. The map-based locations may be moved as necessary when located on the ground. Planned drilling depths are based on the depths of the target units as modeled in the HFM and actual drilled depths may vary depending upon the geology encountered during drilling. The planned drilling depths shown are the full depth of the target HSUs for wells on Pahute Mesa and on the Bench. Planned depths for wells on the south side of the Bench and in the TMCC have been limited for the deepest target HSU(s) to bottom elevations consistent with upgradient target depth elevations. Figure 6-1 shows the proposed locations. Plate 1 shows the well locations on a large-scale topographic base, and Plate 2 shows the well locations on a map of the HSUs at the water table, which includes and identifies pertinent structural features. Drilling order may differ from the priority order in some cases to improve efficiency of drilling operations and reduce costs primarily related to considerations for access to drilling locations (i.e., from the NTS or off the NTS). Drilling is planned to take place over several years with breaks during the winter when inclement weather would make drilling operations inefficient. Considered in the drilling priority is the acquisition of information that may affect the optimal placement of subsequent wells. The well locations are designed to answer a sequence of questions:

1. Where and how rapidly are contaminants being released from their sources and moving off Pahute Mesa (plume identification)?

2. What are the geologic structures and HSUs that control convergence of groundwater flow and RN transport in the area of the Bench?

3. Do contaminants move in preferential higher-permeability pathways from the Bench area into and across the Timber Mountain caldera?

The answer to the first question will strongly affect approaches to addressing the latter questions and may affect locations of the subsequent drill holes. While specific locations of all wells are listed, their final locations and priorities could change as the drilling program proceeds based on the specific objectives and new information. It is intended that drilling be conducted in several separate campaigns, allowing new information to be evaluated before subsequent campaigns.

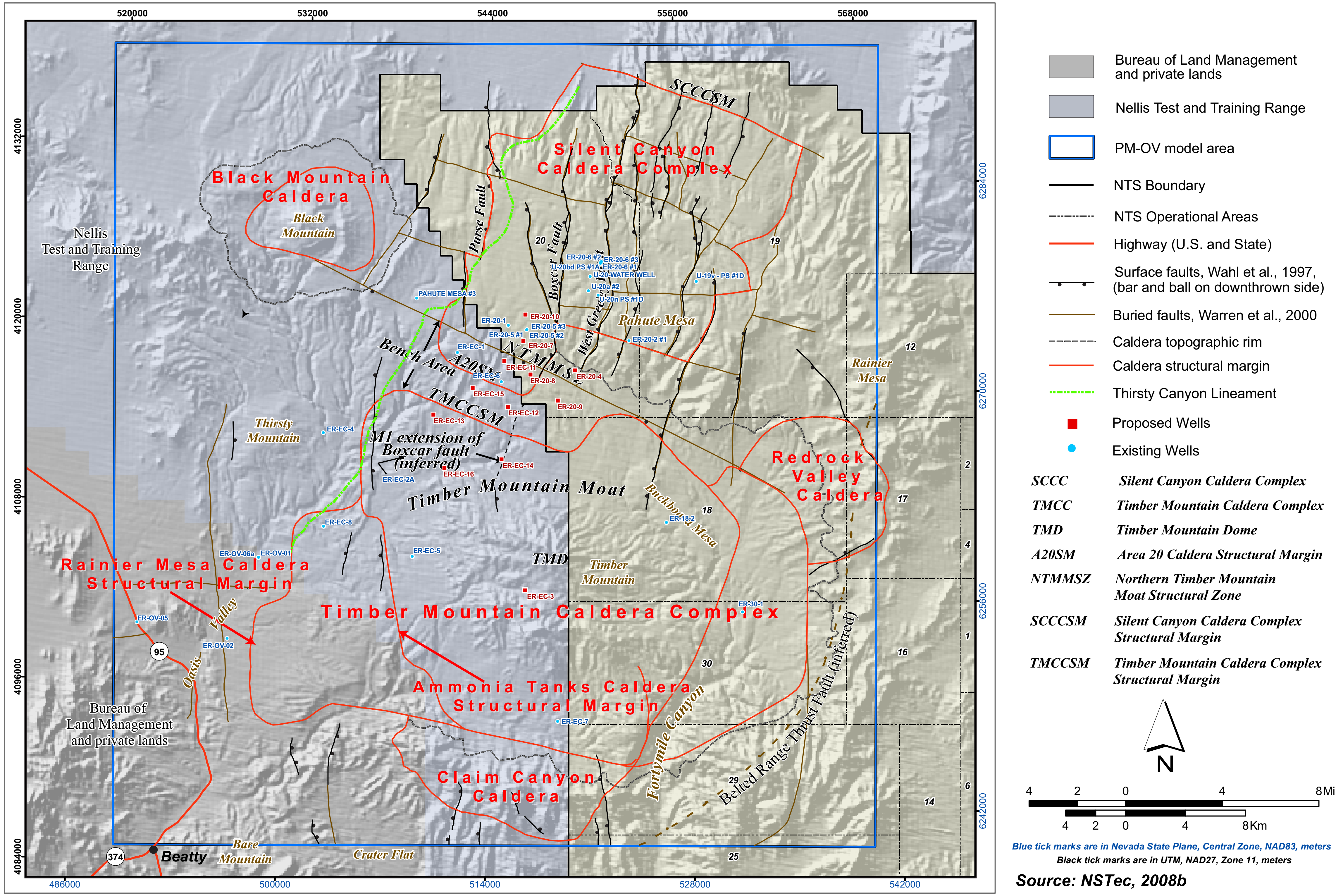

Figure 6-1
Locations of Proposed Hydrogeologic Investigation Wells

Table 6-2 presents information on the location specifications, data collection objectives, and proposed testing for each well. Included are cross-references for the proposed wells with the *ad hoc* Subcommittee prioritized data needs listed in Table C.1-1. Continuous evaluation of information gained from each well and the associated reduction in uncertainty will provide the basis for judging the sufficiency of new data for addressing the uncertainties. The types of well construction and testing planned for each well are also indicated. Well locations have been assigned UGTA Project well names for identification are cross-referenced to the *ad hoc* Subcommittee well names in Table 6-2. These UGTA specific well names are cross-referenced to the *ad hoc* Subcommittee recommendations for new well drilling listed in Table C.1-2, which defines investigation objectives for each well. Figure 6-1 shows the well locations and the physiographic, geologic, and structural features referred to in the descriptions.

A decision point is associated with the contingency well (ER-20-11). The highest priority objective for the first well, ER-20-7, is to locate RN transport downgradient from the ER-20-5 well cluster (at the TYBO test location), both to confirm the predicted flow path and to observe RN contaminant plume evolution. If RNs are not found at the ER-20-7 location, a contingency well is proposed to be drilled to the southeast of the ER-20-5 location to further pursue the objective. This contingency well would be drilled in the second drilling season as the new priority 4, and subsequent priority wells shifted downward.

6.1.1.3 Drilling Operations

Specific information on the drilling and completion of each hole will be described in a drilling criteria document. In general, boreholes will be drilled according to typical UGTA Project drilling practices using air-foam rotary techniques or alternative methods as specific drilling conditions and borehole/well completion requirements dictate. Drilling operations will be designed to prevent or minimize cross-connection of distinct aquifer units where multiple aquifer units are penetrated. This is particularly important for wells located where RN contaminants are anticipated or found. Boreholes designed for accessing multiple zones independently for development, sampling, testing, and monitoring may require more complex designs and potentially larger boreholes.

Table 6-2
Well-Specific Objectives and Drilling Information
(Page 1 of 3)

UGTA Well ID (*ad hoc* Subcommittee #)	Data Need [a]	Location Specifications	Data Collection Objectives	Testing
ER-20-7 (CAB #2) (1)	1E, 3C	Downgradient of the ER-20-5 well cluster based on Pahute Mesa flow model flow paths; north of the NTMMSZ.	Investigate RN migration downgradient from the ER-20-5 well cluster/TYBO test. Characterize NTMMSZ hydrologic properties and transition to Bench area in conjunction with ER-EC-11.	Single-well hydraulic testing (possibly limited by RN production), MWAT observation well, geochemical sampling, RN sampling.
ER-EC-11 (13)	1C, 1H	In the Bench area, south of the NTMMSZ and north of the A20SM, downgradient from ER-20-7.	Investigate RN migration downgradient from ER-20-7, across NTMMSZ into Bench area. Investigate predicted transport paths through Bench. Characterize NTMMSZ hydrologic properties in conjunction with ER-20-7.	Single-well hydraulic testing, MWAT observation well, geochemical sampling, potential RN sampling.
ER-20-8 (2)	1C, 1H	In the Bench area, on the west side of the M1 extension of the Boxcar fault (inferred), north of the A20SM.	Investigate predicted flow path through Bench area downgradient from ER-EC-11. Characterize M1 extension of Boxcar fault (inferred) hydrologic properties in conjunction with ER-20-9 and ER-EC-12.	Single-well hydraulic testing, potential MWAT production well or MWAT observation well, geochemical sampling.
ER-20-11A or ER-20-11B	1E, 3C	Downgradient of the ER-20-5 site - alternate flow path to the southeast; north of the NTMMSZ.	Investigate contaminant plume migration downgradient from ER-20-5 well cluster/TYBO test. Characterize NTMMSZ hydrologic properties in conjunction with ER-20-8.	Single-well hydraulic testing (possibly limited by RN production), MWAT observation well, geochemical sampling, RN sampling.
ER-EC-12 (4)	1C, 1H	In the Bench area, west of the M1 extension of the Boxcar fault (inferred), south of the A20SM and north of the TMCCSM.	Investigate predicted flow path through Bench area along the M1 extension of Boxcar fault (inferred) downgradient from ER-20-8. Characterize fault hydrologic properties in conjunction with ER-20-8.	Single-well hydraulic testing, potential MWAT production well or observation well, geochemical sampling.

Table 6-2
Well-Specific Objectives and Drilling Information
(Page 2 of 3)

UGTA Well ID (*ad hoc* Subcommittee #)	Data Need [a]	Location Specifications	Data Collection Objectives	Testing
ER-EC-13 (5)	1B, 1A, 1G	Northwest of TMD in the Timber Mountain moat, south of the TMCCSM, where the FCCM is thought to be thick.	Investigate hydrostratigraphy of FCCM and TMCM composite units, characterize TMCCSM in conjunction with ER-EC-15.	Single-well hydraulic testing, potential MWAT observation well, geochemical sampling.
ER-EC-14 (8)	1H, 1B, 1A, 1G	Northwest of TMD in the Timber Mountain moat, south of the TMCCSM, near the TMD margin on the west side of the M1 extension of the Boxcar fault (inferred).	Investigate flow path downgradient of Bench area around northwest side of TMD along the M1 extension of Boxcar fault (inferred) downgradient from ER-EC-12. Characterize fault hydrologic properties in conjunction with ER-EC-12.	Single-well hydraulic testing, potential MWAT observation well, geochemical sampling.
ER-EC-15 (12)	1C, 2A	In the Bench area north of the TMCCSM, south of the A20SM, in line with ER-EC-13 and ER-EC-11.	Investigate Bench area south of the A20SM, alternate western transport paths. Characterize TMCCSM in conjunction with ER-EC-13.	Single-well hydraulic testing, potential MWAT observation well, geochemical sampling.
ER-20-9 (3)	1C, 1H	South of the NTMMSZ and north of the TMCCSM, on the east side of the M1 extension of the Boxcar fault (inferred) across from ER-20-8.	Investigate flow paths off Pahute Mesa east of Boxcar fault. Characterize M1 extension of Boxcar fault (inferred) hydrologic properties in conjunction with ER-20-8.	Single-well hydraulic testing, potential MWAT observation well, geochemical sampling.
ER-EC-16 (6)	1B, 1A, 1G	West of TMD in the Timber Mountain moat, near the TMD margin on the west side of the M1 extension of the Boxcar fault (inferred).	Investigate flow paths along TMD margin downgradient from ER-EC-14. Characterize TMD margin hydrologic properties. Site for potential tracer test in the FCCM/TMCM.	Single-well hydraulic testing, potential MWAT observation well, geochemical sampling, potential tracer test well.
ER-20-10 (14)	3B	Nearby, downgradient from the BENHAM test; (near-field well).	Track RN migration from BENHAM test toward ER-20-5 well cluster. Evaluate RN transport evolution along the flow path.	Single-well hydraulic test (potentially limited by RN production), geochemical sampling, RN sampling.

Table 6-2
Well-Specific Objectives and Drilling Information
(Page 3 of 3)

UGTA Well ID (*ad hoc* Subcommittee #)	**Data Need** [a]	**Location Specifications**	**Data Collection Objectives**	**Testing**
ER-20-4 (19)	1H	North of NTMMSZ, west of the West Greeley fault; existing ER-20-4 undrilled well site.	Investigate flow paths from Central Pahute Mesa along West Greeley fault. Characterize the West Greeley fault and NTMMSZ hydrologic properties.	Single-well hydraulic testing, potential MWAT observation well, geochemical sampling.
ER-EC-3 (9)	1I	Central TMD	Determine the water table elevation and vertical gradient in the TMCM beneath TMD, characterize the fracturing/fault structure and hydraulic conductivity beneath the TMD.	Determine head change with depth, conduct single-well hydraulic testing, geochemical sampling.

[a] See Table C.1-1.

6.1.1.4 Typical Data Collection

During drilling and well completion, data will be collected similar to the typical UGTA Project data collection suite for past drilling programs. A typical program for well development and hydraulic testing will be conducted for each new well. During the constant-rate test for each well, other nearby wells will be instrumented to collect response data of opportunity across distances, which would provide basic information for use in design of MWATs and supplement the data from the multiple-well tests for comprehensive joint analysis of the hydraulic network response data. A groundwater geochemical characterization sample as specified in the UGTA Quality Assurance Project Plan (QAPP) (NNSA/NSO, 2003) will be collected after the well has been fully developed. Additional sampling and testing activities may be conducted for specific wells related to individual circumstances or other data collection needs, such as for geochemical flow path evaluation, and particularly for wells encountering RN contamination.

6.1.1.4.1 Drilling Records

During drilling, the following information will be recorded:

- Drilling narrative
- Drilling parameters
- Fluid management data
- Water production

6.1.1.4.2 Drill Cuttings Collection

Drill cuttings will be collected during the drilling. Composite drill cutting samples will be collected for geologic analysis at regular 3-m (10-ft) intervals during the drilling process starting at the base of the conductor casing and continuing to the total depth of the borehole. The collection and management of geologic cuttings and core for the UGTA Project will be conducted in accordance with the UGTA internal contractor procedures. Sample handling, packaging, storage, and chain-of-custody maintenance will be conducted in accordance with applicable internal contractor procedures. All internal contractor procedures will be compliant with the requirements of the UGTA QAPP (NNSA/NSO, 2003). The cuttings as well as core will be stored at the U.S. Geological Survey (USGS) Mercury Core Library. The term of storage is indefinite.

6.1.1.4.3 Drill Cuttings Sample Description

Drill cuttings descriptions will be recorded on a lithologic log in compliance with UGTA internal contractor procedures and requirements of the UGTA QAPP (NNSA/NSO, 2003). The lithologic log is the basis for identification of geologic formations penetrated by the borehole. Description methods may be modified for cuttings containing RNs. Descriptions of cuttings provide information such as lithology (e.g., color, grain size, and texture), percentages of minerals, and degradation or alteration of primary minerals. Cutting descriptions are interpreted to determine stratigraphic formations, tops of formations, unit thicknesses, lithologic composition, and the presence or absence of fractures. Samples of cuttings may be used for petrographic and chemical analysis or other properties relevant to data needs such as fractures, degree of alteration, matrix clay content, porosity, and permeability. In addition, samples of cuttings can be used for chemical analysis of bulk elemental and mineralogic constituents, and possibly RNs, if encountered.

6.1.1.4.4 Coring

Two types of coring are available: sidewall coring and continuous coring. Sidewall cores (rotary or percussion method) can be collected as part of geophysical logging and are included in the standard data collection suite. Sidewall core can be taken after drilling and the interval of interest is identified. However, sidewall cores are not suitable for all types of characterization use, and certain data collection objectives require continuous core. Continuous coring adds substantial time and cost to drilling operations and is considered a specialized data collection activity to be specified and authorized individually as appropriate data collection opportunities are identified.

In general, core is used for mineralogic studies, fracture studies, and bulk properties (e.g., density, porosity) and also can be used for contaminant studies where a contaminant plume is encountered. The two types of coring provide core samples with different qualities for data collection and analysis. Continuous core preserves large-scale features of the formation for evaluation and analysis, and is the only type of core suitable for some purposes. Formation intervals of interest for coring are typically identified based on their occurrence in proximal boreholes. However, continuous core cannot be collected after the fact in the exploratory borehole once the hole has been drilled by rotary methods. In investigation boreholes where there is no prior knowledge of location-specific formation depths or characteristics, continuous core intervals must be specified in advance, and cannot be narrowly targeted. There are two alternatives for obtaining continuous core after the interval of interest is identified: core drill the interval of interest via directional methods allowing for a side track of the original borehole, or drill a new hole from the surface to the target depth. For optimum fracture information, the core hole may be oriented based on information from the fracture characterization logs to cross high-angle fracturing at as low an angle as possible. This increases the sampling of fractures as well as improving sample recovery.

Collecting continuous core using the first approach may substantially interrupt normal drilling operations, and the second approach requires a separate drilling operation. Either approach will require specific NNSA/NSO authorization. Consequently, continuous coring is not included as a predetermined data collection activity but is proposed as an activity of opportunity, to be added to the data collection program when authorized.

6.1.1.4.5 Geophysical Logging

A comprehensive suite of geophysical logs will be conducted in the open borehole following drilling to total depth. Logs may be run at intermediate depths if upper intervals are to be cased off during drilling in order to collect full-depth geophysical log information for the hole. Geophysical logging may include fracture characterization logs (Data Need 1A in Table C.1-1) and other specialty logs to provide additional data-need-specific and well-specific objectives information.

The proposed standard geophysical logging suite provides basic definition of the geologic, hydrologic, and physical characteristics of rock units encountered within the boreholes. These logs provide discrete control for the HFM. In addition, the geophysical logs help determine and ensure appropriate completion of the borehole. In most cases, geophysical logs are collected within the uncased borehole before well completion. Geophysical logging will be conducted through the saturated and unsaturated intervals of each borehole from the well total depth to the bottom of the conductor casing. The recommended suite of saturated-zone geophysical logs/core includes the following:

- Caliper
- Spectral gamma ray
- Temperature/differential temperature
- Compensated density

- Neutron porosity
- Resistivity
- Sonic
- Borehole deviation (gyroscopic)
- Sidewall cores (percussion/rotary)
- Video log
- Acoustic televiewer
- Formation micro-imager (FMI)/electric micro-imager (EMI)
- Nuclear magnetic resonance
- Chemistry log (electrical conductivity [EC], pH, temperature, specific ion)
- Temperature log(s)
- Flow log(s)
  - Thermal flowmeter (low flow rate, ambient conditions)
- Magnetic susceptibility

Additional characterization data collected downhole during the testing program include:

- Chemistry log (EC, pH, temperature, specific ion)
- Temperature log(s)
- Flow log(s)
  - Thermal flowmeter (low flow rate, ambient conditions)
  - EM flowmeter (if available)
  - High-performance spinner flowmeter (high flow rate, stressed conditions)

6.1.1.5 Well Completion

After circulating to reduce the residual effects of drilling, geophysical logging will be conducted and completion intervals in the borehole identified. Well completion includes installing and cementing casings, placing screened intervals, stemming gravel and sand, and installing other well hardware. Well completion strategies will vary from well to well, depending upon the specific objectives and hydraulic testing plan for each well. The UGTA Project typical well completion (Figure 6-2) will be the default design, which will be adapted based on additional requirements, borehole conditions, and specific well completion objectives.

Well drilling and completion will be designed to prevent or minimize cross-connection of distinct aquifer units where possible when aquifer units are penetrated. This is particularly important for wells located where RNs are anticipated or found. Wells designed for accessing multiple units independently for development, sampling, testing, and monitoring will require more complex design and potentially larger boreholes/completions. Wells intended for use as production wells for MWATs

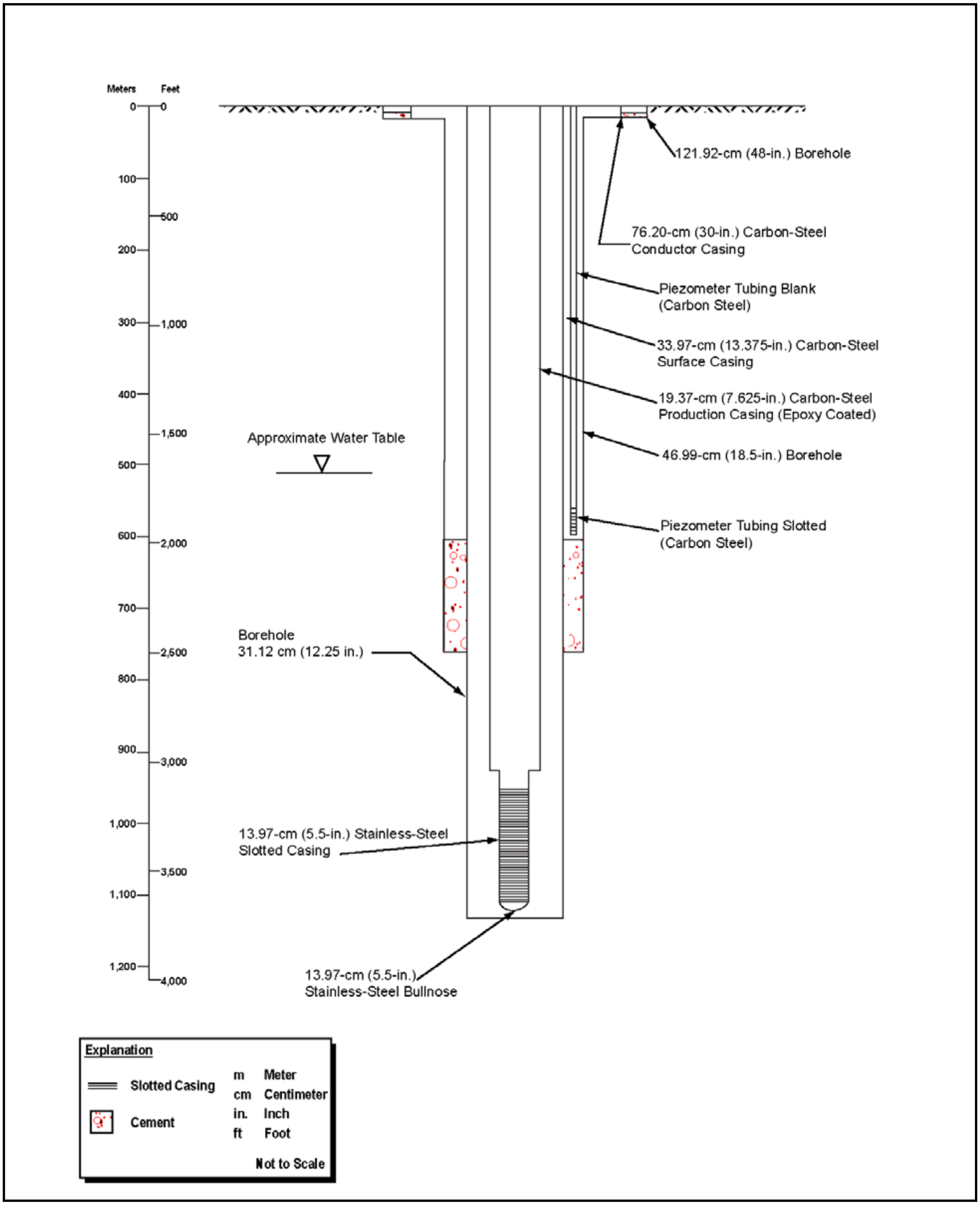

Figure 6-2
UGTA Typical Well Design

may also require a larger diameter borehole to accommodate a pump capable of production rates necessary to meet testing objectives.

6.1.1.5.1 Well Development

Well development is required to remove residual drilling-induced fluids, return formation water to natural ambient water quality, and develop an efficient hydraulic connection to the formation. Data collection includes performance testing using step-rate tests. This information provides a measure of the effectiveness and completeness of hydraulic well development, and the information is also used for analysis of well losses for hydraulic tests. Flow and temperature logs collected during the stress periods (at multiple production rates) will be collected for evaluation.

Development is conducted in two steps: open-borehole development and completion-zone development. The first step is conducted in the open borehole before well completion, provided the borehole is stable, after the total depth is reached and drilling is completed. The second step is conducted in the completion zone or zones after well construction is complete. The rate of water production during development is monitored to collect information on the production capacity of the formation. Produced water is monitored both visually and with water quality monitoring instrumentation to observe changes occurring during development and to evaluate whether natural water quality has been restored. Drilling fluids used during drilling typically have an NDEP-approved tracer added for which residual concentration can be readily monitored during development to determine when drilling-induced fluids and chemical changes have been removed. In wells where contaminants have been encountered, development must remove residual contaminants from the non-contaminated aquifer unit(s) that may have been introduced during drilling. Produced fluids are monitored for fluid management purposes, as required in the *Attachment I Fluid Management Plan* (FMP) *for the Underground Test Area Project* (NNSA/NSO, 2009). Samples taken for fluid management purposes along with samples collected for laboratory analysis will be handled in accordance with applicable internal contractor procedures that are compliant with the UGTA QAPP (NNSA/NSO, 2003), and chain of custody will be maintained.

6.1.1.5.2 Static Flow, Temperature, and Geochemical Logging

After the well has been developed and has reached equilibrium with the natural groundwater system, logs are run to collect equilibrium vertical flow information, temperature profile, and geochemical parameters profiles. These logs may be run after recovery from hydraulic testing to ensure they reflect the most complete development.

6.1.1.5.3 Stressed Flow and Temperature Logging

Stressed flow and temperature logs are run after development of the well as part of the hydraulic testing program. These may be combined with the step-rate test at the end of development or run during the single-well test.

6.1.1.6 Well-Specific Objectives and Drilling Information

Table 6-2 provides well-specific information about data collection objectives for the proposed drilling location, cross-referencing the data need identified by the *ad hoc* Subcommittee (Table C.1-1). Table 6-1 contains the location and specific drilling target information. This information is presented at an overview level in this document. The drilling criteria for the Pahute Mesa Phase II CAI wells will provide greater detail and specifics about operational plans. The target HSUs and anticipated drilling depths are based on the Phase I HFM and flow model. Drilling may encounter different conditions than predicted by the HFM, and adjustment to total drilling depth may be required. Data collection and well completion also may be adjusted to adapt to revised objectives dependent upon conditions encountered.

6.1.2 Hydrologic Data Collection

A variety of characterization activities may be conducted in conjunction with the new wells. The data collection program for each well will be designed to characterize the geology and hydrogeology at each location, and address other well-specific objectives. Additional data collection objectives include characterization of the large-scale hydrogeology throughout the area where the new wells will be drilled, which will drive additional data collection during testing activities.

6.1.2.1 Water-Level Monitoring

Water-level monitoring will be conducted within the CAU in addition to individual well testing, including both new wells and existing wells. Existing well locations will be selected for monitoring based on location relative to new wells for monitoring during drilling and single-well testing to capture incidental information for characterizing hydraulic connectivity to potentially aid in the design of MWATs. Continuous-recording instrumentation will be installed to record background head variations and long-term water-level trends, responses to barometric and earth-tide stresses, and hydraulic responses to pumping of other wells. Following the drilling and testing program, additional long-term water-level monitoring may be conducted to support background hydrology characterization.

6.1.2.2 Single-Well Aquifer Tests

Single-well aquifer tests are conducted at each well after well development. These tests establish the basic hydraulic connectivity of the well to the formation(s) and evaluate in-well hydraulics, and test results are used to determine hydraulic parameters for the local formation. Nearby wells will be monitored during the single-well tests to provide larger-scale connectivity information, which will be used in the design of MWATs (see Section 6.1.2.3).

6.1.2.2.1 Groundwater Sample Collection

The single-well test pumping period also provides extended development and thorough purging before collecting the groundwater geochemical characterization sample from each well.
The geochemical characterization sample analysis, as specified in the UGTA QAPP (NNSA/NSO, 2003), includes:

- Major anions and cations
- Trace elements
- ^{13}C for inorganic carbon and ^{14}C activity for organic and inorganic carbon
- Radioisotopes, including ^{36}Cl and ^{3}H (see Section 5.2.11)
- Strontium and uranium isotopic ratios
- Dissolved noble gases, including helium-3 (^{3}He)
- Stable isotopes of hydrogen and oxygen
- Colloids

In addition, where RNs are encountered, samples will be taken for additional analytes, including fission and activation products (^{99}Tc, ^{129}I, ^{137}Cs, ^{152}Eu) and actinides (particularly Pu). During drilling or testing, when RNs have been identified in groundwater, time-series sampling may be conducted, and samples analyzed for limited parameters to provide information on the variation of RN concentrations with respect to the borehole locations.

6.1.2.3 Multiple-Well Aquifer Test

Multiple-well aquifer tests may be conducted to evaluate the large-scale hydraulic properties of formations and to evaluate the hydraulic properties of the structural boundaries/fault system (Topics 1B, 1C, 1G, 1H, and 1J in Table C.1-1). Such tests would involve monitoring of hydraulic responses in a network of wells to pumping in a central production well. The test design may include multi-HSU objectives requiring the isolation of one or more specific intervals within a borehole for independent response monitoring. Wells used for such tests may require specific design features to support this data collection. Production wells for MWATs may need to be larger in diameter to accommodate higher-rate pumps than has been standard UGTA Project practice for single-well tests. Evaluation of potential test scenarios by the *ad hoc* Subcommittee determined that production rates of 500 gallons per minute (gpm) or greater, and test durations of up to 90 days may be required to achieve objectives for large-scale hydraulic characterization.

Selection of a production well(s) and observation wells for an MWAT would optimally be determined after drilling, completing, and testing all new wells so that the test design can be optimized to suit the conditions encountered. The observation well network would be specified to consider responses propagated both along geologic structure(s) and across HSU units to provide comprehensive data within the context of the large-scale hydrogeologic structure. However, decisions about completing wells as potential production wells or observation wells must be made immediately after drilling because well completions for the different purposes will require different configurations. In addition, suitability for completion as a production well requires connectivity to high-permeability formation(s) and/or structure, and suitable borehole conditions for high productivity. Based on the specific objectives for MWATs listed in the next section, the focus area for MWATs and possible alternate locations for the production wells can be identified in advance, and decisions for completions as production wells and observation wells made depending upon conditions encountered during drilling. Existing wells in areas adjacent to the new investigation wells may also be included in the observation well network to cover those areas.

6.1.2.3.1 Objectives

Multiple-well aquifer tests may be used to evaluate:

- Connectivity across and along the NTMMSZ separating Pahute Mesa from the Bench area
- Connectivity across aquifer HSUs in the Bench area and along/across the A20SM
- Connectivity along and across the M1 extension of the Boxcar fault (inferred) from the Bench area to the TMD margin
- Connectivity across the geologic transition (TMCCSM) from the Bench area to the Timber Mountain moat
- Variability of hydraulic conductivity of subunits within the thick composite FCCM and TMCM units northwest of Timber Mountain
- Connectivity of high-permeability subunits across the FCCM and TMCM composite units

6.1.2.3.2 Test Design

Several MWATs may be required to pursue all of these objectives. In addition, completion of all the objectives will depend upon the availability of wells in suitable locations to support testing for each objective. This primarily depends upon new wells completed for Phase II. Existing wells would be incorporated in testing, but new wells are required to specifically address the objectives. In order of well priority, an MWAT in the Bench area would be supported by new wells and several existing wells. A second MWAT in the TMCC moat area also may be supported. Depending upon the results of these two MWATs, the need for additional testing would be assessed. Wells would be instrumented on a priority basis, limited by available equipment. Well instrumentation priorities will be determined based on data objectives refined after analysis of the single-well hydraulic testing results.

6.1.2.4 Single-Well Tracer Test

Single-well tracer tests could be conducted to provide information on fracture-matrix mass transfer (Table C.1-1). Specific wells (Table 6-2) have not been identified for such testing.

Single-well tracer tests have both active and passive elements: injection of a tracer, a passive drift period, and then pumpback of the tracer. The drift period provides information to determine natural groundwater flow rates. A refinement would add an initial injection and pumpback without a drift period to provide information on the effects of the injection/pumpback operations, which are difficult to control downhole. Wells installed for tracer tests may require more extensive characterization of the fracture system than the standard data collection to better support analysis of tests. This could include fracture logs and downhole logging associated with tracer injection. The tracer tests may target multiple intervals within the formation at the site, and the design of tracer test wells may require specific features to support the tracer testing, such as separable injection/production intervals. The wells used for tracer tests may be non-standard size to accommodate special equipment. Single-well tracer tests may be an element of a joint program with a forced-gradient tracer test and provide initial information for use to design a forced-gradient tracer test. Information from both types of tests on one site would improve the analysis for that site as well as provide a basis for comparing information from the two types of tests for other locations where only single-well tracer tests were conducted. Analysis of tracer test results requires determination of formation properties around the well within the extent of tracer movement during the test and may require additional hydrologic characterization.

6.1.2.4.1 Objectives

Specific objectives for single-well tracer tests are to obtain data to determine matrix diffusion MTCs for fracture-matrix interactions, for both WTA rocks in the Bench area and the volcanic TMCM rocks northwest of Timber Mountain. Single-well tracer tests are simpler and less expensive than forced-gradient tracer tests, and may be conducted in more wells.

6.1.2.5 Cross-Hole Tracer Test

A cross-hole forced-gradient tracer test could be conducted to provide information on fracture matrix mass transfer (Table C.1-1). The proposed wells (Table 6-1) do not include a paired well set for such a test. If a forced-gradient tracer test becomes a priority, a second well would be drilled nearby a previously drilled well. The ER-EC-16 location (Table 6-2) was identified by the *ad hoc* Subcommittee as the highest priority location for a forced-gradient experiment (FGE) (Table C.1-2).

A forced-gradient tracer test uses a pair of wells, one of which is pumped while tracer is injected into the other well. The forced flow field moves tracer from the injection well to the production well independent of the natural gradient. However, the flow path is dependent upon the formation properties between the wells, which must be determined for analysis of the test results. Connectivity between the two wells can be evaluated with hydraulic testing, and the flow path involved in tracer transport is defined somewhat better than for a single-well tracer test. Wells installed for tracer tests require thorough characterization of the fracture system to support analyses of the tests. Tracer tests may be conducted on multiple intervals of the formation(s), and the design of the tracer test wells may require special construction features to support the tracer testing such as separable injection and production intervals, affecting the well size and configuration. Forced-gradient tracer tests may be an element of a joint program with a single-well tracer test conducted in one or both of the wells used for the forced-gradient test. Information from both types of tests on one site would improve the analysis for that site as well as provide a basis for comparing information from the two types of tests for other locations where only single-well tracer tests were done.

6.1.2.5.1 Objectives

Specific objectives for forced-gradient tracer tests are to obtain data to determine matrix-diffusion mass-transfer coefficients for fracture-matrix interactions, for both WTA rocks in the Bench area and the volcanic TMCM rocks northwest of TMD.

6.1.2.6 Coring and Fracture Analysis in Radionuclide Plume or Tracer Test Formation

Cores from rock through which a groundwater tracer has moved could be analyzed to provide data on flow of groundwater through individual fractures, which could be used to determine fracture properties appropriate to RN transport. Such core could also be analyzed to evaluate matrix diffusion *in situ*. This method would be applicable to rock through which an RN plume is moving, or to the tested formation after a tracer test. This activity could be added to the characterization program if an RN plume were located, or to a tracer test (Table 6-2). In the case where an RN plume has been identified, a new borehole nearby or a sidetrack of the exploration borehole could be continuously cored through the contaminated interval, and the core analyzed for the location of RNs in the fractures and diffusion of the tracer into the matrix from the fractures. The continuous core would provide information on the specific fractures that conducted flow containing tracer, assumed to be the same as the natural hydraulically active fractures. Fracture spacing relevant to transport could thereby be determined for that location. In the case of a tracer test, core would be collected from the test interval. Alternately, a simpler approach yielding reduced information would use sidewall coring or over-coring to collect samples from the interval of interest. A variant for observing matrix diffusion *in situ* would be to place tracer in a borehole where the borehole sidewall can be accessed (specific well construction features would be required). After some time, the formation in the test interval would be sampled, and the core samples analyzed to determine diffusion into the matrix.

Specific well(s) have not been identified for application of these types of data collection activities because they would be additions to new drilling dependent on several factors, such as location of an RN plume or conduct of a tracer test, priorities for well(s) and testing, and suitable formation conditions.

6.1.2.7 Fluid Electrical Conductivity Logging

Flowing fluid electrical conductivity (FEC) logging (also known as hydrophysical logging) could be used to locate the major flowing intervals in wells, estimate the relative transmissivity of the flowing intervals, and estimate specific discharge. Hydraulic conductivity of the flowing intervals can be estimated in conjunction with the results of the single-well aquifer test. To conduct such tests, deionized (DI) water is pumped into the borehole in a circulation loop to replace the formation water. The replacement process is monitored by logging with an EC probe. When completed, DI water injection is halted, and the evolution of the EC profile along the wellbore is monitored by logging with the EC probe as natural cross-flow from the formation through the borehole displaces the DI water. This is done under both ambient and pumped conditions, providing additional information. Pumping rates are typically low. Data are interpreted under several assumptions, resulting in a non-unique analysis with uncertainty.

A specific well(s) has not been identified for FEC logging. This activity may be determined to be a priority for a specific well(s) based on results hydraulic testing.

6.1.2.8 Temperature Profiling

Temperature profile data are useful for evaluating transient groundwater flow changes and natural groundwater flow patterns. For example, where substantial temperature profile changes occur during pumping, such data could provide information to improve the conceptual model used for aquifer test analyses and decrease uncertainty in the resultant estimation of hydraulic conductivity. It takes several hours to log an entire borehole using a temperature tool trolled along the borehole to obtain depth-discrete measures of temperature; thus, rapid depth-discrete changes during starting and stopping of pumping are not captured. Distributed temperature sensors (DTSs) could be used in applications where rapid and frequent collection of the temperature profile is required to capture a rapidly evolving temperature profile. The DTS technology can capture temperature profiles at 1-m resolution, updated as rapidly as every 60 seconds, up to 2 km deep, with temperature resolution of 0.02 degrees Celsius (°C). Temperature profiling using DTS technology may be determined to be appropriate for hydraulic testing applications.

6.2 Additional Studies

Additional studies including both field data collection and data analysis are identified to address uncertainties identified by the *ad hoc* Subcommittee, listed in Table C.1-1, and other reviews discussed in Section 5.0. These studies interact with the well drilling and field program, and may also include additional field data collection. These studies address the variety of uncertainties discussed in Section 5.0, and will be prioritized according to the needs for Phase II modeling.

6.2.1 Geologic and Geophysical Studies

Proposals for data analysis activities to address specific geologic and hydrostratigraphic concerns to reduce uncertainty for the HFM used for flow and transport modeling are:

- Develop alternative conceptual models of the Bench area, along predicted flow paths.
  - The Bench area has complex geology and stratigraphy, and the geologic structures that control many of the defined geologic contacts are not fully constrained. Modeled flow paths converge in the Bench area. The variability in the flow paths and transport predictions may be strongly controlled by spatial variability in volcanic units and structural features that disrupt these rocks. The effects of these uncertainties need to be investigated

through development of alternative geologic models of the Bench area and evaluation of their effects on transport predictions.

- Develop conceptual models of heterogeneity in the volcanic aquifer (VA) and volcaniclastic confining unit (VCU) HSUs in Western Pahute Mesa.

  - The Phase I flow and transport models apply uniform properties to VA and VCU HSUs in Western Pahute Mesa, although it is known that properties vary spatially. Uncertainty regarding flow and transport related to the variability would be investigated using heterogeneity models for the properties.

- Expand the enhancement of the TMCM in the HFM to include the eastern portion of Timber Mountain.

  - The TMCM is a thick composite HSU that includes intervals of permeable fractured welded tuffs and lava flows within generally low-permeability tuffs. Further evaluation of geologic data has supported development of a sub-HSU model of the TMCM for the western Timber Mountain area that differentiates these different rock units. Additional work would extend the differentiation through the remainder of the TMCM extent, and the sub-HSU model would then be loaded into the EarthVision HFM.

- Evaluate the connectivity of permeable intervals within the CHZCM to the groundwater flow system.

  - Many cavities are located in the CHZCM that, per CHESHIRE investigations, have embedded permeable intervals (LFAs) providing potential for transfer of RNs from the cavity to the groundwater flow system. This work could lead to more confident subdivision of LFA and TCU intervals in the CHZCM. Such subdivision is incorporated in the Phase I reactive mineral model, but lateral extents are uncertain.

- Investigate the physical nature of the structural boundaries/faults along the southern edge of Pahute Mesa and bounding the Bench area that potentially affect flow off Pahute Mesa and toward Timber Mountain.

  - The structural boundaries/faults in the HFM defining the caldera margins and intervening Bench area represent geologic discontinuities in the HFM, and also may have distinct hydraulic properties. Properties for structural boundaries/faults in the Phase I flow model are adjusted as a calibration factor. Information directly evaluating hydraulic properties would increase confidence in the hydraulic effects of the these features.

- Investigate the extent of hydrothermal alteration in the Bench area and downgradient (Transvaal Hills) that may affect the hydrology and, consequently, groundwater flow paths.

- Areas of HSUs affected by hydrothermal alteration may have hydraulic properties differing from general data for the HSUs. Information on the effect of hydrothermal alteration on hydraulic properties and on the extent of the alteration would improve the model.

6.2.1.1 Field Activities

Data collected from the drilling activities discussed in Section 6.1.1 would provide certain field data for supporting these analyses. In conjunction with the hydrologic investigation program, the field locations of major faults (structural boundaries) in the HFM — particularly the NTMMSZ (i.e., Moat fault), the M1 extension of the Boxcar fault (inferred), the SCCCSM (structural boundary for the SCCC within the Bench), and the TMCCSM (structural boundary for the Area 20 caldera and Rainier Mesa caldera) along the south of the Bench — would be evaluated for location, orientation, and physical features.

6.2.1.2 Data Analyses

Following subject-specific data analyses, the results of individual studies and analyses will be integrated into the HFM (and alternatives). The HFM model document will be updated with a revised geologic conceptual model and supporting descriptions of new information on geology and structure; in particular, composite unit subdivisions, faults, structural margins, and hydrothermal alteration.

6.2.2 Hydrology Studies

Specific data analysis topics concerning hydrology to reduce uncertainty for the flow model used for transport modeling are:

- Additional studies to refine the recharge models.
    - Currently, three different types of recharge models with two subsets are used to estimate recharge for the flow model, producing estimates with a range of a factor of over two.
- Development of alternate conceptual models based on systematic review of the hydraulic test data.
- Re-evaluation of existing test data for the ER-EC wells for additional information on formation hydraulic properties, refinement of hydraulic property values, and in conjunction with analysis of new test data.

- Further development of methodologies for the evaluation of the effect of the faults on groundwater flow.
- Further development of the temperature model of the Pahute Mesa model area and use in evaluation regarding recharge and groundwater flow.
- Further characterization of the head configuration within the study area.

6.2.2.1 Field Activities

Data collected from the drilling and testing activities discussed in Section 6.1.1 would provide new field data for these analyses for each new well. Additional temperature data may be obtained from existing wells and boreholes to support improvement of the temperature model. Long-term water-level monitoring of new and existing wells may be conducted to characterize seasonal head variation and long-term trends of head.

6.2.2.2 Data Analyses

Following the integration of individual studies and analyses, the flow model will be updated to incorporate the new hydrologic information. In addition, the flow model documentation will be supplemented with descriptions of new information on hydrology as well as incorporation into the flow model.

6.2.3 Isotope- and Geochemistry-Based Studies

Specific data analysis activities concerning isotope- and geochemistry-based data to reduce uncertainty for the conceptual flow used for transport modeling are:

- Refine the geochemical mixing models for the geochemistry-based flow path analysis using new geochemical information from the Phase II wells.
- Integrate the revised geochemical mixing models with the conceptual HFM (and alternatives), conceptual flow model, and recharge models.
- Review revised ^{14}C dataset for use in evaluating groundwater travel times through the Pahute Mesa flow system.

6.2.3.1 Field and Laboratory Activities

Field activities include incorporation of all requisite parameters for the geochemistry-based flow path analysis in the geochemical sampling and analysis for new wells. The sampling objective would be HSU-specific; isolation of individual aquifer HSUs and individual development of separate completions is necessary to provide optimal samples. In addition, new sampling and analyses of groundwater from existing wells for which current and complete geochemical data are not available, including ^{14}C data upgradient of the drilling focus area, would fill data gaps in the available geochemical information and support improvement of the isotope- and geochemistry-based flow path analyses. Sampling efforts may include field support for purging wells and obtaining quality samples.

6.2.3.2 Data Analyses

Analysis activities include compilation of new geochemistry data, review of the Pahute Mesa geochemistry dataset, and reinterpretation of the pattern of geochemical evolution of groundwater flow through the system. Within the more focused area of the new proposed investigations, the greater density of data would provide better resolution for geochemistry-based analyses. The geochemical flow path analysis document would be updated with the new information and interpretations, and these interpretations would be used to refine the flow model.

6.2.4 Transport Parameter Studies

Reduction of uncertainty for transport parameters used for transport modeling includes the parameters affecting fracture-matrix interaction such as fracture spacing (possibly determined from other parameters) and diffusion coefficients. Other information that may be used to determine the transport parameter values includes information on mineralogy and fracture coatings, measures of effective porosity for transport, fracture aperture, hydraulically active fracture spacing, and other related information.

Specific concerns for data analyses to reduce uncertainty in transport parameters used for transport modeling are:

- Refine the conceptual model and appropriate parameter distributions for fracture aperture, fracture spacing, and matrix diffusion coefficients.
- Develop alternate conceptual models for spatial distribution of parameter variability.
- Develop an approach for determining appropriate values for effective porosity for fractured HSUs, particularly for the FCCM and TMCM, taking into account the variability of orientation and spacing.
- Evaluate the anisotropy of effective porosity and potential effect on anisotropy of the MTC.

6.2.4.1 Field and Laboratory Activities

Field data supporting these analyses would be collected from the hydrologic investigation program (Section 6.1.1). Flow logging under stress, discussed in Section 6.1.1.5.3, provides data for determining the hydraulically active fracture spacing. Tracer test data collection, discussed separately in Sections 6.1.2.4 and 6.1.2.5, would provide information on matrix diffusion.

As mentioned in Section 6.1.1.4.4, core may be collected from wells/drilling locations opportunistically, depending upon encountering RNs during drilling. Continuous core taken from contaminated intervals in wells in which RNs have been identified may be analyzed to identify the fractures in which the RNs were migrating, the depth of diffusion of the RNs from each fracture into the matrix, and the concentration gradient. Based on estimates of the time and concentration history of the RNs in the fractures, diffusion coefficients from the fracture into the matrix can be estimated as well as the appropriate fracture spacing for use in transport modeling. This methodology could also be applied to core from the BULLION tracer test site because diffusion of the residual tracer from the tracer test into fractures would provide similar information for the LFA test interval. Sidewall core taken from tracer injection wells used for tracer tests some time after the tracer test could be analyzed for diffusion of the tracer into the matrix to determine diffusion coefficients.

6.2.4.2 Data Analyses

The various types of data collected can be used to determine various parameters related to fracture-matrix interactions. Where more than one kind of data are collected, the analyses can be coordinated to reduce uncertainty. Variability and representativeness of the parameters can be assessed as more data are available for analysis. The analyses will be designed to fulfill the transport parameter evaluation objectives.

6.2.5 Source-Term Studies

Specific topics for additional data analyses regarding RST and HST uncertainties are:

- Develop a more realistic assessment of how the RST translates to the HST.
  - Use available data to develop a comprehensive conceptual model, including uncertainty, of how the RST interacts with the environment for all the different test settings on Pahute Mesa, and in the near and far field. Investigate processes that remove RNs from the RST, in particular, gas phase transport, and develop an understanding of the impact of the identified uncertainties.
- Evaluate the variability of source release from cavities and transfer to the groundwater flow system as a function of the working point in various rock types (HGUs - WTA, VTA, VCU).
- Assess the variability of source-term distribution and geochemical processes in the exchange volume to refine and bound the abstraction to the SSM.
- Identify all important processes and the important RN/mineral interactions, and evaluate whether they are appropriately represented in the SSM.
- Improve the simplified source-term upscaling.
- Assess colloid-facilitated transport.
  - Within the uncertainty bounds on parameters governing colloid facilitated Pu transport, Pu mobility simulated in the Phase I transport model could contribute to the definition of the contaminant boundary. Develop better understanding of processes and constraints for model parameters associated with colloid facilitated transport in NTS groundwater. Specific areas for reducing uncertainty include: (1) assessment of the actual Pu-colloid source. Currently, it is not known or understood how much of the radiologic inventory is available to migrate on colloids; either formed in the cavity or as a sorptive process of Pu onto natural colloidal minerals. (2) Assessment of colloid mobility in natural groundwater; specifically in fractures. Natural colloids are measured in NTS groundwater, but the

distances they can travel are not well understood. Conduct field and laboratory investigations to reduce uncertainty on the mobility parameters for colloids.

6.2.5.1 Field and Laboratory Activities

Well ER-20-10 in Table 6-1 is specifically located to assess the HST of the BENHAM test by sampling the RNs in the groundwater system just outside of the test-affected zone. Sampling the RNs near the BENHAM cavity would provide data useful for assessing transfer of RNs to the groundwater flow system and RN transport processes between BENHAM and the ER-20-5 well cluster.

6.2.5.2 Source-Term Data Analyses

6.2.5.2.1 Evaluate SSM Predictions for Source Term Versus Existing Hot Well Data

The Phase I Pahute Mesa transport model indicates that ^{14}C (MCL = 2,000 picocuries per liter [pCi/L]) will be an important RN for predicting the contaminant boundary. However, recent hot well ^{14}C analyses have not identified any locations with ^{14}C concentrations above 2,000 pCi/L. The UGTA Project geochemistry database contains only 3 of 280 entries for ^{14}C with activities above 2,000 pCi/L. The data appear to suggest that the importance of ^{14}C to contaminant boundary calculations may be overstated by models. Similar observations have been made for the other non-sorbing RNs (^{36}Cl, ^{99}Tc, ^{129}I) reported as relevant to the prediction of the contaminant boundary. The apparent inconsistency between the SSM-determined source term and existing hot well data will be investigated, requiring review of the near-field process model and derived SSM model, evaluation of available hot well data, unclassified and classified source term information, and RN partitioning models.

6.2.5.2.2 Evaluate Generation and Stability of Actinide Colloids

The current transport models lack the ability to accurately predict the colloidal transport of actinides, such as Pu, because actinide loading onto colloids and the mechanisms of attachment/detachment are not well understood. Further, the source of the actinide colloids is not known (generation from test debris, glass dissolution, or sorption to natural colloids). Determining where and how actinides are bound to colloids would help eliminate key uncertainties in the UGTA Project transport models. Additional work is necessary to incorporate a defensible colloid model into Phase II transport modeling calculations. The proposed work includes laboratory experiments focusing on reduction of the uncertainty in colloidal actinide source-term flux. If source-term fluxes are found to be substantially below the MCL for alpha emitters (15 pCi/L), colloid-facilitated transport would not contribute to the predicted contaminant boundary.

6.2.6 Other Data Analysis Recommendations

Additional topics for data analyses will be determined based on data collected and considerations related to development and evaluation of the Phase II flow, transport, and supporting models. Databases will be maintained and updated to support Phase II analyses and modeling.

6.3 Field Support

Field support includes those activities associated with the acquisition of scientific data and information, including waste management, health and safety, and sampling and analysis. These support activities, along with the current versions of the documents that describe the corresponding policies and practices to be followed, are discussed in the following subsections. The CAI activities will be conducted under the policies and practices that are in effect at that time, as specified in the appropriate governing documents. The following general descriptions of field support activities are provided for the CAI work that is described in Section 6.0.

6.3.1 Waste Management

Waste management is one element of a comprehensive onsite environmental compliance program to be implemented at Pahute Mesa Phase II investigation sites. The development of this program is tailored to anticipated site conditions; however, it includes contingencies in case field operating conditions change. Periodic field evaluations are conducted to ensure proper implementation of this program and onsite compliance. The program also includes waste minimization (Section 6.3.1.2) and fluid management (Section 6.3.3.2). The details of the comprehensive compliance program may be found in the *Underground Test Area Project Waste Management Plan* (WMP) (NNSA/NSO, 2009) and site-specific planning and field documents. The UGTA Project FMP is included as Attachment 1 to the WMP (NNSA/NSO, 2009). Waste management covers the segregation, tracking, characterization, and disposal of wastes generated during field activities. Pahute Mesa Phase II CAI activities that are expected to generate waste include drill site construction, well drilling, well completion, well development, testing, and sampling operations (herein termed “well installation activities"). Other investigation activities also may include periodic groundwater sampling of newly installed wells and existing wells. Also, waste in the form of personal protective equipment (PPE), sampling equipment, and drilling materials is generated as a result of this investigation. The largest volume of waste generated during drilling and sampling activities is effluent (fluids) and groundwater. The management of fluids and groundwater produced at the Pahute Mesa Phase II wells is addressed in the UGTA Project FMP (NNSA/NSO, 2009), discussed later in this section. Other wastes — such as sanitary, hydrocarbon, and hazardous waste — are generated as a result of the operation and maintenance of heavy equipment as well as other support functions as part of the specific type of activity.

6.3.1.1 Investigation-Derived Waste Management

Management of investigation-derived waste (IDW) is described in the UGTA Project WMP (NNSA/NSO, 2009), which provides a general framework for waste management at Pahute Mesa Phase II investigation sites. Details regarding the characterization, storage, treatment, and disposal of wastes generated at Phase II investigation sites are to be addressed in site-specific field instructions or similar working-level documents. All wastes generated as a result of the Phase II investigation activities are to be managed and disposed of in compliance with applicable federal, state, and local laws and regulations. Based on an evaluation of available data and technical input from scientists supporting the UGTA Project program, the wells that are currently proposed for drilling and completion are considered to be far-field wells except for ER-20-10. Wells ER-20-7, the contingency well (ER-20-11) to locate RN transport downgradient from the ER-20-5 well cluster, and possibly ER-EC-11 are considered to be potential near-field wells. The potential for generating radioactive waste is considered remote for the other wells. Any well that is found to be RN-contaminated in excess of the UGTA FMP criteria will be recategorized to near-field status. In particular, the presence of ^{3}H in excess of the fluid management criteria listed in the UGTA Project FMP (NNSA/NSO, 2009) will require the well to be recategorized as a near-field well. The designation of near- and far-field is important because the waste management strategies for the near- and far-fields wells differ. Near-field activities require establishment of a controlled area where radioactive contamination would be closely monitored and managed; far-field activities do not require such monitoring. Process knowledge regarding the presence of hazardous materials or radioactive contaminants as well as data from sampling and analysis, combined with available onsite monitoring results, are used to define the waste management strategy for each well location. The potential for generating hazardous, radioactive, and mixed waste streams are assessed separately for each well location. Prevention of hazardous waste generation is emphasized during the operations conducted under this Phase II CAIP. When required, personnel are trained and procedures implemented to address management of radioactive and hazardous waste streams.

Waste characterization is based on the results of process knowledge, fluid management monitoring and sampling, and groundwater characterization sampling. This information is used to assign the appropriate waste type (i.e., sanitary, hydrocarbon, hazardous, radioactive, or mixed) to the IDW. Direct sampling of waste may be necessary if process knowledge is inadequate for characterization.

6.3.1.2 Waste Minimization

The generation of IDW is minimized through the implementation of a comprehensive compliance program. Waste minimization is achieved through the control of hazardous materials, materials substitution, and waste segregation. Hazardous materials are controlled, managed, and tracked in accordance with Occupational Safety and Health Administration (OSHA) requirements and applicable procedures and protocols. Material substitution is implemented wherever possible to prevent or minimize the generation of a hazardous waste. Waste such as effluent and PPE are segregated to the greatest extent possible to minimize the generation of hazardous, radioactive, and/or mixed waste.

6.3.2 Health and Safety

The health and safety of workers and the public as well as protection of the environment will have the highest priority during the Pahute Mesa Phase II CAI, in accordance with the NNSA/NSO Integrated Safety Management System. Worker protection will be achieved through compliance with DOE Orders, OSHA regulations, the primary Real Estate/Operations Permit (REOP) holder’s Health and Safety Plan (HASP), and secondary REOP Field Activity Work Packages (FAWPs). Requirements specified in these documents are subject to change, and the work performed for this CAI is to be conducted in accordance with the most current published versions of these documents. The current UGTA Project HASP/FAWP (NSTec, 2008c) is the governing document under which all UGTA Project ER operations are conducted. The UGTA Project HASP (NSTec, 2008c) prescribes the minimum procedures that will be followed while performing field operations and describes the roles and responsibilities of key project personnel. The requirements are written to comply with DOE Orders and current federal regulations such as 29 *Code of Federal Regulations* (CFR) 1910 (CFR, 2009b) and 29 CFR 1926 (CFR, 2009c). The governing documents will be updated to be current with regulations at the time the drilling or testing programs are initiated.

Individual subprojects, sites, and/or tasks require the production of a FAWP to identify the nature of anticipated work, particular site features, hazards communication, and protective measures to be employed on that site. Work will be conducted in accordance with the FAWP, which will address the anticipated physical, chemical, and radiological hazards associated with the activity. The FAWP will be written to comply with the requirements of the UGTA Project HASP (NSTec, 2008c).

The principal hazards associated with activities at drilling sites are those general or physical hazards associated with industrial operations. These activities involve heavy equipment operation, potential for falling objects, and rotating and moving machinery. Environmental conditions such as the weather and terrain may increase the potential for accidents. The remoteness of some of these sites and the terrain may delay the response time for medical and fire services. During the spring, summer, and fall months, personnel may encounter snakes, spiders, and scorpions, and possibly mountain lions. Some deer mice in Nevada have been found to carry the hantavirus. Although the possibility of encountering deer mice in Pahute Mesa Phase II fieldwork may be low, the risk exists and needs to be evaluated during planning for field activities.

Hazardous chemicals, including lead, at levels of occupational health concern are not anticipated in the groundwater. The only anticipated source of chemical hazards to workers is from the materials brought on site. These materials may include fuel for the drill rig and generators; small volumes of nitric, hydrochloric, or sulfuric acid to be used as sample preservatives; and testing standards and reagents used for groundwater analysis. Proper storage and handling of these materials, as outlined in the FAWP, reduce the potential for accidents involving chemical hazards.

When radiological constituents are present in groundwater at levels of occupational health concern or are anticipated due to the proximity of the well to an underground nuclear test, additional documents apply. Work controls are guided by the *Nevada Test Site Radiation Protection Program* (RPP) (NSTec, 2008a), *NV/YMP Radiological Control* (RadCon) *Manual* (NNSA/NSO, 2004), and

10 CFR 835, “Occupational Radiation Protection” (CFR, 2009a). The NTS RPP establishes the policy by which radiological doses are maintained within acceptable limits and radiation exposures are maintained as-low-as-reasonably-achievable (ALARA) below these limits. The NV/YMP RadCon Manual represents DOE-accepted guidelines and best practices for implementing NTS and YMP radiation protection programs in accordance with the current 10 CFR 835 regulations (CFR, 2009a). The governing documents will be updated to be current with regulations at the time the drilling program is initiated.

Groundwater from some wells installed as part of the Pahute Mesa Phase II CAI may contain RN concentrations above EPA drinking water standards. The primary RN that may generally be encountered at elevated levels is ^{3}H in the form of tritiated groundwater. Due to the distance of the wells from underground nuclear tests — except ER-20-10 and potentially ER-20-7, the contingency well (ER-20-11), and possibly ER-EC-11 — significant amounts of ^{3}H or mixed fission products are not expected to be encountered. As a precautionary measure, operations will be conducted to ensure that personnel exposure to water vapor, splashes of groundwater, and drilling fluids will be minimized and that access to the site is restricted to only personnel involved in the field activities. Wells ER-20-10, ER-20-7, and the contingency well (ER-20-11) are located proximal to tests specifically to investigate known RN contaminant plumes. Well ER-EC-11 is located downgradient along a predicted flow path. It is not known what levels of RNs may be encountered, and drilling, testing, and sampling of these wells will be handled accordingly.

The ^{3}H concentration in groundwater produced at the surface is monitored hourly. If ^{3}H is detected above the action level set in the UGTA Project HASP/FAWP (NSTec, 2008c), operations are conducted in accordance with the current 29 CFR 1910 (CFR, 2009b) regulations and Radiological Work Permits (RWPs). Precautions include wearing water-impervious clothing when handling materials that have contacted the groundwater and establishing radiologically controlled areas to prevent the contamination of personnel. Engineering controls such as closed fluid transport systems and sampling enclosures also may be invoked to prevent worker contact with groundwater and to keep potential exposure ALARA. The governing documents will be updated to be current with regulations at the time the drilling program is initiated.

Workplace radiological monitoring is specified in the RWPs and is used to control potentially contaminated materials and prevent these materials from leaving the established radiologically controlled area. Such precautions also control potential contamination from other RNs.

6.3.3 Sampling and Analysis

Sampling and analysis of solids and fluids will be performed during this investigation. The associated activities include sample collection, onsite field screening for potential contamination, and offsite laboratory analysis. Onsite field screening for the leading indicator contaminants is conducted to reduce the risks to the environment and ensure the health and safety of project personnel and the public. Laboratory analyses of samples are used to ensure compliance with program requirements and for characterization of process materials and the groundwater.

6.3.3.1 Solid Sampling and Analysis

Solid samples of interest include surface and subsurface soils, rock cuttings, and cores collected from the boreholes during drilling. Surface and subsurface soil samples will be collected before initiating construction activities. At drilling pad sites, nonintrusive surface radiological surveys will be conducted with portable survey instruments. Surface and shallow subsurface soil samples also will be collected for field and laboratory chemical and radiochemical analysis. Rock-cuttings samples are collected from the drilling fluid discharge line as the borehole is advanced. Core samples are collected using percussion sidewall, rotary sidewall, vertical rotary, or similar techniques. The sampling frequency and intervals for collection of rock cuttings and core samples are performed in accordance with task-specific plans and the appropriate procedures. Field screening for any potential contaminants is conducted at each sample interval. Field analysis of rock cuttings and core samples is performed by onsite geologists to describe and identify the rocks penetrated during drilling operations. Laboratory testing to determine hydrologic, physical, and chemical properties also may be performed on selected cuttings and core samples. The activities associated with the collection, processing, and description of cuttings and core are performed as directed in task-specific plans and in accordance with approved procedures.

6.3.3.2 Fluid Sampling and Analysis

Fluid samples of interest include process fluids and groundwater. Process fluids are those fluids produced during the drilling, well construction, development, and purging activities that occur before collecting a representative groundwater sample. They include drilling fluid compound formulations, water produced during well completion, well development activities, and water purged before sampling. Groundwater is defined as water that is considered representative of the aquifer and is suitable for sampling and aquifer characterization purposes.

Fluids generated during all phases of the operation are managed in accordance with the UGTA Project FMP (NNSA/NSO, 2009), site-specific plans, and field instructions. Fluids produced during drilling, well completion, and well development and testing are collected for both field and laboratory analysis. Fluids that do not meet the fluid management criteria for release to an unlined infiltration basin are contained in lined sumps.

In addition, fluids produced during well purging or development are monitored for pH, conductivity, and temperature to determine stabilization before collecting groundwater characterization samples. These activities are conducted in accordance with the site-specific plans, field instructions, and the appropriate procedures. Additional parameters may be monitored as prescribed in the site-specific plans and instructions.

Groundwater samples include characterization samples from newly installed wells and samples from wells used as water-supply wells for drilling and well construction. Groundwater characterization samples are collected from the newly installed wells at the completion of well development and periodically thereafter until the well is taken out of service or until monitoring is no longer required. Water-supply wells are sampled before their use. Sampling and analysis of the water-supply wells ensure that the groundwater is free of target constituents. This also establishes background water chemistry and radiochemistry levels for constituents of concern, and provides baseline data for wells not previously sampled.

Process fluid and groundwater samples are collected, processed, and transported in accordance with state and federal regulations and applicable internal contractor procedures. If onsite monitoring or other knowledge indicates the potential for environmental samples to meet the definition of hazardous material under U.S. Department of Transportation (DOT) regulations, internal contractor procedures for the transport of hazardous materials shall be followed. These contractor procedures mandate compliance with applicable DOT shipping regulations. Specific guidance for this type of sampling is provided in site-specific plans and instructions and in accordance with appropriate internal contractor procedures. Process fluid samples collected for fluid management purposes are analyzed for selected metals, ^{3}H, gross alpha, and gross beta parameters as specified in the UGTA Project FMP (NNSA/NSO, 2009). All groundwater samples are then sent to analytical laboratories to be analyzed for the parameters listed in Table 5-1 of the UGTA Project QAPP (NNSA/NSO, 2003). The analyses listed in this table include metals, major ions, general chemistry, age and migration parameters, radiological indicator parameters, nuclear fuel products, and other RNs.

6.3.3.3 Quality Assurance

All sampling and analysis tasks are conducted in accordance with the requirements of the UGTA Project QAPP (NNSA/NSO, 2003). Section 7.0 of this document provides a summary of the QA program.

6.3.3.4 Field Quality Control

Project participants ensure that field quality control (QC) samples are collected and submitted to a selected analytical laboratory in a manner consistent with the UGTA Project QAPP (NNSA/NSO, 2003). The frequency, number, and type of QC samples collected during sampling activities are specified in site-specific plans, project plans, the UGTA Project QAPP (NNSA/NSO, 2003), and appropriate procedures. The types of QC samples may include field duplicates, equipment rinsate blanks, and, if necessary, rinsate source blanks. Collection and documentation of field QC samples are conducted in accordance with approved plans and procedures that meet the requirements of the UGTA Project QAPP (NNSA/NSO, 2003).

6.3.3.5 Waste Management

Waste in the form of PPE, sampling equipment, and drilling materials will be generated as a result of this investigation. Specific requirements for characterization sampling of these wastes are contained in Section 6.3.1.1 of this document and in the UGTA Project WMP (NNSA/NSO, 2009).

7.0 Quality Assurance

A comprehensive QA program applies to all activities performed under the UGTA Project, including those defined in this document. That program is documented in the UGTA Project QAPP (NNSA/NSO, 2003). The scope of work specified in this Phase II CAIP requires three different types of activities addressed in the UGTA Project QAPP: (1) assessment of existing data, (2) modeling, and (3) collection of new data. The UGTA Project QAPP also requires that methods be in place for the control and transfer of data, control of interpretive work products, and control of data within the central database. All UGTA participating organizations and contractors will apply methods and procedures compliant with the UGTA QAPP (NNSA/NSO, 2003).

7.1 Assessment of Existing Data

Section 5.1 of the UGTA Project QAPP (NNSA/NSO, 2003) states that new and existing data shall be evaluated against current requirements for their intended use. Criteria are specified to address evaluation of data concerning the quality of the data documentation and the quality of the data. In addition, considerations for transfer of data to a CAU are discussed in the *Transferability of Data Related to the Underground Test Area Project, Nevada Test Site, Nye County, Nevada* (SNJV, 2004c).

7.1.1 Data Documentation Evaluation

Data documentation evaluation addresses determination of the level of knowledge about the data collection process and data traceability, categorized according to standardized levels. The five levels of data documentation evaluation flags are as follows:

- Level 1: New data collected in accordance with NNSA/NSO project-specific QAPPs, approved State of Nevada procedures, and/or participant-specific procedures. This ranking indicates that all supporting documentation for the data is on file and available for review by data users.
- Level 2: Data collected in accordance with approved plans and procedures as required for Level 1; however, one or more documentation requirements may be deficient in some way. Examples of data documentation deficiencies may include lost or destroyed field-data collection forms, or data acquired using interim or draft procedures.

- Level 3: Data collected using accepted scientific methodology (e.g., American Society for Testing and Materials [ASTM], EPA methods). The data are accompanied by supporting and corroborative documentation such as testing apparatus diagrams, field or laboratory notes, and procedures.

- Level 4: Data collected before issuing and implementing project-approved standard policies, procedures, or practices governing data acquisition and qualification. The methods of data collection are documented and traceable; however, the validity of data use or compliance with reference procedures is indeterminate, or supporting documentation may not exist.

- Level 5: Data obtained under unknown, undesirable, or uncertain conditions. When data documentation is unknown, any available supporting or helpful descriptions of the intended use and conditions of data capture should be described.

Data documentation level is taken into account in evaluating data quality and also indicates the level of available documentation for further examination when using the data.

7.1.2 Data Quality Evaluation

The criteria used to evaluate the quality of the different types of required data are dependent on the type and the intended use of the data. The general procedure includes assigning one or more flags, termed data quality evaluation flags, to each record or group of similar records compiled in the dataset, indicating the data quality or suitability of the individual data record for the intended usage. This may be taken into account in data analysis, either qualitatively or quantitatively.

7.1.3 Data Transfer

The UGTA Project data transferability document (SNJV, 2004c) points out that the UGTA Project relies on data from a variety of sources and states that a process is needed to identify relevant factors for determining whether material-property data collected from other areas can be used to support groundwater flow, RN transport, and other models within a CAU. This document describes the overall data transfer process and documentation of the data transfer decision and process. The document and its accompanying appendices do not provide the specific criteria to be used for transfer of data for specific uses. Rather, it outlines the bases for the criteria to be established by separate parameter-specific and model-specific data transfer protocols. The CAU data documentation packages and data analysis reports will apply the protocols and provide or reference a document with the data transfer evaluations and decisions.

7.2 Modeling

The QA requirements for modeling are specific in Section 5.2 of the UGTA Project QAPP (NNSA/NSO, 2003) and generally consist of software/hardware configuration control, technical evaluation of new codes, code verification and validation activities, and software documentation. Output from modeling runs will be well documented and traceable to the code from which it was generated. Participating organizations’ procedures will provide for the specific methods used for performing these activities.

7.3 Collection of New Data

Extensive requirements for the collection of samples to obtain new data are provided in Section 5.3 of the UGTA Project QAPP (NNSA/NSO, 2003). Participating organizations' standard procedures must meet the requirements of the QAPP and will be used to perform sample collection, handling, documentation, and analysis. Data from newly acquired samples will be evaluated against the criteria established in the UGTA Project QAPP (NNSA/NSO, 2003) and this Phase II CAIP before use.

8.0 Records and Data Availability

8.1 Data Availability

The duration of the work as described in this plan, through peer review of the CAU model completing the Phase II CAI is projected in the current UGTA life-cycle baseline (LCBL) to be approximately 11 years (fiscal year [FY] 2008 through FY 2019). The LCBL is subject to change.

Verified and validated analytical results for sampling will be scheduled for availability within 90 calendar days of the date on which they are collected for the purposes of this investigation. Other quality-affecting data or measurements will be scheduled for availability on a similar schedule following completion of task activities.

8.2 Document/Records Availability

This Phase II CAIP and all unclassified primary supporting documents/documentation are available to the extent allowed by law (and as addressed in paragraph XIII.3 of the FFACO [1996, as amended February 2008]) in the DOE Public Reading Rooms located in Las Vegas and Carson City, NV, and from the UGTA NNSA/NSO Federal Sub-Project Director. The NDEP maintains the official administrative record for all activities conducted under the auspices of the FFACO (1996, as amended February 2008). For further information about where to obtain documents and other data relevant to this plan, please contact the UGTA NNSA/NSO Federal Sub-Project Director at (702) 295-3314.

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Appendix A

Data Quality Objectives

A.1.0 Data Quality Objectives for Central and Western Pahute Mesa: CAUs 101 and 102

The DQO process is a systematic project planning tool developed by the EPA to help collect environmental data that are important to decision making. The EPA has published DQO guidance for implementing the process for various EPA programs (e.g., EPA, 1987, 1993, 2000, and 2006). Section 1.5, "Implementing Corrective Action Investigations and Corrective Actions," of the Corrective Action Strategy (Appendix VI of the FFACO [1996, as amended February 2008]) states that DQOs will be incorporated throughout the corrective action process.

The DQO process documented in the Pahute Mesa CAIP (DOE/NV, 1999) was used to determine characterization activities for the Phase I CAI. For Phase II planning, the DQOs have been revised in consideration of regulatory changes since publication of the Pahute Mesa CAIP and to account for the results and conclusions of the Phase I CAI.

A.1.1 Data Quality Objectives Approach

The EPA guidance for the DQO process was most recently updated in 2006 (EPA, 2006). While the DQO process and guidance has been refined, the DQO process established for the Pahute Mesa CAIP (Appendix A of DOE/NV, 1999), based on EPA (1987 and 1993) guidance, is still appropriate and consistent with the revised guidance. The DQO process diagram (Figure A-1 of the Pahute Mesa CAIP [DOE/NV, 1999]) shows the process used to establish DQOs. The Phase II DQOs are consistent with previously specified DQOs but are presented in the format specified in EPA (2006). The Phase II DQOs are revised as a result of changes in the NTS boundary (Statutes at Large, 1999); changes in the FFACO (1996, as amended February 2008) regarding definition of the contaminant boundary; and the development of the conceptual and numerical models and parameter information during the Phase I CAI, which focuses the DQOs more specifically.

The *ad hoc* Subcommittee, which included representatives of NDEP and the CAB, met to review the state of knowledge of Pahute Mesa CAU hydrogeology and the status of flow and transport modeling at the conclusion of the Phase I CAI. These subjects are updated in Sections 3.0 (CAU Description) and 5.0 (Modeling) of the Pahute Mesa CAIP (DOE/NV, 1999). The nature and importance of subject uncertainties affecting the uncertainty of the flow and transport models were evaluated, and the subject uncertainties were prioritized as data needs. The results of the *ad hoc* Subcommittee discussions were summarized in Section 1.3.3 of this document and are further discussed in Appendix C. The *ad hoc* Subcommittee meetings and conclusions provide the basis for updating the DQOs for this Pahute Mesa Phase II CAIP.

A.1.2 Data Quality Objectives Process

The following presentation is organized according to the seven-step method of the EPA (2006) DQO guidance. The DQO process consists of a progression of seven steps, discussed in detail in Sections A.1.2.1 through A.1.2.7 of this document. The Phase II revisions for each step are presented in this section. Revisions are made concerning revisions of the FFACO (1996, as amended February 2008), the revision to the NTS boundary, and revisions concerning Phase II data collection and analysis as a result of evaluation of Phase I modeling results.

A.1.2.1 State the Problem

The first step of the process is a statement of the problem, which is documented in the FFACO (1996, as amended February 2008), Section 3.2: "The UGTA Corrective Action Strategy was developed to address the contamination created by the testing of nuclear devices in shafts and tunnels at the NTS."

A.1.2.2 Identify the Goal of the Study

As stated in the FFACO (1996, as amended February 2008), Section 3.2: "The objective of the CAI process is to define boundaries around each UGTA CAU to establish areas that contain water that may be unsafe for domestic and municipal use." The statement of the decision to be made given in the Pahute Mesa CAIP (DOE/NV, 1999) is still appropriate for the Phase II CAI: "Can an acceptable groundwater flow and transport model be formulated for Pahute Mesa using the existing data?"

A.1.2.3 Identify Information Inputs

Information inputs include all types of information required to support the analytic process, described in Section A.1.2.7 of this document, including information on the contaminant sources and the source term, information needed to develop hydrogeologic models and conceptual models for flow and transport, and analytic parameter information. The information inputs are discussed in detail in the Pahute Mesa CAIP (DOE/NV, 1999) and further in Phase I CAI documents, listed in Appendix B of this document, particularly in the HFM, source term, (SNJV, 2004c), flow model and addendum (SNJV, 2006 and 2007), and transport model document (SNJV, 2009).

Information inputs specifically addressed in this Phase II CAIP are related to the uncertainties in the current CAU conceptual models and parameter information identified by the *ad hoc* Subcommittee. These uncertainties were organized within the following categories:

- Understand flow and transport in pathways away from Pahute Mesa.
- Understand inflow to Pahute Mesa.
- Reduce uncertainty in source term applied in CAU model.

Each category can be broken down into a number of statements of uncertainty, termed Data Needs, listed in the second column of Table C.1-1 of this document. This approach to identifying uncertainties differs from the Pahute Mesa CAIP (see Section 4.2.1 of DOE/NV, 1999) but supports more specific statements of functional uncertainties. These statements of uncertainties are based on the evaluated effects of the uncertainties on the transport prediction uncertainty, which directly supports assessment of priorities regarding the potential improvement to be gained with reducing uncertainty of the models. This approach represents a shift from directly assessing parameter information to assessing the relative importance of different types of information within the context of the models and modeling uncertainty.

A.1.2.4 Define the Boundaries of the Study

The boundaries of the Pahute Mesa CAUs, Central Pahute Mesa (CAU 101) and Western Pahute Mesa (CAU 102) are specified in the FFACO (1996, as amended February 2008). The boundaries of the modeled area are defined in the flow and transport model documents (SNJV, 2006, 2007, and 2009), which were determined to encompass the area in which transport of contaminants may occur.

A.1.2.5 Develop the Analytic Approach

The analytic approach as it was to be applied to the Pahute Mesa CAUs was outlined in the Pahute Mesa CAIP (DOE/NV, 1999) and further described in the Pahute Mesa modeling strategy document (SNJV, 2004a). The models that have been developed are described in the HFM document

(BN, 2002), the source-term model document (SNJV, 2004c), the groundwater flow model and addendum documents (SNJV, 2006 and 2007), and the transport model document (SNJV, 2009). These models can be assessed for utility and uncertainty regarding their use in predicting the contaminant boundary, and served as the basis for the Phase II DQO development.

A.1.2.6 Specify Performance Criteria

The performance criteria is: Simulation modeling of contaminant transport will be used to forecast the location of contaminant boundaries within 1,000 years and must show the 95th percentile of the model results (boundary outside of which only 5 percent of the simulations exceed the SDWA standards [CFR, 2009]). These criteria for the determination of the contaminant boundary directly affect the criteria for data collection because the data must be adequate to develop models that predict future contaminant transport with a degree of specificity that will be acceptable per the FFACO.

The criteria for determining data collection priority are reduction of uncertainty. Specific parameter data collection most closely relates to the estimation problem discussed in Section 6.2.2 of EPA guidance (EPA, 2006), and procedures similar to those discussed are used for evaluation of parameter data, as discussed in the UGTA Project data transferability document (SNJV, 2004b). However, the larger consideration is the overall uncertainty in the models, which is also a function of the conceptual models used to create and then calibrate the numerical models. The HFM uncertainty, in particular, is not amenable at the largest scale to statistical evaluation due to the large scale and complexity, and attendant high cost of drilling.

The DQO development approach used for the Pahute Mesa CAIP (DOE/NV, 1999) to gather the missing information did not use statistical approaches. This was not inconsistent with the EPA approach (EPA, 1987, 1993, and 1994): "Non-probabilistic or subjective (judgmental) sampling approaches can be useful and appropriate for satisfying certain field investigation objectives (EPA, 1993)." The Phase II DQO process also used a judgmental approach, consistent with current EPA guidance: "Judgmental sampling involves the selection of sampling units on the basis of expert knowledge or professional judgment. Emphasizing historical and physical knowledge of the underlying site condition and sampling units ... make judgmental sampling an appealing option for some applications (Section 7.2 of EPA, 2006)." This approach is necessary for evaluating the problem as a whole because major elements of the models cannot be dealt with probabilistically.

The reference further states: “Conclusions are made solely on the basis of scientific judgment, and therefore, depend entirely on the validity and accuracy of this judgment.” To this end, a panel of subject matter experts (i.e., the *ad hoc* Subcommittee) was assembled to evaluate the data and the models and related uncertainties, and to render judgment concerning priorities for reducing uncertainty.

A.1.2.7 Develop the Plan for Obtaining Data

The deliberations of the *ad hoc* Subcommittee that determined the data needs, data collection and analysis activities, and priorities are summarized in Appendix C of this document. Table C.1-1 lists specific statements of the data collection or data analyses required to satisfy the data needs. Section C.1.3 lists the analyses proposed for Phase II that were judged to provide potential improvement of the flow and transport models.

A suite of data collection and analyses activities is proposed in Section 6.0 of this document to refine the inputs to the groundwater flow and transport models used to calculate the contaminant boundary. These activities are organized within the subject categories listed below, with a description of the foci for the activities in each category:

- **Hydrogeologic investigation program:** The objective for the hydrogeologic investigation program is to collect data that will reduce uncertainty within the HFM, flow, source term, and transport models, and may also provide information on RN migration along predicted flow paths that could be used to verify and calibrate transport predictions. The investigation program addresses both conceptual model uncertainties and parameter uncertainties.

- **Geologic and geophysical studies:** Proposals for data analysis activities to address specific geologic and hydrostratigraphic uncertainties in the HFM used for flow and transport modeling.

- **Hydrology studies:** Proposals for data analysis activities to address reduction in hydrologic uncertainty for the flow model used for transport modeling, including the recharge model, formation hydraulic parameters, and hydrology of faults.

- **Isotope- and geochemistry-based studies:** Proposals for data analysis activities to address reduction in uncertainty for the conceptual flow model based on isotope- and geochemistry-based flow path analysis.

- **Transport parameter studies:** Proposals for data analysis activities to address reduction in uncertainty for transport parameters used for transport modeling, including the parameters affecting fracture-matrix interaction such as fracture spacing and diffusion coefficients, matrix mineralogy, fracture coatings, measures of effective porosity for transport, fracture aperture, and hydraulically active fracture spacing.

- **Source-term studies:** Proposals for data analysis activities to improve the source-term model and SSM for specifying the HST for use in CAU-scale transport modeling. This includes a variety of investigations and analysis to further evaluate the available RN inventory for each test and the local-to-intermediate scale transport processes.

- **Flow and transport model evaluation and optimization:** Proposals for improvements to the flow and transport models and to the modeling evaluation process that will be used to optimize those models to ensure the most realistic predictive capability.

The specific activities for each of the subject categories are described in more detail in Section 5.0 of this document.

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Appendix B

Pahute Mesa Phase I CAI Documents

B.1.0 Major Supporting Documents

Table B.1-1 is a chronological list of UGTA Project documents that were published as part of the Phase I CAI or specifically to support Phase I CAI work. This table includes documents predating the Pahute Mesa CAIP (DOE/NV, 1999) but reports on tasks referenced in the Pahute Mesa CAIP as Phase I CAI work. These documents describe CAI development, data collection and data analysis activities, and modeling. This bibliography represents a history of all of the work done for the Phase I CAI, and a library of the information available for the Pahute Mesa CAUs. The table includes the title of the document, the author(s) and date, and a brief synopsis of the content of each document.

Table B.1-1
Phase I CAI Supporting Documents
(Page 1 of 19)

Report	Report Synopsis
Drilling and Completion Criteria for Underground Test Area Operable Unit Well Cluster ER-20-6 (IT, 1995)	This document describes the drilling, testing, and completion criteria for Well Cluster ER-20-6. The purpose of this well cluster was to investigate the nature and extent of potential RN migration originating from the BULLION (U-20bd) test. Thus, Well Cluster ER-20-6 was intended to serve as a groundwater monitoring point for possible future investigations into the mobility of test-related RNs. This report includes site-specific fluid management requirements, predictive geology and hydrology for the well, site phenomenology information, the anticipated RN distribution in the vicinity of Well Cluster ER-20-6, and a lithologic log for U-20bd.
Groundwater Flow Model of the BULLION Test Site and Associated Particle Tracking Analysis (GeoTrans Inc., 1995)	This report discusses the proposed downgradient Well Cluster ER-20-6. To assist in locating other wells of the cluster, a numerical model of the flow field was developed along with a particle tracking model. These models were used to evaluate the migration potential of the RNs and the ability of an extraction well ER-20-6 to capture the RNs.
Criteria for the Forced-Gradient Experiment at the BULLION Event Location (IT, 1996a)	This criteria report discusses an UGTA Project TWG recommendation for tracer experiments to collect data on the transport of RNs in the groundwater system for the BULLION FGE. As such, these data would be used in modeling the transport of the RNs expended from the underground nuclear tests, and to characterize the HST for the BULLION test.
Drilling and Completion Criteria for Underground Test Area Well Cluster ER-20-6 (IT, 1996b)	This Addendum to the *Drilling and Completion Criteria for Underground Test Area Operable Unit Well Cluster ER-20-6* (IT, 1995) presents revised objectives and completion criteria for Well ER-20-6. The full background for the change in objectives and the operational changes to the criteria are addressed in this document.
Geohydrology of Pahute Mesa-3 Test Well, Nye County, Nevada (Kilroy and Savard, 1996)	This well was drilled to monitor conditions near the western edge of the NTS. Drilling was conducted with conventional rotary methods and an air-foam drilling fluid to a depth of 3,019 ft. A 10.75-inch diameter steel casing was installed to a depth of 1,473 ft. This report presents data collected from the drilling, testing, and monitoring of the Pahute Mesa-3 test well, and provides an initial geohydrologic interpretation of the data. This report includes discussions of the drilling, construction, and well testing; and descriptions of geology, geohydrology, hydraulic properties, water levels, and water quality for the formations penetrated by the test well. Also, data collected during drilling, borehole geophysical surveys, injection tests, an aquifer test, and geochemical sampling are presented and interpreted. Water levels are presented for the two-year period following well completion (September 1988-January 1991).

Table B.1-1
Phase I CAI Supporting Documents
(Page 2 of 19)

Report	Report Synopsis
Map Showing Ground-Water Levels Beneath Eastern Pahute Mesa and Vicinity, Nevada Test Site, Nye County, Nevada (O'Hagan and Laczniak, 1996)	This report presents water-level and basic well construction data for drill holes in and around the primary area of underground testing on eastern Pahute Mesa, and water-level contours based on the most recent water-level measurements made in each drill hole. These measurements are presented for 72 wells over about 30 years. The purpose of this information is to: (1) benefit those involved in the siting, drilling, and design of drill holes to house nuclear devices, (2) study groundwater hydrology and RN transport beneath the Pahute Mesa area, and (3) investigate regional groundwater flow at and near the NTS.
Recompletion Report and Summary of Well History for Water Well UE-19c (DOE/NV, 1996a)	Water Well UE-19c was drilled in 1964 and later became a water supply well for LANL. This report describes recompletion activities, the results, the well history, and available historical data for this well. The well was recompleted in 1992 to establish an access point for monitoring water levels in volcanic aquifers at Pahute Mesa. As such, a water-level access tube was successfully installed during recompletion activities.
Recompletion Report and Summary of Well History for Well PM-3 (DOE/NV, 1996b)	This report describes recompletion activities for Well PM-3. Recompletion activities were conducted between January and March 1992 that included cleaning the hole, plugging the bottom portion of the hole, installing two piezometers in the most transmissive intervals in the well, and partially developing each piezometer. Circulation was never achieved. As such, all the water used during drilling remained downhole. The piezometers were not developed because of the recompletion criteria. However, the PM-3 piezometers were made available for water-level measurements.
Analysis of Fractures in Volcanic Cores from Pahute Mesa, Nevada Test Site (Drellack et al., 1997)	This report presents fracture data from core samples collected from drill holes UE-18t and UE-19x, and core segments from UE-18r, U-20c, UE-20c, UE-20e #1, UE-20f, and UE-20bh #1. Fracture analyses using borehole televiewer and formation microscanner data were performed on UE-18r, UE-20bh #1, ER-20-2 #1, and ER-20-5 #1. Wells ER-20-2 #1 and ER-20-5 #1 were not cored. The analyzed data relate to several attributes of the fractures, including distribution, density, aperture, openness, roughness, orientation, and fracture-lining mineralogy. These attributes were compared against hydrogeology and hydrostratigraphy, which could be used to generate values for hydrologic model inputs such as hydraulic conductivity and RN retardation.

Table B.1-1
Phase I CAI Supporting Documents
(Page 3 of 19)

Report	Report Synopsis
BULLION Forced-Gradient Experiment Implementation Plan (Part 1 of 2); Part 2 of 2 Attachment 1 Tracer and Tritium Transport Simulations for Planning of the BULLION Forced-Gradient Experiment (IT, 1997)	This BULLION FGE implementation plan provides: (1) the purpose and objectives of the BULLION FGE and a brief overview, (2) project planning activities, (3) a breakdown of the individual component activities and the management of conducting the FGE, (4) the overall schedule and contingency for the FGE relative to project planning and schedule, and (5) a reference section. Appendix A presents detailed information regarding health and safety requirements for the FGE, and Appendix B provides the overall fluid management strategy for the FGE. A discussion of analytes is grouped into various categories throughout the document. Part 2 of 2 Attachment 1 documents and summarizes the numerical flow and transport model developed for the BULLION FGE. The results of tracer and ^{3}H transport simulations used for planning the proposed FGE are presented and explained.
Completion Report for Well Cluster ER-20-5 (DOE/NV, 1997)	This report discusses the drilling and completion of Well Cluster ER-20-5, the first near-field drilling program the UGTA Project initiated at the NTS. The primary task included collecting geological, geophysical, hydrological, and water chemistry data from new and existing wells to define groundwater quality in addition to pathways and rates of groundwater migration. The well cluster is located near the location of the underground nuclear test, TYBO, which was conducted in emplacement hole U-20y. Water production, RN, and geology data were analyzed for the completion design to maximize data collection. On November 11, 1995, Well ER-20-5 #1 was drilled to a total depth of 860.5 m (2,823 ft) and was completed in a welded ash-flow tuff aquifer. On February 5, 1996, Well ER-20-5 #3 was drilled to a total depth of 1,308.8 m (4,294 ft) and penetrated an LFA. Well ER-20-5 #2 was abandoned because of drilling problems.
Nature and Extent of Lava-Flow Aquifers Beneath Pahute Mesa, Nevada Test Site (Prothro and Drellack, 1997)	This report summarizes the results of a study conducted by BN geologists to better define the hydrogeology of LFAs at Pahute Mesa. The purpose of the study was to aid in the development of the hydrostratigraphic framework for Pahute Mesa and to provide information on the distribution and hydraulic character of LFAs beneath Pahute Mesa; for more accurate computer modeling of the Western and Central Pahute Mesa CAUs: 101 and 102. This study assimilated and synthesized geologic data from various sources. These data were then used to prepare maps and cross sections to define the subsurface distribution of LFAs beneath Pahute Mesa. Existing hydrologic data were also compiled, reviewed, and integrated with geologic data to provide information on the hydrologic characteristics of Pahute Mesa LFAs.
Processing and Geologic Analysis of Conventional Cores from Well ER-20-6#1 Nevada Test Site (Prothro et al., 1997)	This report documents and describes the processing, geologic analysis, and preservation of the conventional cores from Well ER-20-6 #1, which was deemed appropriate as the BULLION FGE and other RN migration studies associated with the ER-20-6 well cluster progressed.

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Report	Report Synopsis
Completion Report for Well Cluster ER-20-6 (DOE/NV, 1998)	This report discusses the drilling and completion of Well Cluster ER-20-6, which was the second near-field drilling program the UGTA Project initiated at the NTS. This well cluster was drilled near the location of the underground nuclear test, BULLION, conducted in emplacement hole U-20bd on June 13, 1990. This test site was selected because of the test's yield, its hydrogeologic setting, the date since detonation, and its relatively shallow depth of burial. The ER-20-6 project was designed to accommodate an FGE. The monitoring wells, ER-20-6 #1 (March 6, 1996) and ER-20-6 #2 (March 25, 1996), were drilled on the same pad to a total depth of 975.4 m (3,200 ft). The pumping well ER-20-6 #3 (April 11, 1996) was drilled to a total depth of 975.4 m (3,200 ft) on an adjacent pad. All three wells were completed in the LFA.
Geohydrology of Monitoring Wells Drilled in Oasis Valley Near Beatty, Nye County, Nevada, 1997 (Robledo et al., 1998)	This report provides well-construction data and geologic and geophysical logs for 12 monitoring wells that were installed in 1997 at seven sites in or near Oasis Valley. These wells were drilled to depths ranging between 65 to 642 ft and were installed to measure water levels and collect water-quality samples. Water levels were measured in October 1997 and February 1998 and ranged from about 18 to 350 ft bgs. Development rates, times, and volumes of water pumped for these monitoring wells are presented. The monitoring wells were ER-OV-1, ER-OV-02, ER-OV-03a, ER-OV-03a2, ER-OV-03a3, ER-OV-03b, ER-OV-03c, ER-OV-03c2, ER-OV-04a, ER-OV-05, ER-OV-06a, and ER-OV-06a2. Flowmeter data identified transmissive zones in one borehole penetrating volcanic rock. Zones with the highest transmissivity are reported at depths of about 205 ft in the "rhyolitic lavas of Colson Pond" and 340 ft within the "tuff of Oasis Valley." Seven geologic units were identified and described from samples.
Principal Facts for New Gravity Stations in the Pahute Mesa and Oasis Valley Areas, Nye County, Nevada (Mankinen et al., 1998)	This gravity study was undertaken to better define the boundaries of the interpreted major regional structures in the PM-OV area. Gravity data were collected from 487 gravity stations that were established in the PM-OV during November 1997, March 1998, and June 1998. The precise locations of these gravity stations were determined using a differential global positioning system. Gravity and aeromagnetic data and results from a concurrent magnetotelluric study were combined with existing geologic data to develop robust tectonic models of the subsurface. The results were intended to provide constraints in the development of hydrological models for groundwater flow in the area. All gravity data and their associated parameters are presented in Table 1.
Report and Analysis of the BULLION Forced-Gradient Experiment (IT, 1998a)	The BULLION FGE was conducted to provide information relative to the transport of RNs in groundwater; between June 2 and August 28, 1997, on Pahute Mesa at the NTS. This document is a report and analysis of the FGE objectives, including: (1) observing the transport process and characterization of transport parameters (e.g., effective porosity, dispersivity, and matrix diffusion) for use in predictive modeling of contaminant transport, and (2) characterizing the HST and the relative mobility of mobile RNs.

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Report	Report Synopsis
Value of Information Analysis for Corrective Action Unit Nos. 101 and 102: Central and Western Pahute Mesa, Nevada Test Site, Nevada (IT, 1998b)	This report describes the basis for and presents the results of a VOIA for the Pahute Mesa underground test area of the NTS. The VOIA was used to evaluate and compare potential characterization options at the Pahute Mesa underground test area for site remediation purposes.
Western Pahute Mesa - Oasis Valley Hydrogeologic Investigation Wells and Drilling Completion Criteria (IT, 1998c)	This criteria report describes the drilling and completion specifications for 13 potential wells in the Western Pahute Mesa-Oasis Valley (WPM-OV) area. These wells were intended to provide information on the geology, hydrogeology, and water chemistry from an area that was assumed to be hydrologically downgradient from underground nuclear test areas. The proposed wells were ER-EC-1, ER-EC-2A, ER-EC-3, ER-EC-4, ER-EC-5, ER-EC-6, ER-EC-7, ER-EC-8, ER-EC-9, ER-EC-10, ER-OV-7, ER-OV-8, and ER-18-2.
Analysis of Tracer Responses in the BULLION Forced-Gradient Experiment at Pahute Mesa, Nevada (Reimus and Haga, 1999)	This reports presents an analysis of tracer test data and polystyrene microsphere data from the BULLION FGE. Wells ER-20-6 #1 and ER-20-6 #2 were injected with a solute and colloid tracers, while Well ER-20-6 #3 was pumped at ~116 gpm. The well tracer responses yielded valuable information about transport processes, which included longitudinal dispersion, matrix diffusion, and colloid transport in the hydrogeologic system in the vicinity of the BULLION nuclear test cavity.
Corrective Action Investigation Plan for Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nevada Test Site, Nevada (DOE/NV, 1999)	This report is a requirement of the FFACO (1996, as amended February 2008) that summarizes the site-specific historic data for the Pahute Mesa CAUs. This report describes the characterization activities implemented to evaluate the extent of contamination in groundwater due to underground nuclear testing, and the development of a groundwater flow model to predict the contaminant boundary.
Development of Phenomenological Models of Underground Nuclear Tests on Pahute Mesa, Nevada Test Site- BENHAM and TYBO (Pawloski, 1999)	The primary goals of this study were to: (1) identify the modification of the media at a pertinent scale, and (2) provide the information for groundwater modeling. Results of this study are applicable at near-field (model domain of about 500 m) and intermediate-field scale (model domain of about 5 km). The objectives of this modeling effort were to: (1) evaluate site-specific data and information from the BENHAM and TYBO tests, (2) augment the dataset with generalized containment data, and (3) develop a phenomenological model suitable for input to computer simulations of groundwater flow and RN transport after the BENHAM and TYBO tests.
Field Instruction for Western Pahute Mesa - Oasis Valley Well Development and Hydraulic Testing Operations (IT, 1999a)	This field instruction provided guidance to IT Corporation, Las Vegas, office field representatives involved in well development, hydraulic testing, and groundwater sampling of wells to ensure data were collected in a consistent and safe manner. The scope of this field instruction included roles and responsibilities for IT field staff, required reading and training, water-level monitoring, discharge flow monitoring, water-quality monitoring, groundwater characterization sample collection, datalogger operations, data management, equipment decontamination, environmental compliance, and Integrated Safety Management.

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Report	Report Synopsis
Geologic Evaluation of the Oasis Valley Basin, Nye County, Nevada (Fridrich et al., 1999a)	This report documents the results of a geologic study of the area between the underground nuclear testing areas on Pahute Mesa and the springs in Oasis Valley. New map and geophysical data for the Oasis Valley are integrated in this report. The Oasis Valley geophysical data consists of gravity, aeromagnetic, and paleomagnetic data. The goal of this report was to integrate the new geologic and geophysical data to develop a comprehensive, testable model of the structure and stratigraphy of the Oasis Valley area.
Geologic Map of the Oasis Valley Basin and Vicinity, Nye County, Nevada (Fridrich et al., 1999b)	This map and accompanying cross sections includes new geologic and geophysical field data. As such, this map is an updated synthesis of the geologic framework of the Oasis Valley area. This map covers nine 7.5-minute quadrangles in Nye County, Nevada, centered on the Thirsty Canyon southwest quadrangle, and is a compilation of one published quadrangle map and eight new quadrangle maps. These new maps were partly revisions of unpublished reconnaissance maps prepared by various experts.
Geophysical Framework of the Southwestern Nevada Volcanic Field and Hydrogeologic Implications (Grauch et al., 1999)	This report discusses a review that was conducted of the SWNVF subsurface tectonic and magmatic features that were inferred or interpreted from previous geophysical work. Inferred lithology was used to suggest associated HGUs in the subsurface and to develop hypotheses for regional groundwater pathways where no drill-hole information exists. Also, this report discusses the subsurface features in the west and northwestern parts of the NTS. Potential controls on regional groundwater flow away from areas of underground nuclear-weapons testing at Pahute Mesa are addressed.
The CHESHIRE Migration Experiment, A Summary Report (Sawyer et al., 1999)	The CHESHIRE test was a high-yield test conducted below the water table on Pahute Mesa on the NTS. This report provides unclassified data and describes a conceptual model for RN migration associated with a nuclear test that is applicable to other tests on Pahute Mesa similar in yield, hydrogeologic setting, and age.
The Silent Canyon Caldera Complex- A Three-Dimensional Model Based on Drill-Hole Stratigraphy and Gravity Inversion (McKee et al., 1999)	This report discusses the SCCC, which is the dominant structural framework of Pahute Mesa on the NTS. The SCCC rock units represent a combination of seven HSUs based on their predominant hydrologic characteristics. A 3-D geologic model, using EarthVision (Dynamic Graphics, 2002), was developed from the caldera structures and other faults on Pahute Mesa and the seven HSUs. This modeling computer program generated cross sections, isopach maps, and 3-D oriented diagrams to aid in visualizing and modeling the groundwater flow system beneath Pahute Mesa.
Well Development and Hydraulic Testing Plan for Western Pahute Mesa - Oasis Valley Wells (IT, 1999b)	This document presents the technical program for well development, hydraulic testing, and groundwater sampling for eight wells. This technical program was expected to provide information on the hydraulic characteristics of local HSUs and the chemistry of the local groundwater. The eight groundwater wells were ER-EC-1, ER-EC-6, ER-EC-4, ER-EC-8, ER-EC-5, ER-EC-7, ER-18-2, and ER-EC-2A.

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Report	Report Synopsis
Completion Report for Well ER-EC-1 (DOE/NV, 2000a)	Well ER-EC-1 was drilled in the spring of 1999 as part of the DOE/NV hydrogeologic investigation well program in the WPM-OV region just west of the NTS. A 44.5-cm surface borehole was drilled and cased off to the depth of 675.1 m bgs. The borehole diameter was then decreased to 31.1 cm for drilling to a total depth of 1,524.0 m. A preliminary composite static water level was measured at the depth of 566.3 m. One completion string with three isolated, slotted intervals was installed in the well. Detailed lithologic descriptions with preliminary stratigraphic assignments are included in this report.
Completion Report for Well ER-EC-4 (DOE/NV, 2000b)	Well ER-EC-4 was drilled in the summer of 1999 as part of the DOE/NV hydrogeologic investigation well program in the WPM-OV region just west of the NTS. A 44.5-cm surface borehole was drilled and cased off to the depth of 263.7 m bgs. The borehole diameter was then decreased to 31.1 cm for drilling to a total depth of 1,062.8 m. Two months after installation of one completion string with three isolated, slotted intervals, a preliminary composite static water level was measured at the depth of 228.3 m. Detailed lithologic descriptions with preliminary stratigraphic assignments are included in this report.
Completion Report for Well ER-EC-6 (DOE/NV, 2000c)	Well ER-EC-6 was drilled in the spring of 1999 as part of the DOE/NV hydrogeologic investigation well program in the WPM-OV region just west of the NTS. A 66-cm surface borehole was drilled and cased off to the depth of 485.1 m bgs. The borehole diameter was then decreased to 31.1 cm for drilling to a total depth of 1,524.0 m. A preliminary composite static water level was measured at the depth of approximately 434.6 m before the well installation of one completion string with four isolated, slotted intervals. Detailed lithologic descriptions with preliminary stratigraphic assignments are included in this report.
Mineralogical, Chemical, and Isotopic Characterization of Fracture-Coating Minerals in Borehole Samples from Western Pahute Mesa and Oasis Valley, Nevada (Benedict et al., 2000)	This report describes the mineralogy of fracture-lining phases in volcanic rocks from the WPM-OV region and includes stable isotope ratio ($^{13}C/^{12}C$ and $^{18}O/^{16}O$) and rare-earth element data for fracture-lining calcite. This report summarizes the results of a mineralogical and geochemical investigation of fracture-coating phases obtained from archived borehole core and cuttings samples from the WPM-OV region. The objective was to provide data that were needed to validate the UGTA Project flow and transport models for this region. Four main conclusions are presented.
Quality Assurance and Analysis of Water Levels in Wells on Pahute Mesa and Vicinity, Nevada Test Site, Nye County, Nevada (Fenelon, 2000)	This report states that accurate water-level measurements are essential to determine groundwater flow paths that may contain contaminants from underground nuclear tests conducted on Pahute Mesa. It is suggested that quality-assured data can be used to construct flow maps, calibrate steady-state and transient groundwater flow models, locate sites for future remedial monitoring, and identify existing trends that can be used as a means to understand the factors that influence the groundwater flow system.

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Report	Report Synopsis
Unclassified Radiologic Source Term for Nevada Test Site Areas 19 and 20 (Smith and Goishi, 2000)	This report presents a histogram plotting the annual frequency of 76 underground nuclear tests conducted between 1965 and 1992 in Areas 19 and 20 of the NTS. The histogram consists of all tests that were detonated below or within 100 m of the water table. These tests comprise the RST for Pahute Mesa, which is residual radioactivity that includes ^{3}H, fission products, activation products, unburned nuclear fuels, and actinides produced by neutron reactions. Table I of the report presents 47 RNs summed by isotope for 76 nuclear tests detonated below or within 100 m of the water table, and Table II reports the Table I moles and curies for each RN divided by 76 and represents a mean value for these tests.
Evaluation of the Hydrologic Source Term from Underground Nuclear Tests on Pahute Mesa at the Nevada Test Site: The CHESHIRE Test (Pawloski et al., 2001)	This report develops, summarizes, and interprets a series of detailed, unclassified simulations to forecast the nature and extent of RN release and near-field migration in groundwater away from the CHESHIRE test over 1,000 years. The results are referred to as the CHESHIRE HST.
Geology in the Vicinity of the TYBO and BENHAM Underground Nuclear Tests, Pahute Mesa, Nevada Test Site (Prothro and Warren, 2001)	This report discusses a re-evaluation of the subsurface geologic environment in the vicinity of the TYBO and BENHAM underground nuclear tests, to better understand the hydrogeologic conditions for more accurate flow and transport modeling. Existing geologic descriptions of eight drill holes were updated with data from petrographic, chemical, and mineralogic analyses, and current stratigraphic concepts of the region. These updated descriptions were used to develop a detailed geologic model of the TYBO-BENHAM area, which was evaluated relative to groundwater flow and RN migration to assess the model's implications for flow and transport modeling.
Underground Test Area Fracture Analysis Report: Analysis of Fractures in Volcanic Rocks of Western Pahute Mesa - Oasis Valley (IT, 2001)	This report describes the analysis of fracture data acquired from borehole image logs from eight wells: ER-18-2, ER-EC-1, ER-EC-2A, ER-EC-4, ER-EC-5, ER-EC-6, ER-EC-7, and ER-EC-8. This report also includes a brief summary of the geology and hydrogeology of the WPM-OV study area, a description of the fracture analysis methodology employed, a detailed discussion of the cumulative analysis of the fracture data, and recommendations for applications of the data.
A Hydrostratigraphic Model and Alternatives for the Groundwater Flow and Contaminant Transport Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nye County, Nevada (BN, 2002)	This report presents the evaluation of geologic data and the resulting 3-D HFM. The framework was built using a collection of stratigraphic, lithologic, and alteration data; a structural model; and results of geophysical, geological, and hydrological studies to formulate the hydrostratigraphic system.
Analysis of Well ER-18-2 Testing, Western Pahute Mesa - Oasis Valley FY 2000 Testing Program (IT, 2002a)	This report documents the analysis of the hydraulic and groundwater sampling data collected for ER-18-2 during the WPM-OV well development and testing program conducted during FY 2000. These data were analyzed to provide information on the hydraulic characteristics of HSUs and the chemistry of the local groundwater.

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Report	Report Synopsis
Analysis of Well ER-EC-1 Testing, Western Pahute Mesa - Oasis Valley FY 2000 Testing Program (IT, 2002b)	This report documents the analysis of the hydraulic and groundwater sampling data collected for ER-EC-1 during the WPM-OV well development and testing program conducted during FY 2000. These data were analyzed to provide information on the hydraulic characteristics of HSUs and the chemistry of the local groundwater.
Analysis of Well ER-EC-2a Testing, Western Pahute Mesa - Oasis Valley FY 2000 Testing Program (IT, 2002c)	This report documents the analysis of the hydraulic and groundwater sampling data collected for ER-EC-2a during the WPM-OV well development and testing program conducted during FY 2000. These data were analyzed to provide information on the hydraulic characteristics of HSUs and the chemistry of the local groundwater.
Analysis of Well ER-EC-4 Testing, Western Pahute Mesa - Oasis Valley FY 2000 Testing Program (IT, 2002d)	This report documents the analysis of the hydraulic and groundwater sampling data collected for ER-EC-4 during the WPM-OV well development and testing program conducted during FY 2000. These data were analyzed to provide information on the hydraulic characteristics of HSUs and the chemistry of the local groundwater.
Analysis of Well ER-EC-5 Testing, Western Pahute Mesa - Oasis Valley FY 2000 Testing Program (IT, 2002e)	This report documents the analysis of the hydraulic and groundwater sampling data collected for ER-EC-5 during the WPM-OV well development and testing program conducted during FY 2000. These data were analyzed to provide information on the hydraulic characteristics of HSUs and the chemistry of the local groundwater.
Analysis of Well ER-EC-6 Testing, Western Pahute Mesa - Oasis Valley FY 2000 Testing Program (IT, 2002f)	This report documents the analysis of the hydraulic and groundwater sampling data collected for ER-EC-6 during the WPM-OV well development and testing program conducted during FY 2000. These data were analyzed to provide information on the hydraulic characteristics of HSUs and the chemistry of the local groundwater.
Analysis of Well ER-EC-7 Testing, Western Pahute Mesa - Oasis Valley FY 2000 Testing Program (IT, 2002g)	This report documents the analysis of the hydraulic and groundwater sampling data collected for ER-EC-7 during the WPM-OV well development and testing program conducted during FY 2000. These data were analyzed to provide information on the hydraulic characteristics of HSUs and the chemistry of the local groundwater.
Analysis of Well ER-EC-8 Testing, Western Pahute Mesa - Oasis Valley FY 2000 Testing Program (IT, 2002h)	This report documents the analysis of the hydraulic and groundwater sampling data collected for ER-EC-8 during the WPM-OV well development and testing program conducted during FY 2000. These data were analyzed to provide information on the hydraulic characteristics of HSUs and the chemistry of the local groundwater.
Categorization of Underground Nuclear Tests on Pahute Mesa, Nevada Test Site, for Use in Radionuclide Transport Models (Pawloski et al., 2002)	This report summarizes an evaluation of general features, summarizes pretest and post-test information for tests on Pahute Mesa, and identifies categories of tests for HST modeling.

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Report	Report Synopsis
Completion Report for Well ER-EC-2A (NNSA/NV, 2002)	Well ER-EC-2A was drilled in January and February 2000 as part of the DOE/NV hydrogeologic investigation well program in the PM-OV region just west of the NTS. A 44.5-cm surface borehole was drilled and cased off to a depth of 412.9 m bgs. The borehole diameter was then decreased to 31.1 cm for drilling to a total depth of 1,516.1 m. Two months after installation of one completion string with three isolated, slotted intervals, a preliminary composite static water level was measured at the depth of 228.0 m. Detailed lithologic descriptions with preliminary stratigraphic assignments are included in this report.
Diffusive and Advective Transport of ^{3}H, ^{14}C, and ^{99}Tc in Saturated, Fractured Volcanic Rocks from Pahute Mesa, Nevada (Reimus et al., 2002)	This report presents the results of laboratory experiments in which the advective and diffusive transport behavior of ^{3}H (as tritiated water), ^{14}C (as bicarbonate ion), and ^{99}Tc (as pertechnetate ion) were studied in saturated, fractured volcanic rocks from Pahute Mesa. These RNs were selected because: (1) the large inventory, mobility, and hence potential high contribution to offsite dose/risk of ^{3}H if groundwater travel times are short; (2) the importance of ^{14}C groundwater dating and flow model calibration efforts; and (3) the desire to obtain transport information for a long -lived anionic species that is also sensitive to redox conditions (^{99}Tc). The transport experiments consisted of diffusion cell tests and fracture transport. Several conclusions are discussed.
Geochemical and Isotopic Interpretations of Groundwater Flow in the Oasis Valley Flow System, Southern Nevada (Thomas et al., 2002)	This report summarizes a geochemical evaluation of the PM-OV groundwater flow system in support of the flow and contaminant transport modeling for the WPM CAU. The evaluation provides a baseline interpretation of the groundwater geochemistry for this region to support verification of the UGTA Project hydrologic flow and transport model. The types of analyses include major ion and trace element chemistry; stable isotopes of hydrogen, oxygen, and carbon; ^{14}C and ^{3}H; dissolved noble gases; chlorofluorocarbons; and strontium and uranium isotopes.
Ground-Water Discharge Determined from Measurements of Evapotranspiration, Other Available Hydrologic Components, and Shallow Water-Level Changes, Oasis Valley, Nye County, Nevada (Reiner et al., 2002)	This report describes the natural groundwater discharge in the Oasis Valley, which is replenished from inflow from an extensive recharge area that includes the northwestern part of the NTS. An estimate of groundwater discharge from the Oasis Valley was examined in numerous studies to evaluate any potential risk associated with underground nuclear test-generated contaminants. As a result of these studies, this report refines and improves the estimated groundwater discharge from Oasis Valley by quantifying ET, compiling groundwater withdrawal data, and estimating subsurface outflow.
Matrix Diffusion and Colloid-Facilitated Transport in Fractured Rocks: Model and Parameter Validation (Zavarin, 2002)	This report reviews the results of matrix diffusion and colloid-facilitated transport in fractured rock and evaluates the implications of the results on modeling fracture flow at the NTS. The data are examined in the context of the CHESHIRE HST model results.

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Report	Report Synopsis
Reconnaissance Estimates of Recharge Based on an Elevation-dependent Chloride Mass-balance Approach (Russell and Minor, 2002)	This study describes the DRI evaluation of net infiltration and determination of recharge via the development of recharge models for data gathered from 17 springs located in the Sheep Range and Spring Mountains, and on the NTS. The objective was to improve an existing aquifer-response method based on the chloride mass-balance approach. Results of the recharge estimates are reported.
Summary of Well Testing and Analysis, Western Pahute Mesa - Oasis Valley FY 2000 Testing Program (IT, 2002i)	This report summarizes the results of the analysis of the WPM-OV well development and testing program conducted during FY 2000. The program included the testing of eight wells: ER-18-2, ER-EC-1, ER-EC-8, ER-EC-5, ER-EC-6, ER-EC-4, ER-EC-2a, and ER-EC-7. This summary report is based on the individual well analysis reports.
SUMMARY REPORT Borehole Testing and Characterization of Western Pahute Mesa - Oasis Valley ER-EC Wells (Oberlander et al., 2002)	This summary report presents results of borehole flow logging during pumping at wells ER-EC-1, ER-EC-2A, ER-EC-4, ER-EC-5, ER-EC-6, ER-EC-7, and ER-EC-8 on the Nellis Air Force Range in Nye County, Nevada. The borehole flow logging data include hydraulic conductivity with depth calculations in tuff, lava, and breccia; flow rate logging; and temperature data. Hydraulic conductivities in tuff, calculated for a combined vertical interval, were 97 m (318 ft) ranging from 66 to 0.2 meters per day (m/d) (217 to 5.4 feet per day [ft/d]). Hydraulic conductivities in lava, calculated for a combined vertical interval, were 38 m (124 ft) with a maximum value of 183 to 0.7 m/d (600 to 2.2 ft/d). Only three hydraulic conductivity values were assigned to a breccia lithology, which averaged 22 m/d (70 ft/d). The ER-EC wells demonstrated the majority of groundwater inflow occurs over intervals much smaller than individual screen joints.
TYBO/BENHAM: Model Analysis of Groundwater Flow and Radionuclide Migration from Underground Nuclear Tests in Southwestern Pahute Mesa, Nevada (Wolfsberg et al., 2002)	This report provides a description of an integrated modeling approach used to simulate groundwater flow, RN release, and RN transport near the TYBO and BENHAM underground nuclear test sites.
A Petrographic, Geochemical, and Geophysical Database, and Stratigraphic Framework for the Southwestern Nevada Volcanic Field (Warren et al., 2003)	This relational digital database consists of geologic data on the SWNVF that had been characterized over 30 years primarily by LANL, USGS, and published literature. The available data include surface and subsurface geology, stratigraphy and age dating, geochemistry, petrographic analyses, mineralogy, and physical and geophysical measurements. This database defines the subsurface geology of the NTS areas through "geologic interval" data tables. These tables provide stratigraphic assignments, lithologies, alterations, and other characteristics for more than 750 drill holes within the region. Geophysical logs from approximately 400 drill holes are included. This database can be downloaded or accessed through the Internet on the website of Earth and Environmental Sciences. Selected information can be extracted with spatial (X, Y, Z) and temporal (age or stratigraphy) attributes to evaluate schemes for predictive analysis and NTS modeling.

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Report	Report Synopsis
Colloid- Facilitated Transport of Low-Solubility Radionuclides: A Field, Experimental, and Modeling Investigation (Kersting and Reimus, eds., 2003)	This report integrates the results from a series of field, laboratory, and modeling studies to evaluate the potential for colloids to transport low-solubility RNs at the NTS. Results of groundwater and fractured core experiments conducted on Pahute Mesa wells are discussed. The wells were ER-20-5#1, ER-20-5 #3, U-20n PS1 DDH (CHESHIRE upper and lower), UE-20c, PM-1, and PM-2. The major findings of these field studies are discussed.
Completion Report for Well ER-18-2 (NNSA/NSO, 2003)	Well ER-18-2, located on Buckboard Mesa, was drilled in the spring of 1999 as part of the DOE/NV hydrogeologic investigation well program in the western part of the NTS. A 44.5-cm surface borehole was drilled and cased off to the depth of 408.1.1 m bgs. The borehole diameter was then decreased to 31.1 cm for drilling to a total depth of 762.0 m. Approximately two months after installation of one completion string with three isolated, slotted intervals, a preliminary composite static water level was measured at the depth of approximately 369.7 m. Detailed lithologic descriptions with preliminary stratigraphic assignments are included in this report.
Contaminant Transport Parameters for the Groundwater Flow and Contaminant Transport Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nye County, Nevada (Shaw, 2003)	This report documents the analysis of the available transport parameter data conducted in support of the development of a CAU groundwater flow model for Central and Western Pahute Mesa: CAUs 101 and 102. The groundwater flow model is a component of the CAU model, which is a major part of the UGTA Project strategy.
Evaluation of Cesium, Strontium, and Lead Sorption, Desorption, and Diffusion in Cores from Western Pahute Mesa, Nevada Test Site, Based on Macroscopic and Spectroscopic Investigations (Papelis and Um, 2003)	This report summarizes the results of sorption, desorption, diffusion, and spectroscopic experiments conducted with five different cores from wells on WPM. The core samples comprise PM-1 (4,823 ft), PM-2 (4,177 ft), UE-18r, (2,228 ft), UE-20c (2,855 ft), and UE-20c (2,908 ft). The experiments demonstrated the significance of aquifer material properties on the observed RN transport behavior and the importance of a combination of studies to reduce transport modeling uncertainties.
Geochemistry Technical Basis Document (Benedict et al., 2003)	This document presents a methodology in which data can more effectively contribute to the development, calibration, and verification of groundwater flow and solute transport models for the UGTA Project as it relates to the PM/OV flow system. Three chapters comprise: (1) an introduction to the geochemical parameters, (2) a methodology for using these parameters to define geochemical conceptual models, and (3) a description of the process that defines how the conceptual models are reconciled with hydraulic and hydrogeologic data and how they are used to verify flow and transport models.

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Report	Report Synopsis
Hydrologic Resources Management Program and Underground Test Area Project FY 2001 - 2002 Progress Report (Rose et al., 2003)	This report summarizes the results of chemical and isotopic analyses of groundwater samples collected from six near-field wells during FY 2001 and FY 2002. These data were collected to develop a database that describes the state of the HST of near-field wells and to support groundwater contaminant transport models at the NTS. Two of the sampled near-field wells were located in the Pahute Mesa area. Pumped samples were collected from ER-20-5 #3 (TYBO-BENHAM) and bailed samples were collected from U-19v PS 1ds (ALMENDRO). The well data and analytical results for these near-field wells are summarized in five tables.
Impact of Test Heat on Groundwater Flow at Pahute Mesa, Nevada Test Site (Carle et al., 2003)	This study evaluates an investigation into the complex phenomenology of underground nuclear tests and the resulting impacts on groundwater flow and RN transport relative to an improvement to HST models called "test heat." The investigation involves unprecedented development of new techniques and capabilities, integration of different disciplines, and analysis of scant and disparate data. As such, this study evaluates the impact of test heat with consideration for different tests and interdependent effects of test-related variations in pressure; and saturation and spatial variations of permeability and porosity.
Laboratory Experiments to Evaluate Diffusion of ^{14}C into Nevada Test Site Carbonate Aquifer Matrix (Hershey et al., 2003)	This study reports the results of three sets of laboratory experiments used to investigate the retardation of ^{14}C in the carbonate aquifers at the NTS. These experiments evaluated the diffusion of ^{14}C into the carbonate aquifer matrix, adsorption and/or isotopic exchange onto the fracture surfaces of the carbonate aquifer. The retardation factors were used to calculate groundwater velocities from a proposed flow path at the NTS.
Radionuclide Decay and In-growth Technical Basis Document (Kersting et al., 2003)	This report assesses the decay and in-growth of RNs from the RST deposited by underground nuclear tests conducted on the NTS between 1951 and 1992. The goals of this report were to: (1) simplify the transport modeler's task by identifying where in-growth is unimportant and where it needs to be considered, (2) evaluate RN decay chains, and (3) provide specific recommendations for incorporating RN daughters of concern in the calculation of the RN inventory. Figures of RNs show U-series, Np-series, Ac-series, and Th-series chain decay plots for Pahute Mesa Areas 19 and 20, and four other geographic areas on the NTS. These plots show the effects of radioactive decay with time for individual RNs and the relative contribution of in-growth from parent isotopes.
Simulation of Net Infiltration and Potential Recharge Using a Distributed Parameter Watershed Model for the Death Valley Region, Nevada and California (Hevesi et al., 2003)	This study reports the development and application of a distributed parameter watershed model to estimate the temporal and spatial distribution of net infiltration for the Death Valley region. As stated, because of uncertainty relative to the input parameters, "averaging results from multiple realizations is more likely to provide a more robust estimate of current climate potential recharge."

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Report	Report Synopsis
Temperature Data Evaluation (Gillespie, 2003)	The objective of this study was to identify the quality and quantity of available heat flow data at the NTS. When sufficient spatially distributed heat flow values are obtained, a heat transport model coupled to a hydrologic model may be used to reduce the uncertainty of a non-isothermal hydrologic model of the NTS. In this investigation, 145 digital format temperature logs from 63 NTS boreholes were considered. Thirteen boreholes were found to have temperature profiles suitable for the determination of heat flow values from one or more borehole intervals. Well PM-1, located on Pahute Mesa, displayed remarkable linear thermal gradients with vertically consistent heat flow values of 43.6 milliwatts per square meter ($mW\ m^{-2}$), which seems to indicate the absence of either vertical or horizontal groundwater flow within the hydrologic units penetrated by the borehole.
Temperature Dependence of Sorption Behavior of Lead and Cesium Metal Ions on Western Pahute Mesa and Rainier Mesa Aquifer Rocks (Decker et al., 2003)	This study was conducted to address two hypotheses: (1) RN sorption is temperature, rock, and mineral dependent and (2) for the rocks and cations studied, sorption is occurring through an exothermic reaction resulting in a decrease in sorbed concentration with an increase in temperature. This study demonstrated that the sign of the heat of adsorption calculated from the data was dependent upon the model used to simulate the experimental data. This study and another study demonstrated that temperature dependent sorption behavior should be expected, and that thermodynamics of the reaction between the sorbing ion and the mineral surface will determine the relationship between temperature and sorption behavior. This study summarizes the effects of elevated temperature on the sorption behavior of two RN analog ions — cesium and lead (at three temperatures) — and on core samples from WPM wells UE-18r (2,228 ft) and PM-2 (4,177 ft).
A Non-Electrostatic Surface Complexation Approach to Modeling Radionuclide Migration at the Nevada Test Site: I. Iron Oxides and Calcite (Zavarin and Bruton, 2004a)	This report examines the interaction between several RNs considered relevant to the UGTA Project as well as iron oxides and calcite. The term iron oxide defines a group of minerals that include oxides and hydroxides of iron. Modeling the interaction between RNs and these minerals was based on surface complexation (SC). This report evaluates the effectiveness of the Non-Electrostatic Model (NEM), which is a simplified SC model, to describe sorption under various conditions. The NEM approach provides a simple but robust mechanistic basis for modeling RN migration with a minimum number of fitting parameters. A database of RN SC reactions for calcite and iron oxide minerals was developed.
A Non-Electrostatic Surface Complexation Approach to Modeling Radionuclide Migration at the Nevada Test Site: II. Aluminosilicates (Zavarin and Bruton, 2004b)	This document is a companion report to Zavarin and Bruton (2004a). In this report, a second set of reactions were developed: SC and ion exchange (IE) to aluminosilicate minerals. Thus, the one-site NEM and the Vanselow IE models were used to fit a large number of published sorption data. As a result, a simplified reaction constant database was developed to be used in reactive transport simulations in chemically and mineralogically heterogeneous environments.

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Report	Report Synopsis
Completion Report for Well ER-EC-5 (NNSA/NSO, 2004a)	Well ER-EC-5 was drilled in the summer of 1999 as part of the DOE/NV hydrogeologic investigation well program in the WPM-OV region just west of the NTS. A 44.5-cm surface borehole was drilled and cased off to the depth of 342.6 m bgs. The borehole diameter was then decreased to 31.1 cm for drilling to a total depth of 762.0 m. Forty days after installation of one completion string with three isolated, slotted intervals, a preliminary composite static water level was measured at the depth of approximately 309.9 m. Detailed lithologic descriptions with preliminary stratigraphic assignments are included in this report.
Completion Report for Well ER-EC-7 (NNSA/NSO, 2004b)	Well ER-EC-7 was drilled in the summer of 1999 as part of the DOE/NV hydrogeologic investigation well program in the WPM-OV region just west of the NTS. A 44.5-cm surface borehole was drilled and cased off to the depth of 265.8 m bgs. The borehole diameter was then decreased to 31.1 cm for drilling to a total depth of 422.5 m. The planned depth of 762 m was not reached due to stability problems. Twenty days after installation of one completion string with three isolated, slotted intervals, a preliminary composite static water level was measured at the depth of approximately 227.8 m. Detailed lithologic descriptions with preliminary stratigraphic assignments are included in this report.
Completion Report for Well ER-EC-8 (NNSA/NSO, 2004c)	Well ER-EC-8 was drilled in the summer of 1999 as part of the DOE/NV hydrogeologic investigation well program in the WPM-OV region just west of the NTS. A 44.5-cm surface borehole was drilled and cased off to the depth of 129.8 m bgs. The borehole diameter was then decreased to 31.1 cm for drilling to a total depth of 609.6 m. Twenty-four days after installation of one completion string with three isolated, slotted intervals, a preliminary composite static water level was measured at the depth of approximately 98.4 m. Detailed lithologic descriptions with preliminary stratigraphic assignments are included in this report.
High-Temperature Studies of Glass Dissolution Rates Close to Saturation (Zavarin et al., 2004a)	This report documents glass dissolution experiments that were performed to measure glass dissolution rates close to saturation. The glass dissolution data are compared with glass dissolution predictions of the CHESHIRE test as reported in Pawloski et al. (2001). Conclusions of the reported experimental data are: (1) dissolution rates of analog and nuclear melt glasses are equivalent and (2) it appears that glass dissolution rates in HST simulations were too fast; particularly at high temperatures.
Hydrologic Data for the Groundwater Flow and Contaminant Transport Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nye County, Nevada (SNJV, 2004a)	This report describes an assessment of hydrologic data and information in support of the CAU groundwater flow model. Relevant information, existing data, and newly acquired data were analyzed for the hydrologic components of the groundwater flow system of Pahute Mesa and vicinity.

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Report	Report Synopsis
Hydrologic Resources Management Program and Underground Test Area Project FY 2003 Progress Report (Rose et al., 2004)	This report describes technical studies conducted in FY 2003 on Pahute Mesa and other geographic areas on the NTS. Results for chemical and isotopic data for groundwater samples are presented for near-field wells U-20n PS1-DDh (CHESHIRE), U-19q PS #1d (CAMEMBERT), and U-19v PS #1ds (ALMENDRO). Results are presented for chemical and isotopic measurements of groundwater samples from the UGTA Project environmental monitoring wells ER-EC-1, ER-EC-2A, ER-EC-4, ER-EC-5, ER-EC-6, ER-EC-7, ER-EC-8, and ER-18-2. Also, this report provides a brief summary of Transmission Electron Microscope studies of colloids separated from groundwater samples collected from wells ER-20-5-1 and ER-20-5-3.
Modeling Approach/Strategy for Corrective Action Units 101 and 102, Central and Western Pahute Mesa (SNJV, 2004b)	This report summarizes the data and information that are the technical basis for the groundwater flow model. Two approaches are described that propose developing the models to forecast how the hydrogeologic system, which includes the underground nuclear test cavities, will behave over time. One approach is the development of numerical process models to represent the processes that influence flow and transport. The other approach shows how simplified representations of the process models are used to assess the interactions between model and parameter uncertainty.
Nuclear Melt Glass Dissolution and Secondary Mineral Precipitation at 40 to 200°C (Zavarin et al., 2004b)	This document summarizes the results from five nuclear melt glass dissolution/secondary mineral precipitation experiments conducted over a range of temperatures from 40 to 200°C. This documents reports several findings, two of which are that the model in Zavarin et al. (2004a): (1) appears to predict the behavior of glass dissolution and secondary mineral precipitation rates more accurately than the CHESHIRE model of Pawloski et al. (2001), and (2) provides results on the size, composition, and concentration of colloids in the groundwater at wells ER-20-5 #1 and ER-20-5 #3.
Unclassified Source Term and Radionuclide Data for the Groundwater Flow and Contaminant Transport Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nye County, Nevada (SNJV, 2004c)	This report documents the evaluation of the information and available data on the unclassified source term and RN contamination for CAUs 101 and 102. The methodology to estimate HSTs for these CAUs is also documented in this report.
Upscaling Radionuclide Retardation-Linking the Surface Complexation and Ion Exchange Mechanistic Approach to a Linear K_d Approach (Zavarin et al., 2004c)	This report documents how a method to link the near-field HST and large-scale CAU-model RN retardation approaches were developed. A partially validated mechanistic approach for the porous flow reactive transport case is provided. Included is a summary on the process of upscaling the near-field HST model mechanistic RN retardation approach to a simplified large-scale CAU K_d approach.

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Report	Report Synopsis
Colloid Characteristics and Radionuclide Associations with Colloids in Source-Term Waters at the Nevada Test Site (Abdel-Fattah et al., 2005)	This study presents results of a continued effort by LANL to collect colloid concentrations and size distributions in groundwater samples from monitoring wells. During FY 2004, the associations of Cs, U, Np, and Pu with colloids in groundwater samples from wells that had low concentrations of RNs in the groundwater were also sampled. The near-field wells were U-20n (CHESHIRE), RNM-1 (CAMBRIC), U-4u (DALHART), and U-19ad PS #1a. Groundwater was collected from a surface discharge line.
Evaluation of Groundwater Flow in the Pahute Mesa - Oasis Valley Flow System Using Groundwater Chemical and Isotopic Data (Kwicklis et al., 2005)	This report documents the use of groundwater geochemical and isotopic data from the vicinity of the PM/OV flow system to interpret groundwater flow patterns as well as to independently evaluate the groundwater flow model that is currently being developed. A combination of graphical methods and inverse geochemical models form the basis for the PM/OV model area.
Np And Pu Sorption to Manganese Oxide Minerals (Zhao et al., 2005)	This report describes experiments that quantified the sorption and desorption of Np(V) and Pu(IV) onto three Mn oxide minerals (pyrolusite, birnessite, and hollandite) as a function of pH and time. Results of the experimental data and a review of literature data in this report, provides sufficient data to incorporate Mn oxide sorption reactions into HST (and upscaled) models and provide less conservative estimates of RN transport.
Radionuclide Reaction Chemistry as a Function of Temperature at the Cheshire Site (Burton et al., 2005)	This report describes a task to compile thermodynamic data available in literature and to evaluate the options and benefits of applying temperature-dependent RN speciation to future HST modeling. The focus of this evaluation was LLNL's experience of HST modeling at CHESHIRE. The literature search and the few reactions that could be extrapolated to higher temperatures revealed the change in dominant complexes with temperature could not be addressed at the time of this task. However, it was determined that the effect of temperature on speciation could be qualitatively examined.
Temperature Profiles and Hydrologic Implications from the Nevada Test Site Area (Gillespie, 2005)	The subject of this report is a presentation and analysis of the earlier investigation of 13 original temperature profiles reported in Gillespie (2003) as well as 18 temperature profiles collected during FY 2003, and 14 profiles collected during FY 2004. Heat flow values (mW m^{-2}) for PM/OV wells were ER-18-2 (56.3), ER-19-1 (30.9), ER-20-5 #1 (40.8), ER-20-6 #1 (40.8), ER-OV-03a2 (181.6), ER-OV-06a (65.6), PM-1 (36.2), and U-20 Water Well (20.8). Temperature profiles were obtained from wells ER-20-6 #1, ER-20-6 #2, and ER-20-6 #3, but because of the impact of the residual heat generated by the BULLION nuclear test, it was not possible to determine heat flow values for the ER-20-6 well cluster.

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Report	Report Synopsis
Colloid Characteristics and Radionuclide Associations with Colloids in Near-Field Waters at the Nevada Test Site (FY 2005 Progress Report) (Reimus et al., 2006)	This study presents results of a continued effort by LANL to collect colloid concentrations and size distributions in groundwater samples from near-field monitoring wells. During FY 2004 and FY 2005, the associations of Cs, U, Np, and Pu with colloids were also measured in groundwater samples from eight near-field wells. This report presents FY 2005 data for ER-20-5 #1 (TYBO), ER-20-5 #3 (TYBO), U-3cn PS#2 (BILBY), and UE-2ce (NASH). The FY 2004 data for four near-field wells are presented in Abdel-Fattah et al. (2005).
Evaluating Alternative Groundwater Flow Models with Geochemical Mixing Targets (Wolfsberg et al., 2006)	This paper was submitted to the MODFLOW and MORE 2006 Conference Proceedings. Three distinct groundwater types are identified on the basis of their Cl, SO_4, δ^2H, and $\delta^{18}O$ compositions in the PM-OV flow system (Kwicklis et al., 2005) and groundwater from Rainier Mesa. The groundwater samples from PM/OV wells were ER-EC-1, ER-EC-4, U-20 Water Well, UE19h, and UE-19c Water Well. This paper summarizes the geochemical analysis, the reverse transport simulation methodology, and the quantitative comparison and ranking of the alternative flow model calibrations that are available for use in future assessments of contaminant migration.
Geochemical Data Analysis and Interpretation of the Pahute Mesa - Oasis Valley Groundwater Flow System, Nye County, Nevada August 2002 (Rose et al., 2006)	This final report summarizes results of a geochemical investigation to determine groundwater flow paths in the PM/OV flow system. Responses to review comments from the August 2002 draft report were incorporated in this final report as well as new chemical and isotopic data from eight, recently drilled, deep exploratory/monitoring wells in WPM-OV. Based on the new data, two chemically and isotopically distinct groundwater masses were identified in association with known water-level discontinuity near the Purse and West Purse Faults in western Pahute Mesa. Six conceptual flow path models using conservative tracer and geochemical modeling techniques were tested.
Groundwater Flow Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nevada Test Site, Nye County, Nevada (SNJV, 2006)	This report discusses a steady-state groundwater flow model of the Pahute Mesa CAUs 101 and 102 that was constructed using a suite of hydrostratigraphic frameworks, recharge distributions, and hydraulic parameter assignment conceptualizations. Model calibration and sensitivity analyses, and geochemical verification were conducted and documented.
Addendum to the Groundwater Flow Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nevada Test Site, Nye County, Nevada (SNJV, 2007)	This addendum was prepared to address review comments on the final *Groundwater Flow Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nevada Test Site, Nye County, Nevada* document by the NDEP in a letter dated July 19, 2006. The addendum includes revised pages that address NDEP review comments and comments from other document users. Change bars are included on the pages to indicate revised text. Also, this addendum includes clarifications to Plate 1 and a revised compact disc of Appendix D perturbation plots in Sections D.3.1 and D.3.2.

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Report	Report Synopsis
Effect of Reducing Groundwater on the Retardation of Redox-Sensitive Radionuclides (Hu et al., 2007)	This report discusses a review that was performed on the typical rock and groundwater types encountered at the NTS, the salient geochemical behavior of important redox-sensitive RNs, and the current understanding of redox conditions in saturated underground nuclear test cavities and ambient groundwaters. Results are presented on a series of laboratory batch sorption experiments designed to investigate the effect of reducing groundwater conditions on RN retardation. Redox potential ranges are presented for 22 wells, including Pahute Mesa wells UE-19h, PM-1, ER-20-6 #3, U-20bh #1, and ER-20-1. This report summarizes the effect of reducing groundwater conditions on the sorption and retardation of redox-sensitive RNs deposited in the subsurface as a result of underground nuclear testing at the NTS.
Final Report Hydraulic Conductivity with Depth for Underground Test Area (UGTA) Wells (Oberlander et al., 2007)	This report evaluates hydraulic conductivity with depth in volcanic tuffs at the following WPM-OV wells: ER-EC-1, ER-EC-2A, ER-EC-4, ER-EC-5, ER-EC-6, ER-EC-7, and ER-EC-8. These wells illustrate a wide range of data values and statistical distributions when associated with specific hydrogeologic characteristics such as the stratigraphic unit, HSU, HGU, and the lithologic and alteration modifier used to describe the hydrogeologic setting. Results are considered relevant as they show how these units are considered in conceptual models and represented in groundwater models.
Phase I Transport Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nevada Test Site, Nye County, Nevada (SNJV, 2009)	This document presents a study to understand the behavior of RN migration in the Pahute Mesa CAU model and to define, both qualitatively and quantitatively, the sensitivity of such behavior to (flow) model conceptualization and (flow and transport) model parameterization. A list of components were assembled to identify key features and processes that require further investigation with the goal to reduce conceptual and parameteric uncertainty during a second phase of numerical model activities. The components identified in this analysis are bench characterization, transport through fractures, heterogeneity, specific discharge, depth decay, recharge, boundary flows, and source term.

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Appendix C

TWG Pahute Mesa Phase II CAIP *ad hoc* Subcommittee Findings

C.1.0 TWG Pahute Mesa Phase II CAIP ad hoc Subcommittee

The *ad hoc* Subcommittee — comprised of UGTA Project subject matter experts, NNSA/NSO, NDEP, and CAB representatives — met six times between December 2007 and April 2008 to review the results of the Phase I CAI. The *ad hoc* Subcommittee meetings took place before issuance of the final Pahute Mesa transport model document (SNJV, 2009). However, most subcommittee members were either a member of the transport document modeling team, or reviewed the draft transport document and were familiar with the transport modeling results. Accordingly, the subcommittee recommendations are coordinated and integrated with the transport document results. The subcommittee recommendations are, however, broader than the topics covered in the transport model document. Plate 2 of this document provides a map of the structural features and HSUs at the water table for the Pahute Mesa modeling domain. The locations of existing drill holes and the drill holes recommended in Section 6.0 of this document are also shown on Plate 2.

The series of meetings focused specifically on the results of transport modeling from the Phase I studies, the confidence in the modeling results, insights gained from preliminary calculations of contaminant boundaries and topics of uncertainty that could be addressed through future data collection. The primary task of the subcommittee was to develop recommendations and priorities for data collection and data analysis for the Phase II CAI. The activities of the subcommittee started with background presentations by subject matter experts on major topics comprising the CAU model (alternative geologic and HFM models; calibrated flow model and flow model screening; source-term model; and the preliminary results of the transport modeling, including predictions of contaminant boundaries for 1,000 years).

The subcommittee evaluations of presentations by the program participants who performed work for Pahute Mesa included HFMs, geochemistry, source term, and flow and transport models. Important conclusions from the transport model include:

1. Radionuclide migration toward Oasis Valley is significant and may be more rapid than expected based on Phase I understanding of the flow system, source-term and geochemical data from hot well sampling, processes of RN transport, and preliminary constraints on groundwater ages.

2. A major cause of rapid transport is convergent groundwater flux across the Bench area and along the western and southwest flanks of Timber Mountain. Transport is enhanced by the presence of preferential migration pathways where the higher-permeability TMCM is in contact with the lower-permeability FCCM. The factors causing this convergent flux were present in all alternative HFMs.

3. Radionuclide migration is highly sensitive to fracture matrix interactions and the inferred continuity in fractured rock represented in the model domain for pathways extending from Pahute Mesa to Oasis Valley.

4. Other important parametric uncertainties affecting RN migration include assumptions concerning the availability and release of RNs from the source term, release of colloidal Pu from the source and the effective porosities of RMCs.

5. Increased confidence in the model predictions of RN migration needs to be developed through focused data collection (Phase II), leading to iterative modifications of the flow and transport models.

Following the discussions of background information, the subcommittee identified a five-step process for developing data collection objectives for the Pahute Mesa Phase II studies. These steps are:

1. Identifying topical categories for the Pahute Mesa CAU model (see the Topic column in Table C.1-1), including general discussions of the importance of the topics with respect to overall modeling goals for the CAU studies.

2. Generally identifying data needs that could enhance the identified topics for Phase II studies, emphasizing a comprehensive listing of any data needs that could prove to be beneficial to reducing the uncertainty of the modeling studies and increasing confidence in model predictions (Table C.1-1).

3. Prioritizing the data needs (see the Priority column in Table C.1-1).

4. Identifying sites for exploratory drilling to address the drilling needs (Table C.1-2).

5. Prioritizing and sequencing the drill holes to more efficiently achieve the data collection objectives (see the Priority and Data Collection Objectives columns in Table C.1-2).

Step 1

The important topics identified by the subcommittee for future studies of Pahute Mesa include (see Topic column of Table C.1-1):

1. Improvements in the understanding of flow and transport in fracture-dominated pathways leading off of Pahute Mesa to Oasis Valley.

2. Refinements in understanding of the groundwater inflow into and within Pahute Mesa.

3. Refinements in an attempt to reduce the uncertainty in source term applied to the Pahute Mesa CAU transport model.

Step 2

The subcommittee next attempted to identify all data needs that could improve understanding of the Pahute Mesa CAU and lead to increased confidence in the transport models used to predictive contaminant boundaries. These data needs are listed in Table C.1-1.

Step 3

The subcommittee then prioritized the data needs for the Phase II studies, recognizing that UGTA Project resources are limited, and emphasizing studies most likely to potentially reduce uncertainty and increase confidence in model predictions. The data prioritization became the primary tool for developing a strategy for the Phase II drilling exploration program. Each subcommittee member independently established priorities for the data needs and submitted the assessments to the subcommittee chairman. These assignments were refined through group discussions at a subsequent subcommittee workshop. The primary bases for assignments include identifying information gaps and/or deficiencies, significant uncertainties in model components identified through sensitivity, and uncertainty analysis and confidence that the transport modeling provides reliable predictions of contaminant transport. These combined evaluations recognize that the transport model predictions of contaminant boundaries are the primary decision tool for implementing the UGTA strategy. The final data need rankings by subcommittee member were assembled into a spreadsheet; these rankings were tallied assuming equal weighting of subcommittee members. The final tallies established the assigned priority for the data needs.

The top five data needs in decreasing order of subcommittee rankings are (see also the Priority and Description columns of Table C.1-1):

1. The flow models of Pahute Mesa show convergence of groundwater flow paths off of Pahute Mesa, west of Timber Mountain, east of Thirsty Canyon, and along the approximate geologic contact between the TMCM and FCCM HSUs in the Bench area of the modeling domain. These areas are also strongly affected by structural features associated with the Timber Mountain and SCCC calderas. Are the representations of these flow fields in the flow models realistic, and do the models provide reliable predictions of RN transport?

2. Groundwater flow through the TMCM and FCCM HSUs may be complicated and spatially variable. There are concerns with how the hydraulic properties of these units are represented in the flow and transport models.

3. Plutonium from the 1968 BENHAM test was found at the ER-20-5 site, 1.3 km from the test. The extent of RN migration immediately downgradient of drill hole ER-20-5 is currently unknown. Where and how fast are RNs migrating over time; what are the characteristics and extent of contaminant plumes in this critical area; and why were no RN detected at drill hole ER-EC-6 approximately 4 km from the ER-20-5 site, as would be expected based on Phase I model predictions of transport?

4. What are the hydraulic characteristics of faults in critical migration pathways off of Pahute Mesa? Are these faults barriers or conduits for flow, and are the faults reasonably represented in the models of flow and transport?

5. What is the spatial variability of permeability for HSUs in the critical flow pathways leading off of Pahute Mesa toward Oasis Valley? Are these permeabilities correctly upscaled and represented in the flow and transport models?

Step 4

The next step was to identify sites for drilling wells to achieve the prioritized data needs of Table C.1-2. A wide range of potential drilling sites were evaluated by the subcommittee, emphasizing a range of objectives:

1. The importance of each location with respect to the prioritization of the data needs.
2. The likelihood of successfully gaining information to address the data needs.
3. The availability of data from existing drill holes.
4. The accessibility of the sites for road and drill pad construction.
5. The need for specialized tests including tracer tests and MWATs.

Twenty-one well sites were identified by the subcommittee. The well locations and their data collection objectives are summarized in Table C.1-2.

Step 5

Guidance from the UGTA baseline shows that program resources have been allocated for 10 drill holes for the Phase II data collection activities; the subcommittee next had to prioritize the drill-hole locations. The same procedure used for the prioritization of data needs was used for the drill-hole locations. Each subcommittee member developed independent rankings of well locations, their results were discussed and revised during group discussions, and their final rankings were assembled and tallied in a spreadsheet. The results of the ranking process are shown on Table C.1-2. An important concept that evolved during the discussion of drill-hole rankings was the effects of sequencing of drill holes. This topic is discussed in Section C.1.2.

C.1.1 Data Needs Assessment

Table C.1-1 summarizes the data needs that were identified for Phase II investigations, organized under three broad functional topics. These data needs are more specific to the evaluation of the transport model results than the general data-type needs listed in Section 10.0 of the transport model document (SNJV, 2009), which are focused on conceptual model and parameter uncertainty. The table includes a brief description of the scope for each data need and the priority assigned to each data need regarding the importance for the Phase II CAI. Specific types of testing and data collection were associated with each of the locations beyond the basic, standardized data collection program that would be conducted at each location, such as MWATs and tracer tests. As discussed in Section 5.0, the flow modeling determined a high probability of flow paths from sources on the mesa converging in the Bench area and channeling along the same route toward Timber Mountain. The focus of interest is on these flow paths and the hydrogeologic factors resulting in the convergence. The *ad hoc* Subcommittee identified locations for drilling and well construction, sampling, and testing to collect data as well as additional data analyses using available data to reduce uncertainty in the flow, source term, and transport modeling regarding the data needs identified in Table C.1-1. The *ad hoc* Subcommittee also evaluated new data analyses using existing data.

Table C.1-1
Data Needs Assessment
(Page 1 of 2)

Topic	Data Need		Description	Priority
1. Understand flow and transport in pathways away from Pahute Mesa	A	Fracture-matrix mass transfer	Characterize fracture properties (aperture, fracture spacing, fracture flow paths [tortuosity], fracture coatings, matrix porosity) used for the mass transfer process modeling.	9
	B	Groundwater flow through the FCCM and TMCM	Understand the impact of the TMCM and FCCM on the flow model and how they control flow paths off Pahute Mesa. What are the groundwater flux and velocity in the TMCM? Is there flow in the FCCM?	2
	C	Flow off Pahute Mesa	Verify whether groundwater flow paths converge west of Timber Mountain, east of Thirsty Canyon along TMCM/FCCM interface with the Bench. What is the role of the Moat fault, and how does it affect flow paths leaving the Silent Canyon caldera? Does water diverge or converge in this area?	1
	D	Flow within Pahute Mesa source areas	Characterize groundwater flux and evolution of source term near cavity regions to determine how water flows within Pahute Mesa.	10
	E	Characterize TYBO/BENHAM	Extend the TYBO/BENHAM/ER-20-5 study to understand where RNs are and how they are migrating over time. What are the extent and spatial characteristics of the plume?	3
	F	Deep flow in Fortymile Canyon	Identify Area 19 contributions to east-of-Timber Mountain flow. How much water goes down Fortymile Canyon? Locate the divide for Area 19 flow paths?	12
	G	Heterogeneity	Characterize the spatial variability of permeability for the HSUs? What is the effect on source-term release? How to upscale/represent this in CAU models?	5
	H	Effect of faults on the flow system	Characterize fault hydraulic characteristics - barriers or conduits for flow?	4
	I	TMD “groundwater mound”	Acquire water-level information to determine groundwater mounding beneath TMD, and determine the impact of the “mound” on convergent or divergent flow paths off Pahute Mesa.	6
	J	Hydraulic conductivity depth decay	Determine whether depth decay is representative for composite units.	14

Table C.1-1
Data Needs Assessment
(Page 2 of 2)

Topic	Data Need		Description	Priority
2. Understand inflow to Pahute Mesa	A	Flow from the northwest	Identify inflow west of the Purse Fault to help constrain flow paths off Pahute Mesa. The regional model currently produces high inflow which pushes flow off Pahute Mesa and contributes to convergent flow paths.	13
	B	Flow from the east (relates to deep flow in Fortymile Canyon)	Identify inflow from potential recharge areas at Rainier Mesa to understand whether Area 19 flow paths push water to the west around northern Timber Mountain.	15
	C	Recharge maps	Better characterize the rate and spatial distribution of recharge flux at the water table, predicted for next 1,000 years. Is there too much water in the model?	11
3. Reduce uncertainty in source term applied in CAU model	A	Better “de-composite” tests in composite units	Can source term for tests located in confining units and not contributing to aquifers and the groundwater flow system be reduced.	7
	B	Understand test effects on source term and flow system	Reduce uncertainty in movement of RNs. Can specific RNs be removed from the HST, or tests removed from the sources for the CAU transport model, because they do not contribute significantly over the 1,000-year time frame?	8
	C	Colloidal facilitated transport	Understand characteristics and reduce uncertainty in migration of RNs via colloids.	16

Table C.1-2
Location-Specific Data Collection Objectives
(Page 1 of 2)

Well ID	Priority	Data Need	Location Specification	Data Collection Objectives
1	1	1E, 3C	CAB 2 site, downgradient of ER-20-5 site on the edge of Pahute Mesa; north of the Moat fault	Investigate contaminant plume migration downgradient from TYBO. Characterize Moat fault hydrologic properties and transition to Bench area.
13	2	1C, 1H	On Bench, south of Moat fault across from CAB 2, north of the NTMMSZ; location may be adjusted depending whether contaminants are located in Well 1	Investigate contaminant plume migration downgradient of TYBO and across Moat fault to Bench. Investigate predicted transport paths through Bench. Characterize Moat fault hydrologic properties.
2	3	1C, 1H	On Bench, west side of M1 fault (Boxcar fault extension), north of the NTMMSZ	Investigate predicted transport paths through Bench downgradient from Well 13. Characterize M1 fault hydrologic properties.
4	4	1C, 1H	On Bench, west side of M1 fault (Boxcar fault extension), south of the NTMMSZ	Investigate transport path through the Bench, along M1 fault downgradient from Well 2. Characterize M1 fault hydrologic properties.
5	5	1B, 1A, 1G	Northwest of Timber Mountain in Timber Mountain moat, near moat structural margin/transition from the Bench area	FCCM/TMCM hydrostratigraphy/hydrology, composite unit structure, geochemical sampling, large-scale hydraulic testing of composite units.
8	6	1H, 1B, 1A, 1G	Northwest of TMD in Timber Mountain moat near Timber Mountain margin, west side of M1 fault (Boxcar fault extension)	Investigate transport path downgradient of Bench, along M1 fault downgradient from Well 4. Characterize M1 fault hydrologic properties.
12	7	1C, 2A	Northwest of Timber Mountain on Bench, south of the NTMMSZ, north of Timber Mountain moat boundary across from Well 5	Investigate alternate western transport paths across Bench. Characterize transition from Bench to Timber Mountain moat.
3	8	1C, 1H	On Bench, east side of M1 fault (Boxcar fault extension) across from Well 2	Investigate transport paths off Pahute Mesa east of Boxcar fault. Characterize M1 fault hydrologic properties.
6	9	1B, 1A, 1G	West of TMD in Timber Mountain moat near Timber Mountain margin	Investigate transport paths along TMD margin downgradient from Well 8. Characterize TMD margin hydrologic properties. Tracer test in the FCCM/TMCM.
14	10	3B	Downgradient from BENHAM, between BENHAM and TYBO	Track RN migration from BENHAM toward TYBO. Evaluate contaminant evolution along transport path.
19	11	1H	North of Moat fault, west side of West Greeley fault; ER-20-4 site (undrilled)	Investigate transport paths from Central Pahute Mesa along West Greeley fault and off Pahute Mesa. Characterize West Greeley and Moat fault hydrologic properties.

Table C.1-2
Location-Specific Data Collection Objectives
(Page 2 of 2)

Well ID	Priority	Data Need	Location Specification	Data Collection Objectives
9	12	1I	Central area of TMD	Determine the water table elevation and vertical gradient in the TMCM beneath TMD, characterize hydraulic conductivity of the Timber Mountain core and effect of the fracture/fault structure.
7	13	1B, 1A, 1G	Second well for an *in situ* tracer test in the FCCM/TMCM, paired with a previously drilled investigation well	Forced-gradient tracer-test production well to determine FCCM/TMCM transport properties.
15	14	3B, 3C, 1D	BENHAM drillback and near-cavity	BENHAM cavity, near-cavity sampling and hydrology. Investigate potential for source release from the cavity to the lower aquifer?
16	15	2A	West side of Thirsty Canyon Lineament, along the south edge of Pahute Mesa	Locate lineament structure, characterize the physical nature of the lineament, determine the hydraulic properties along lineament, connectivity to other structure, vertical gradient between volcanic aquifer(s) and LCA.
17	16	1H	Along the west side of the West Greeley fault, central Pahute Mesa	Characterize the effect of West Greeley fault on the flow system. Investigate flow paths to or along the West Greeley fault.
18	17	1C, 2B, 1F	East-central edge of Area 20; ER-20-2 site (existing site, presently undrilled)	Evaluate inflow to Area 20 from the northeast, and the direction of flow across Pahute Mesa on the east side of Area 20.
20	18	1D	ER-20-1 (previously drilled and completed just below the water table)	Deepen to provide full-depth of the TSA for sampling and monitoring the western side of central Area 20 east of the Purse fault. Could serve as a high-rate pumping well for an MWAT characterizing the southwest corner of Area 20.
10	19	1B, 1A, 1G	Northwest corner of TMD, across M1 fault from Well 8	Groundwater flow along TMCM margin, heterogeneity of the TMCM, FCCM/TMCM MWAT.
21	20	1F	Fortymile Canyon corridor northeast to east of Timber Mountain	Determine deep geology, vertical gradient to lower, high-K formation(s), hydrologic properties and geochemistry sample of lower aquifer(s).
11	21	1B, 1A, 1G	Northwest of Timber Mountain in Timber Mountain moat, intermediate between Well 5 and Well 6	FCCM/TMCM heterogeneity, investigate alternate flow paths from Bench.

C.1.2 Drilling Locations

The subcommittee evaluations produced recommendations for a sequence of drilling sites chosen to provide maximum potential for resolving the topical issues and priority data needs summarized in Table C.1-1. The evaluation process by the committee represents an important transition in UGTA studies from exploratory studies designed to generally enhance knowledge of RN transport off of Pahute Mesa to characterization studies designed to address topical problems of flow and transport within and away from the mesa. The overall goal is to develop increased confidence that the results of transport modeling are both realistic physically and the modeling approach can be used to predict the future location of contaminant boundaries for the CAU, the goal of the UGTA strategy. Because drilling is the primary basis for acquiring new data, data collection specifications for acquiring new data were organized around identification of locations for drilling new boreholes and installing wells where data could be collected to resolve issues listed in Table C.1-1. The *ad hoc* Subcommittee identified 21 locations, shown on Figure C.1-1, for drilling and well construction where data collection would address data needs identified in Table C.1-1. This figure focuses on the area from southern Pahute Mesa south to the center of TMD (colored shading) in which the proposed wells are located. The topography is shown in shaded relief, and structural features (broad red lines) are the same as identified on Figure 5-1. It is not implied that all 21 wells would be required to collect sufficient data to achieve an acceptable level of modeling uncertainty. Many wells address multiple data needs; only the primary focus for each well is identified with the data needs. The identified drilling locations collectively address data collection for all identified data needs. A subset of wells will address many issues to a greater or lesser extent. The wells are prioritized according to the data needs prioritization judged to achieve the greatest overall uncertainty reduction regarding the contaminant boundary prediction.

The sequence of drilled wells will determine the sequence of availability of information for resolving the data needs. The subcommittee discussed extensively which wells should be drilled first, recognizing that information from the early wells could strongly impact the priorities and justification for subsequent wells. A general strategy was developed to sequence wells to answer the following interrelated questions:

1. What are the processes of release of RNs from their source tests, and what transport pathways control migration off of the mesa? Finding contaminant plumes will provide the first test of

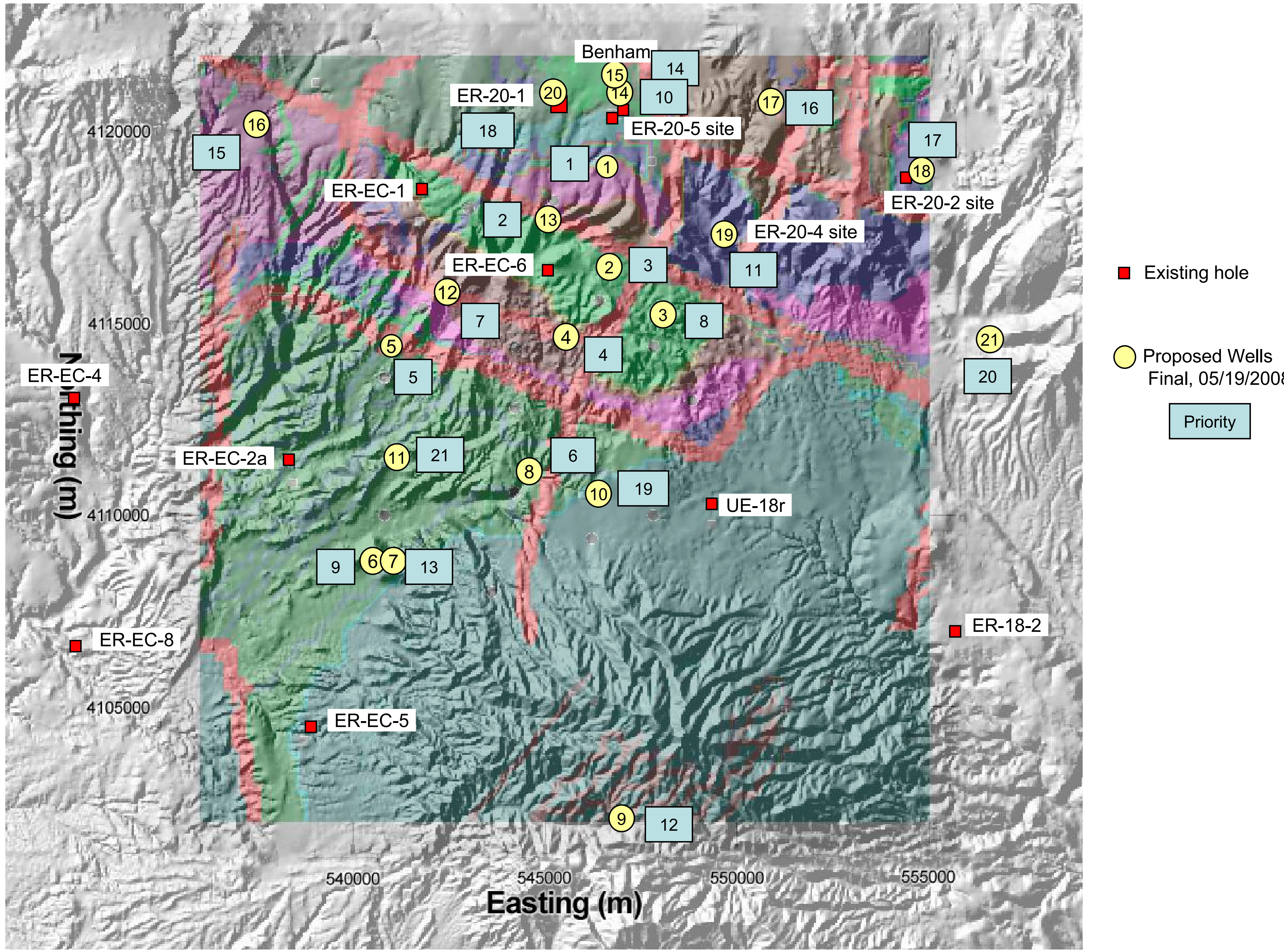

Figure C.1-1
Locations of Potential Wells Identified by the TWG Pahute Mesa Phase II CAIP *ad hoc* Subcommittee
Note: TWG Pahute Mesa Phase II CAIP *ad hoc* Subcommittee working map.

model predictions. If contaminants are not discovered in the near-source wells, then fundamental assumptions of the source tern and transport models may require re-examination.

2. How do RNs move across the Bench area, a site of convergent groundwater flow? Convergent flow across the Bench results in high groundwater flux and increased transport. The model features that result in convergence of flow must be tested during an early stage of the exploration program.

3. What are the controlling pathways for RN transport downgradient of the Bench area and west and southwest of Timber Mountain? Do RNs follow a narrow zone of high-permeability fractured welded tuff near the TMCM and FCCM contact, or is transport more widely distributed across the western Timber Mountain caldera region?

Question 1 is concerned with locating and characterizing contaminant plumes downgradient of TYBO and drill hole ER-20-5, and the first three recommended drill holes are located south, southwest, and southeast of ER-20-5. These data will allow assessment whether the Phase I predictions of RN transport are consistent with contaminant plume locations and RN concentrations. The drill holes will provide information concerning what HSUs control RN transport and the geologic structure and stratigraphy near the Moat fault.

Drill hole ER-20-7 (1 on Figure C.1-1) is directly south of ER-20-5 and is a high-priority site for intersecting contaminants assuming southward migration of RNs. It is sited at the approximate location of the highest-priority drill-hole site recommended by the CAB. Drill hole ER-EC-11 (2 on Figure C.1-1) is located south of the Moat fault in the transition to the Bench area and southwest of TYBO and drill hole ER-20-5. It will allow assessment whether RNs are moving southwesterly off of the Mesa. Previously drilled holes ER-EC-6 and ER-EC-2a did not encounter RNs. These new holes are sited in the same area but not as far off the Mesa and more consistent with the modeled transport path. Drill hole ER-20-8 (2 on Figure C.1-1) is located southeast of drill hole ER-20-5, south of the Moat fault, and will allow assessment of the importance of southeast directed RN migration possibly controlled by the Boxcar fault. Each drill-hole location may account for multiple data needs described in Tables C.1-1 and C.1-2.

Question 2 is concerned with better establishing the stratigraphy, structure, and hydrology in the complex geologic setting of the Bench area that straddles the south edge of the SCCC, a probable outer-caldera highland segment of the SCCC and the north edge of the TMC. Information gained from drilling exploration of this area should allow further evaluation of the validity of converging groundwater flow as well as promote refinements of the alternative geologic models of the area, the permeability and heterogeneity of local volcanic aquifers and confining units, and the hydrological effects of the south extension of the Boxcar fault. Drill hole ER-EC-12 (4 on Figure C.1-1) is located between the south SCCC and north Timber Mountain ring fracture zones and is directly south of drill hole ER-EC-6, where no groundwater contamination was detected. Drill hole ER-EC-13 (5 on Figure C.1-1) is located south of the north ring-fracture zone of Timber Mountain where a thick sequence of FCCM is present at the water table. This volcanic unit is an expected low-permeability HSU that may strongly affect or control groundwater flow convergence in this critical area. The drill hole will allow evaluation of the permeability and heterogeneity of the FCCM. Drill hole ER-EC-13 (5 on Figure C.1-1) is located in an analogous structural and stratigraphic setting as drill hole ER-EC-12 but is southwest of drill hole ER-EC-6. Drill hole ER-20-9 (8 on Figure C.1-1) is located between the SCCC and Timber Mountain calderas, where the Benham aquifer is present at the water table and additionally in close proximity to the extension of the Boxcar fault and relatively impermeable VCUs. Its location in combination with drill holes ER-EC-15 (7 on Figure C.1-1) and ER-EC-12 completes a west-to-east exploration transect across the Bench area.

Question 3 is concerned with further testing the existence and hydrological significance of a channel of high-permeability fractured welded tuff following the contact between the FCCM and TMCM (Plate 2). This feature, if present, strongly affects the distance of transport of RNs from the Bench area toward Oasis Valley. Drill hole ER-EC-14 (6 on Figure C.1-1) is sited near the FCCM and TMCM contact, and will allow assessment of the permeabilities and heterogeneity of these important HSUs. Drill hole ER-EC-16 (9 on Figure C.1-1) is located downgradient of ER-EC-14 and will allow assessment of the permeability and heterogeneity of the FCCM and, specifically, whether the permeability of the HSUs is low and will spatially restrict groundwater flow within the upper part of the higher-permeability TMCM.

Most of the drill holes are located sufficiently close to allow investigation of hydrological effects of pumping tests conducted at adjacent drill holes. The temporal spacing of drilling activities with reduced or no exploration during the winter months will allow for evaluations of the significance of new data acquisition possibly enhanced by modeling studies during the proposed three-year cycle of drilling exploration. It is possible that knowledge gained from early drilling of higher-priority drill holes will affect the data needs and conceptual models of flow and transport in the targeted areas of the Pahute Mesa model domain. These data may affect the locations and justifications of lower-priority drill holes, and an iterative approach to the drilling program will be needed. The assumption for the prioritization by the subcommittee was that up to 12 wells may be accommodated within the project budget. The subcommittee agreed that the prioritization would remain the same if 10 drill holes are completed. The proposed drilling program will allow for evaluation of new data between drilling programs with use of information gained to potentially adjust drilling plans, in consultation with NDEP, for subsequent drilling campaigns. The investigative plan and priorities for the drilling program will need to maintain flexibility as exploration proceeds to maximize information gained through drilling.

C.1.3 Data Analysis Proposals

The *ad hoc* Subcommittee also developed recommendations for additional analysis and development of the flow and transport models, and supporting HFM and source-term models. These recommendations are organized by categories related to the models that they serve. Many of these recommendations could be incorporated into the Phase II tasks for revision of the flow, transport, and supporting models, but others would require specific tasks for implementation.

Geology

1. Expand the Phase I TMCM sub-HSU differentiation model to include eastern Timber Mountain.

2. Load the TMCM sub-HSU differentiation model into the EarthVision HFM.

3. Develop a Bench area detailed model.

4. Develop alternative conceptual models of the Bench.

5. Develop a conceptual model of heterogeneity in VAs and VCUs in Western Pahute Mesa.

6. Subdivide LFA and TCU intervals in the CHZCM.

7. Conduct fault studies south of Pahute Mesa and in the Transvaal Hills, expanding FY 2008 work.

8. Investigate the extent of hydrothermal alteration at the Transvaal Hills, especially to the north.

9. Evaluate the potential effect of the alteration on groundwater flow paths.

10. Develop descriptions of HFM feature alternatives (but not digital models).

Hydrology

11. Revise the Central and Eastern Pahute Mesa hydrologic conceptual models.

12. Refine the hydraulic conceptual model based on a systematic review of hydraulic test data.

13. Re-evaluate existing hydraulic testing data from ER-EC wells for additional information.

14. Develop better understanding of the hydrology of faults. Specifically, investigate the potential for fault controlled anisotropy based on previous hydraulic and tracer tests. Also, use sub-CAU models to model MWATs and estimate large-scale HSU and fault properties.

15. Investigate infiltration of precipitation through the vadose zone to assess potential for reaching saturated zone.

16. Develop a conceptual model of potential recharge on Timber Mountain and a recharge mound beneath TMD.

Geochemistry

17. Incorporate new isotope and geochemistry data from new wells into the geochemical conceptual model, recharge models, geochemistry mixing models, and flow path analysis.

Flow Modeling

18. Use local sub-CAU model for the Bench/northwest Timber Mountain/southern SCCC area to optimize design of MWAT(s) and for interpretation.

19. Evaluate the effect of the TMCM detail model on the flow and transport model results.

20. Evaluate the impact of the Bench detail model and HSU heterogeneity on the flow field.

21. Re-evaluate Phase I alternative models using revised geochemistry mixing models.

22. Develop methods to incorporate smaller scale features through random field generator (decomposite HSUs).

Transport Parameters

23. Develop improved characterization of fracture aperture, fracture spacing, and matrix diffusion.

24. Develop characterization of spatial distribution of fracturing parameters. Measure effective porosity on core, particularly for the FCCM and TMCM.

Source Term

25. Develop improved simplified source model analysis/upscaling. Develop better assessment of source inventory.

26. Investigate potential removal of RNs due to gas phase transport, both early-time and by barometric pumping. Compare to near-field sampling data.

27. Improve the source term applied for each test by incorporating detail information on permeable intervals within the HSU in which each cavity is located.

28. Assess variability of source term distribution and geochemical processes in the exchange volume to refine/bound the abstraction to the SSM.

Transport Modeling

29. Develop improved representative models of fracture system parameters.

C.2.0 References

SNJV, see Stoller-Navarro Joint Venture.

Stoller-Navarro Joint Venture. 2009. *Phase I Transport Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nevada Test Site, Nye County, Nevada*, Rev. 1, S-N/99205--111. Las Vegas, NV.

Appendix D

Community Advisory Board Review and Recommendations

D.1.0 Community Advisory Board Review and Recommendations

As part of the federally chartered Environmental Management Site-Specific Advisory Board, the CAB for NTS Programs is an appointed formal group of volunteers and liaison members organized to provide informed recommendations and advice to the NNSA/NSO Environmental Management Program. This appendix contains the cover letter and a technical summation report from the CAB to NNSA/NSO, data providing their review of the Phase I CAI work, their review of the state of knowledge for the Pahute Mesa CAU, and their recommendations for drilling new wells. Three recommended locations are identified for drilling and provide justification for each location. In particular, Figure 10 of the technical summation report provides a map showing the locations of the recommended drillings.

Attachment 1

Community Advisory Board Review and Recommendations

- Cover letter: "Community Advisory Board for Nevada Test Site Programs (CAB) Recommendation for Proposed Well Locations in the Pahute Mesa Area at the Nevada Test Site — Technical Summation and Stakeholder Summation"
(3 pages)

- Report: *Technical Summation, Recommendations for Proposed Well Locations in the Pahute Mesa Area at the Nevada Test Site*
(31 pages)

Community Advisory Board for Nevada Test Site Programs

September 19, 2007

Mr. Stephen A. Mellington
Assistant Manager for Environmental Management
U.S. Department of Energy – Nevada Site Office
P. O. Box 98518
Las Vegas, NV 89193-8518

RE: Community Advisory Board for Nevada Test Site Programs (CAB) Recommendation for Proposed Well Locations in the Pahute Mesa Area at the Nevada Test Site – Technical Summation and Stakeholder Summation

Dear Mr. Mellington:

The Community Advisory Board for Nevada Test Site (NTS) Programs (CAB) would like to present the Technical and Stakeholder Summations of our Recommendation for Proposed Well Locations in the Pahute Mesa Area at the Nevada Test Site.

In 2002, Mr. Carl Gertz, former Assistant Manager for the U.S. Department of Energy Nevada Site Office Environmental Management (DOE NSO EM), presented the CAB with the opportunity to select a location for a monitoring well. After initial study of the Underground Test Area (UGTA) sub-project, the Committee decided to make recommendations for three wells, which are outlined in the CAB letters to DOE NSO EM dated February 9, 2005 and February 10, 2006.

The Committee has spent five years of extensive study and in-depth review of the DOE NSO EM UGTA project. The Committee worked closely with expert hydrologists, geologists, academia, and regulators; reviewed technical reports and maps; attended numerous meetings with DOE NSO staff, which included State of Nevada and Nye County representatives; listened to numerous briefings by DOE scientists; and conferred with the UGTA Technical Working Group (TWG).

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Additionally, to ensure that potentially-affected stakeholders were aware of this effort, the CAB conducted formal public information meetings in Las Vegas, Pahrump, Amargosa Valley, and Beatty; participated in several meetings with Nye County representatives; sponsored informational groundwater workshops; and presented informational briefings to the town boards in rural communities that would most likely be impacted if radionuclides were detected in groundwater outside the NTS boundaries.

The purpose of the Technical Summation is to summarize groundwater issues that the CAB UGTA Committee studied, identify groundwater uncertainties, and provide justification for our recommended well sites. The committee strongly supports continued research in this area and recommends that DOE make every effort to secure added resources to collect additional hard data. This would demonstrate their commitment to the protection of public health, safety, and the environment for residents living down-gradient of the Nevada Test Site.

The Stakeholder Summation is less technical and designed for readability for the general public. This report summarizes the UGTA project, the Federal Facility Agreement and Consent Order (FFACO) and the State of Nevada Division of Environmental Protection (NDEP) agreement, and highlights the geologic, hydrologic, geochemical, structural, and underground nuclear testing considerations taken to make the well recommendations. The report also addresses additional stakeholder concerns and the need for more community outreach and information.

The CAB wishes to express its appreciation to the DOE NSO EM staff, State regulators, engineers and scientists, the UGTA TWG, and the CAB technical and support staff, who have been extremely helpful and patient with our many questions and requests.

We recognize that the UGTA sub-project is a monumental task requiring a great deal of work toward the goal of gaining a better understanding of NTS geology and groundwater system. We appreciate the opportunity we've been given to delve into the details of the project and have a deeper understanding and appreciation of the effort involved. The CAB UGTA Committee looks forward to participation and review of subsequent phases of the UGTA project as they develop.

Sincerely,

/s/ David Hermann

David Hermann, Chair
Community Advisory Board
for Nevada Test Site Programs

cc: U.S. Senator John Ensign
U.S. Senator Harry Reid
U.S. Congresswoman Shelley Berkley
U.S. Congressman Dean Heller
U.S. Congressman Jon Porter
J. Rispoli, DOE/HQ, (EM-1) FORS
M. Nielson, DOE/HQ, (EM-13) FORS
W. Wilborn, NNSA/NSO EM, Las Vegas
K. Snyder, NNSA/NSO EM, Las Vegas
T. Murphy, State of Nevada, NDEP
C. Sanda, Consensus By Design, LLC
R. Rehfeldt, Navarro Research & Engineering, Inc.
CAB Members

TECHNICAL SUMMATION

Recommendations
For Proposed Well Locations
In The Pahute Mesa Area
At The
Nevada Test Site

The Community Advisory Board
for Nevada Test Site Programs

...Citizens Working Together on Environmental Issues

NEVADA TEST SITE COMMUNITY ADVISORY BOARD (NTS CAB) REPORT

FOR PROPOSED WELL LOCATIONS IN THE PAHUTE MESA AREA

ABSTRACT

In 2002, the U.S. Department of Energy Nevada Site Office Environmental Management (DOE NSO EM) offered the NTS CAB, hereinafter referred to as CAB, an opportunity to identify a site to drill a well in response to stakeholder concerns about the potential movement of radionuclides in groundwater from past nuclear weapons tests on Pahute Mesa. The purpose of this paper is to summarize the groundwater issues that the CAB Underground Test Area (UGTA) committee studied and to provide justification for our recommended well sites. The committee strongly supports continued research in this area and recommends that DOE make every effort to secure added resources to collect additional hard data. This would demonstrate their commitment to the protection of public health, safety, and the environment for residents living near Western Pahute Mesa.

I. INTRODUCTION

The objectives of this paper are to identify groundwater uncertainties for nearby communities and provide the DOE with background for the CAB letter of February 2005[1] which recommended drilling three additional wells in the northwestern part of the Nevada Test Site[2] (NTS). Following the framework outlined by the Federal Facility Agreement and Consent Order (FFACO 1996),[3] the DOE and the Nevada Division of Environmental Protection (NDEP) agreed to work together to prioritize projects dealing with environmental contamination at the NTS that "…protect the public health, safety, and the environment."[4] A major focus of this cooperative effort is based upon the work of scientists from multiple disciplines[5] who are working together to identify current groundwater contamination boundaries[6] for the NTS. This includes the Central and Western Pahute Mesa region, the location of 82 underground nuclear tests[7] with radioactive contamination[8] consisting of long-lived radionuclides such as plutonium.[9] Due to current technological limitations and the prohibitive cost of cleanup,[10] they have chosen to use a modeling/monitoring approach.[11] Identifying boundaries for long-lived radionuclides is a difficult task given the limited number of wells and multiple uncertainties with respect to geology, hydrology, and migration of radionuclides.

As part of their overall strategy, scientists use "flow paths from existing models for determining future or new well locations"[12] in order to collect data for characterization of the region.[13] Residents of Oasis Valley, Beatty, and Amargosa and members of the CAB questioned whether the models[14] and plans for data collection meet nearby residents' immediate concerns given their dependence on the use of well water. They question whether these models are able to predict optimal well locations that may provide scientists with data to support or reject the hypothesis that the contamination has boundaries.

In support of the stakeholder concerns, consider the following three excerpts from the American Society of Mechanical Engineers (ASME) 2001 technical peer evaluation where the experts identify concerns with respect to the strategy to locate wells.

> "The fundamental problem with the above steps and decision points is that 'consensus is required concerning the adequacy of data and data analysis prior to proceeding with the next phase or step of corrective action activities.' This requirement is not achievable without iterations between three activities: 1) data acquisition; 2) modeling; and 3) early verification of modeling predictions….. However, no information was given that suggested plans for interactions between modeling and early verification of modeling predictions."[15]

The experts continue with the following statement

> "Interaction between modeling and near-term confirmation of the models is recommended. This interaction should be based on the transition region between the near field and the far field."[16]

Finally, consider the ASME report recommendation 3, at p. 189 where

> "The sensitivity of the regional flow model to boundary effects in the Oasis Valley/Pahute Mesa area should be investigated further. The central location of many of the CAUs relative to the regional flow model reduces the significance of model boundary effects and allows reasonable assurance

> for developing flow pathways. The one remaining concern is the proximity of Oasis Valley and Pahute Mesa to the northwest boundary of the regional flow model domain. The sensitivity of the regional flow model to edge effects is not known."[17]

These quotes from the technical peer review in 2001 all provide support for additional data.

Furthermore, some experts have identified problems with relying on models that have a relatively small number of observations for a large area, missing observations for large areas, and multiple uncertainties in the underground environment.[19] Responding to these concerns, in 2002, Carl Gertz, Assistant Manager of DOE NSO EM offered the CAB an opportunity to locate a well.[21]

This paper is organized as follows: Section II provides background on groundwater contamination issues for residents living near Western Pahute Mesa; Section III identifies the area of focus for the CAB UGTA committee; Section IV reports three well location recommendations and supporting evidence; Section V presents a brief discussion and Section VI provides conclusions to this paper.[22]

II. BACKGROUND

The purpose of this section is to provide a brief description of information the CAB UGTA committee examined with respect to what is known about the potential movement of radioactive contaminants in groundwater near Pahute Mesa. We identify maps that illustrate the proximity of nearby communities to Pahute Mesa as well as models for the area. We summarize the unexpected findings of Kersting et al. (1999)[23] where they discovered that plutonium, a radionuclide, moved southward in groundwater under Pahute Mesa near the NTS boundary. Next we report uncertainties with respect to geological, hydrological, chemical, and radiological data, as well as the potential for data gaps in this very large area. We end this section with a discussion of several uncertainties.

(a) What is known about the area between Oasis Valley and Pahute Mesa?

The communities of Oasis Valley, Beatty, and Amargosa Valley are the closest communities to Pahute Mesa. For perspective, consider the following maps produced by Laczniak et al. (1996),[24] Mankinen et al. (2003),[25] Stoller-Navarro (2006)[26] and Fridrich et al.

(2007)[27] which we identify as figures 1 through 4b. Figure 1 shows the Pahute and Western Pahute Mesa corrective action units in the northwestern corner of the NTS where there were 64 and 18 underground nuclear tests, respectively.[28] Nuclear tests on Pahute Mesa account for 61 percent of the total radionuclide inventory for the entire NTS.[29] Figure 2 is a map that shows mainly volcanic rock and some valley fill in the area between Pahute Mesa and Beatty. Figure 3 shows geophysical data including the Silent Canyon and Timber Mountain caldera complexes with dashed lines and the “inferred position of the Thirsty Canyon Fault zone” with “wavy pattern, queried where uncertain…” This map in figure 3 highlights the Thirsty Canyon Fault zone and springs near Springdale and Beatty. Mankinen et al. (2003),[30] the authors of this figure, report that “[a]mong the many, potentially important features characterized, the Thirsty Canyon fault zone provides one of the most direct routes for groundwater flowing from the northwestern part of the Nevada Test Site to reach inhabited areas to the southwest and warrants special attention for monitoring efforts.” Figures 4, 4a, and 4b were produced by Fridrich et al.(2007). Figure 4 shows the Thirsty Canyon Fault trending southwest to the spring discharge area just north of Beatty. Figures 4a and 4b provide details for Figure 4 with respect to the multiple domains near Beatty and illustrate the complex geology and hydrology of the area.

Following the FFACO, see Figure 5, the UGTA scientists created a regional flow model for the entire NTS area[31] and later a smaller model commonly referred to as the Pahute Mesa and Oasis Valley model.[32] This second model covers an area of approximately 1,042 square miles[33] and is based on data from 180 wells and springs for the Pahute Mesa region.[34][35] Figure 6 is a map that shows the area of the latest Pahute Mesa and Oasis Valley Groundwater Flow Model produced by Stoller-Navarro (2006). Our focus is on the area between Pahute Mesa and nearby communities of Oasis Valley and Beatty where 7 wells are located between the NTS boundary and the Oasis Valley discharge area[36] and 12 more wells are located in Oasis Valley.[37] For perspective, Figure 7 shows 76 locations where data was collected and used in the Stoller-Navarro (2006) model.[38][39] This map is important because it shows the locations of several key wells near Beatty labeled 70, 71, 73, and 76 for wells number ER-OV-5, ER-OV-2, ER-OV-3a, and ER-OV-4a, respectively.[40] Figure 8 shows hydrogeologic domains such as the Detached Volcanics Domain where ER-OV-5 is located but does not display these other wells. We will consider wells ER-OV-5 and ER-OV-4a in the next paragraph.

The underground water environment of Western Pahute Mesa is described as a fracture-flow environment.[41] Many scientists have studied the geologic, hydrologic, chemical, and physical (porosity and permeability) characteristics of the NTS and region. Based on models and sparse data collected, multiple reports and papers predict a southerly and southwesterly flow of groundwater.[42] Estimated flow velocity for groundwater in the area are “1 to 80 m [per] yr[].”[43] Figure 9[44] illustrates some of these predicted southward flow paths, some of which would flow into Oasis Valley. Note that this figure is based upon work where a higher weight is placed on well ER-OV-4a (weight = 0.77) while a much lower weight is placed on well ER-OV-5 (weight $=1 \times 10^{-3}$). It is unclear whether these weights are based upon an assumption or a result of the Pahute Mesa Model. What is clear, however, is that the model shows predicted flow paths going through ER-OV-4a but not ER-OV-5. These results appear to show different predictions for Oasis Valley and Beatty.[45]

(b) What are some of the issues that individuals in nearby communities are concerned about?

Nearby communities are concerned that the FFACO process to identify boundaries for contaminants may miss potential groundwater flow paths in such an environment. They refer to statements by scientists such as "...we do not plume chase" as an example of scientific disregard for their health and well being. Further, they report skepticism with models that appear to be based on a presumption that there are boundaries to groundwater flow near communities given such a complex fracture-flow environment. Finally, residents in nearby communities express concern about federal budget cuts, as there is a perception that the EM programs at the NTS are a low priority for the entire DOE complex. Overall, citizens in the communities of Oasis Valley, Beatty and Amargosa Valley express support for more real data and less modeling.[48] If modeling must be used, then validation of those models must be provided using data from wells located between residents and the contaminant sources.

(c) Can plutonium migrate in groundwater?

Kersting et al. (1999)[49] report evidence, primarily from well number 1 in the ER-20-5 well cluster, that plutonium[50] from the 1968 Benham test migrated[51] 1.3 kilometers (km) to the south. Note that the sampling point of well number 1 is considerably higher than the depth of burial for the Benham test and is the shallowest of the two wells that were extensively sampled. This result is unexpected because it showed that plutonium, a relatively insoluble radionuclide,[52] was transported away from the immediate vicinity of an underground test cavity. In this case, the plutonium not only traveled horizontally but was detected in two aquifers separated 300 meters vertically.[53] Their findings suggest that "models that either predict limited transport or do not allow for colloid-facilitated transport may thus significantly underestimate the extent of radionuclide migration."[54] In their discussion, the authors consider the possibility that the Benham test, later tests, or pumping of groundwater might have transported the radionuclides. However, they state that this is "highly unlikely." Instead they report that plutonium may have been carried "through fractures a few hundred meters and subsequently transported by groundwater."[55] It is important to note that the authors also state "that [less than] 1% of the observed [plutonium] is in the dissolved fraction of the groundwater."[56] Hence, whatever the transport mechanism, the plutonium migrated as a colloid and not as a dissolved salt in the groundwater. Finally, from an environmental contamination point-of-view, it is important to note that Kersting et al. (1999) qualify their findings by pointing out that the Plutonium measured at ER-20-5 is "a small fraction of the total Plutonium associated with the Benham nuclear test."[57]

(d) What uncertainties exist in this area?

While the area has been studied by many scientists, uncertainties remain with respect to the hydrologic character of the Thirsty Canyon Structure (Fault or Lineament), the Timber Mountain Bench, and the Silent Canyon Caldera. It is not known whether these geologic formations are barriers or conduits for groundwater flows.

Given the unexpected findings by Kersting et al. (1999), a variety of uncertainties, the proximity to nearby communities, and concern by potential receptors that the models appear to presume Beatty and other nearby communities will not be affected by groundwater contamination while Oasis Valley might be affected,[59] we focused our well-site evaluation to the area between the southwestern edge of the Pahute Mesa on the NTS, and nearby communities.

III. APPROACH

The CAB UGTA committee is composed of individuals from multiple disciplines. In order to identify potential sites for wells, our committee obtained information from multiple sources including: stakeholders, scientists (DOE, government contractors, State of Nevada, UGTA peer review group, UGTA Technical Working Group (TWG), and others), reports, academic books and peer-reviewed journal articles. See Appendix I. for a summary of papers and reports.[60] Our goal was to focus on the geological, hydrological, chemical and radiological uncertainties identified in the previous section and identify potential well sites that might reduce some of these uncertainties.

After extensive reviews and meetings over a period of five years,[61] our committee initially provided DOE with three recommended well locations. DOE provided our committee with a map that identifies the nearby communities, existing wells, and our recommended wells shown in Figure 10. We include two additional aerial photographs called Figures 11 and 12 provided by DOE that illustrate the CAB recommendation sites with respect to accessibility. Technical experts working on the UGTA project reviewed the CAB recommendations and provided helpful comments and suggestions.

IV. WELL RECOMMENDATIONS[62]

As stated in the CAB (2005) letter, see Appendix II, three locations for wells were identified as CAB 1, 2, and 3. See Figures 10, 11, and 12 for a map and two photographs of the area with well locations, respectively. With respect to CAB 1, we recommend installing a well down gradient of well ER–20–5 # 1. We recommend CAB 2 be located down gradient of the first well in the transition area between the Silent Canyon caldera and the possible barrier, the Timber Mountain bench area to obtain more information about the bench structure, i.e. groundwater barrier or conduit. Finally, with respect to CAB 3, we are interested in a third well at the junction of the potential barrier structure (the “bench”) and a major fault, the Thirsty Canyon Structure identified by geophysics as a possible fast path into Oasis Valley.[63] On further analysis of the site accessibility, we have withdrawn a specific location for now because of the difficulty of physical access. However a third well in this area is still important to complete a system to enhance our understanding of the groundwater flow direction.

These wells could show us how much farther radionuclides have been transported beyond ER-20-5#1, the general direction of groundwater flow in that area, and may also add to our understanding of the hydrologic characteristics of the bench; i.e. whether it is a barrier or conduit to groundwater flow.

V. DISCUSSION

There are several issues to discuss with respect to our well recommendations. First, many people on the CAB UGTA committee worked on this for over six years through multiple CAB members, multiple technical advisers, multiple public meetings, and personnel changes at DOE. In spite of all of these changes, the level of overall openness and cooperation remained strong throughout the process. The committee was provided with a great deal of support including maps, the latest reports, data, and access to the groundwater modeling team. We were also provided the exact coordinates of the wells and springs used in the latest model published by Stoller-Navarro (2006).

Second, there is a timing issue to consider with respect to this paper. We refer to the Stoller-Navarro (2006) report throughout this document. Although this report was published after the CAB (2005) letter, key presentations and maps presented to the CAB were incorporated in this later report.

Finally, we acknowledge and appreciate the different perspectives provided by the UGTA TWG in their comments to and discussions with committee members. We recognize the tradeoffs between expenditures on sophisticated models and additional data collection through wells. Our recommendation for multiple wells is approximately $18 million,[64] almost a quarter of an annual budget for the NTS EM program and we acknowledge that there are risks to workers associated with drilling at least one well potentially contaminated with radionuclides. We base these recommendations on the following: the current model covers approximately 1,042 square miles and is based upon less than 180 data points with sparse data coverage in the areas between Western Pahute Mesa and Oasis Valley; there is evidence that plutonium did move 1.3 kilometers south over a 30-year period; and finally, there is a need for additional information in areas with sparse coverage to support or reject hypotheses that water flows south rather than west and that wells such as ER-OV-4a appear to serve as a western-most point of potential contaminant flows. If a case is to be made that there are scientifically defensible boundaries for contaminant flows, hard data is critical to this effort to either support or reject this hypothesis.

VI. CONCLUSION

This paper attempts to resolve some of the concerns of down-stream residents about the potential migration of contaminated groundwater to their wells and/or springs. We report what is and is not known about the underground environment down gradient of Western Pahute Mesa, the Thirsty Canyon Lineament and Timber Mountain Bench. Based on what is not known, we identified three locations to site wells and collect data. Upon further examination we now stand by two of these recommendations and recommend, for future research, that a third well be identified in place of the withdrawn recommendation. The authors hope to have stimulated interest in addressing uncertainties and concerns for nearby residents. Our analyses, however simplistic, support adding wells to both provide scientists with additional groundwater data and protect the domestic water supply of nearby residents.

VII. REFERENCES:

<u>Acronyms and Abbreviations</u>

ASME	American Society of Mechanical Engineers
BN	Bechtel Nevada
CAB	Community Advisory Board for Nevada Test Site Programs
CAI	Corrective Action Investigation
CAIP	Corrective Action Investigation Plan
CAU	Corrective Action Unit
DOE	U.S. Department of Energy
DoD	U.S. Department of Defense
DRI	Desert Research Institute
FFACO	Federal Facility Agreement and Consent Order
HFM	Hydrostratigraphic Framework Model
LANL	Los Alamos National Laboratory
NDEP	State of Nevada, Division of Environmental Protection
NTS	Nevada Test Site
NNSA	U.S. Department of Energy National Nuclear Security Administration
NSO EM	U.S. Department of Energy Nevada Site Office Environmental Management
SNJV	Stoller-Navarro Joint Venture

TWG	Technical Work Group
UGTA	Underground Test Area
UNLV	University of Nevada, Las Vegas
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator

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VIII. ENDNOTES AND REFERENCES

[1] Community Advisory Board (2005).

[2] We began our study by considering the entire NTS. Given the relative proximity of residents in the Beatty and Oasis Valley regions, the committee chose to narrow its focus on Pahute Mesa.

[3] The Federal Facility Agreement and Consent Order, (FFACO) March 15, 1996, is an agreement between the State of Nevada Department of Conservation and Natural Resources, Division of Environmental Protection (NDEP), the U.S. Department of Energy (DOE), and the U.S. Department of Defense (DoD). It was last accessed at http://ndep.nv.gov/boff/agree.htm.

[4] U.S. Department of Energy (2007; p. 2). According to the DOE, this public involvement plan will be "incorporated into the FFACO as appendix V."

[5] This group is called the Underground Test Area Technical Working Group (UGTA TWG).

[6] American Society of Mechanical Engineers (ASME) (2001) at pp. 135 - 137. According to ASME, the corrective action strategy contains several phases, regional modeling and CAU-specific modeling in order to determine contaminant boundaries. For a definition of corrective action investigation, see FFACO, 1996, at p. 8 "IV.14."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."

[7] ASME (2001; p.19). The Pahute Mesa is split into two Corrective Action Units (CAUs) called the Western Pahute Mesa CAU which consists of 18 nuclear tests and the Central Pahute Mesa CAU which consists of 64 nuclear tests.

[8] According to Bowen et al. (2001; p. 21, Table V) the total radionuclide inventory for Pahute Mesa is 8.01 E+07 Curies (area 19 + area 20 =1.9 E+07 + 6.09 E+07). For perspective, this is approximately 61 percent of the total radionuclide inventory (1.32E+08 total Curies) for the entire NTS. For additional perspective, the total radionuclide inventory for Western Pahute Mesa alone is 6.09E+07 Curies which is approximately 46 percent, the total for the entire NTS.

[9] The half life of plutonium-239 is 24,100 years according to the DOE (2000; p. 12).

[10] According to ASME (2001, p. 130) the estimated total cost of cleanup is $1.3 to 2.5 billion dollars.

[11] According to the DOE (2003) "the total costs of this 141-year effort is projected at $2.2 billion, which includes 100 years of monitoring." According to another source ASME (2001, p. 127) the cost of the modeling/monitoring approach is an estimated $240 million for 50 years.

[12] Consider excerpts from Gertz's letter to Claire, DOE (2002) describing the DOE strategy for well locations. "The UGTA Project utilizes the flow paths from existing models for determining well locations and will continue to utilize them in executing the strategy. NNSA/NV recognizes that the Pahute Mesa area is of high importance and has focused a considerable amount of effort in this area. Of the 40 new wells that the UGTA Project has drilled, 28 have been drilled in the Pahute Mesa/Oasis Valley area. The UGTA Project is evaluating all of the data collected and developing a model of this area to better determine the optimum locations to collect new data, if needed."

[13] See ASME (1999, pp. 135 – 137) for a description of the first phase on regional modeling and figure 42, process flow diagram for the underground test area CAUs. This was part of the early phase of the FFACO and Corrective Action Investigation Plan (CAIP) (1999) to eventually plan and build a monitoring network of wells.

[14] For a definition of model see National Research Council (2000; p. 5, footnote 5) "A conceptual model is a description of the subsurface as estimated from knowledge of the known site geology and hydrology and the physical, chemical and biological processes that govern contaminant behavior." See p. 50 for a definition of "Validate – Verify conceptual models and the performance of remediation processes or strategies."

[15] ASME (2001; p. 181) "For example, as modeling proceeds with consideration of both 'discrete' and 'distributed' uncertainties, additional data will be needed to increase confidence. The data needed may include evidence (e.g., seismic profiling) or monitoring at either existing or new wells to discriminate between alternative hydrogeologic models and hydrologic properties of the subsurface. During questioning, it was learned that interactions between data acquisition and modeling are in fact taking place and will continue to take place. However, no information was given that suggested plans for interactions between modeling and early verification of modeling predictions."

[16] ASME (2001; p. 188).

[17] ASME (2001; p. 189).

[19] National Research Council (2000, p. 113).

[21] Letter from Gertz to Claire, DOE (2002) states "As you can see in the responses above, NNSA/NV is and will continue executing the UGTA strategy in accordance with your comments and the peer review recommendations. I continue to offer the CAB, in conjunction with their technical adviser, the opportunity to select a location for a sentinel/transition well. My staff will be happy to discuss this with you and assist the CAB in this endeavor."

[22] For a summary of the committee processes, see Nevada Test Site Community Advisory Board, Stakeholder Summation Recommendations to Address Groundwater Concerns at the Nevada Test Site, September 2007.

[23] Kersting et al. (1999).

[24] Laczniak et al. (1996).

[25] Mankinen et al. (2003). "Figure 16… ..inferred position of the Thirsty Canyon fault zone (wavy pattern, queried where uncertain….)…and major springs in the Oasis Valley discharge area. Solid circle, water well; symbols, wells with radioactive contamination. Contour interval 100 m."

[26] McCord et al. (2006). We use several figures from this report. They are figure 1 at p. 83 on pdf file, Figure 1-1: Location of the Pahute Mesa Corrective Action Units. Figure 6 at p. 86 on pdf file, Figure 1-2 Map Showing Location of the Pahute Mesa Model Area; Figure 7 at p. 90 on pdf file, Figure 1-4: Geophysically Inferred Geologic Features of the Pahute Mesa Area; Figure 5 at p. 884 on pdf file, Figure C. 4-1, Location of Boreholes Used in Study; Figure 8 at p.5-24, on p. 253 on pdf file, Figure 5-6 Map Showing Hydrogeologic Domains in the Pahute Mesa/Oasis Valley Model Area; and Figure 9 at p. 7-9, Figure 7-6: Locations of Flow Model Calibration Wells (black circles), Geochemical Target Wells (blue circles), and Pathlines for Forward SPTR Particles Originating in Open Screened Intervals of Wells in Model Domain.

[27] Fridrich (2007) is the source for our figures 4, 4a, and 4b.

[28] ASME (2001) p. 19.

[29] Calculation by authors where we use estimates provided in Bowen et al. 2001, p. 22 where radionuclide inventory (Curies) at Western Pahute Mesa / radionuclide inventory (Curies) for Nevada Test Site = 6.086 E +07 / 1.32 E +08 = .46 or 46 percent.

[30] According to Mankinen et al. (2003) at pdf p. 37 "The Thirsty Canyon fault zone, for example, seems to represent a series of coalesced ring-fracture systems along an older Basin and Range fault. Among the many, potentially important features characterized, the Thirsty Canyon fault zone provides one of the most direct routes for groundwater flowing from the northwestern part of the Nevada Test Site to reach inhabited areas to the southwest and warrants special attention for monitoring efforts. Continued definition of major structural features will help refine sub-basin boundaries and contribute to developing a better conceptual understanding of groundwater flow in the study area."

[31] McCord et al. (2006; p. 2-3) provide a summary of the UGTA Regional Model reports and describe the model which was used to set boundary conditions (see p. 3-20).

[32] See McCord et al. (2006).

[33] McCord et al. (2006; p. ES-8) where they report 2,700 square kilometers and the Universal Transverse Mercator (UTM) for each of the maps are x (horizontal or easting) values of 519,125 m to 569,000 m and y (vertical or northing) values of 4,085,000 m to 4,138,000 m.

[34] See calibration targets of head and flow in McCord et al. (2006, p. ES-17 and p. 5-36, Table 5-6) where 191 represents the total number of data points from well head, spring head, oasis valley discharge, and boundary flow.

[35] See McCord et al. (2006; Section 5, p. 5-8). They use "four types of information, or targets" which are "hydraulic head from wells, estimated spring head in and near Oasis Valley, Oasis Valley discharge derived from Laczniak et al. (2001) and Edge flows estimated from regional model analysis presented in the Pahute Mesa hydrologic data document (SNJV, 2004[.])" to calibrate their flow model multiple times. In the Base Hydrostratigraphic Framework Model (HFM) using no depth decay and no anistropy assumptions they report using 152, 28, 7, and 4 observations, respectively to validate their model which checks out with the number reported under model limitations of 191 calibration targets.

[36] See McCord et al. (2006; p. Table F.1-1), these wells are the ER-EC wells.

[37] See McCord et al. (2006; Table C. 6-1) where it shows the model used 12 wells in Oasis Valley. However, several of these wells are essentially on top of each other meaning only seven wells appear on a map.

[38] Figure 5 is a copy of McCord et al. (2006; p. C-10) map identifying the location of each site which they describe as boreholes.

[39] In technical reports there are references to holes, boreholes and wells. For example, in Laczniak et al. (1996; pp. 30 – 32), the title for their table 5 is "Water levels, underground tests, and associated test and hole parameters used to determine general position of test relative to the water table." They include both sites of atomic tests and wells under a column entitled hole name.

[40] See McCord et al (2006). Figure 7 at p. 884 on pdf file, Figure C. 4-1, Location of Boreholes Used in Study; Figure 8 at p.5-24, on p. 253 on pdf file, Figure 5-6 Map Showing Hydrogeologic Domains in the Pahute Mesa/Oasis Valley Model Area.

[41] Fenelon (2000; p. 4).

[42] See Koonce et al. (2006) and McCord et al. (2004).

[43] See Kersting et al. (2006; p. 56, paragraph 3) where they refer to Blankennagel and Weir (1973) for these flow velocities.

[44] See McCord et al. (2006; p. 7-9) Figure 7-6: Locations of Flow Model Calibration Wells (black circles), Geochemical Target Wells (blue circles), and Pathlines for Forward SPTR Particles Originating in Open Screened Intervals of Wells in Model Domain.

[45] For more details see McCord et al. (2006; pp. 5-10 to 5-15 or pdf pp. 239 – 244) Table 5-2 where wells between Western Pahute Mesa and communities of Oasis Valley and Beatty appear to receive low calibration weights for the model relative to wells to the west of these wells. Wells such as ER-20-5 received a weight of 0.72 which was last sampled on 5/14/96 and the Beatty well which was last sampled on 10/26/1962 received a weight of 1×10^{-3} while the Beatty Wash Terrace Well that was last sampled on 9/27/2001 received a weight of 0.2. ER-OV5 which was last sampled on 9/13/01 which appears to be due north of Beatty received a weight of 1×10^{-3} while ER-OV-4a which was last sampled on 9/13/01 received a weight of 0.77. In the McCord et al, Stoller-Navarro 2006 report, Figure 7 – 6 appears to show that well number ER-OV-4a is an inflection point where the flow switches from a southwestern flow to a southern flow.

[48] In support of citizens request for more data, consider the scientific method summarized by Millard and Neerchal (2001; pp. 13 – 14). The steps are “(1) form a hypothesis…”; “(2) [p]erform an experiment…”; “(3) [r]ecord and analyze the results of the experiment.”; and “(4) [r]evise the hypothesis based on the results. Repeat steps 2 to 4.” On p. 17 they introduce the concept of type I and type II errors, which refer to as a false positive rate and false negative rate, respectively. (One can argue the hypothesis scientists wish to support, in this case a contaminant boundary or no movement of contaminants toward Oasis Valley should bear the burden of proof. The data requirements to reject the null, traditional statistics versus spatial statistics require consideration.)

[49] Kersting et al. (1999).

[50] Kersting et al.(1999) report an isotopic ratio of $^{240}Pu/^{239}Pu$.

[51] Kersting et al.(1999) use the word migration in their title and the verb to migrate throughout their paper. There is an issue that Kersting et al.(1999) discuss at the end of their paper whether the radionuclides traveled as a result of the test itself or whether it is due to the hydrogeology of the area. They state it is highly unlikely that it was a test that caused the radionuclides to travel 1.3 km. Some committee members disagree with this discussion point.

[52] Kersting et al. (1999; p. 56, paragraph 1) "It has been argued that plutonium introduced into the subsurface environment is relatively immobile owing to its low solubility in groundwater [.] and strong sorption onto rocks [.]. Nonetheless, colloid-facilitated transport of radionuclides has

been implicated in field observations [.] [.], but unequivocal evidence of subsurface transport is lacking [.]. Moreover, colloid filtration models predict transport over a limited distance resulting in a discrepancy between observed and modeled behavior[.]."

[53] Kersting et al. (1999; p. 59, paragraph 2).

[54] Kersting et al. (1999; p. 56, abstract, last sentence).

[55] Kersting et al. (1999; p. 59, paragraph 2).

[56] Kersting et al.(1999; p. 59, paragraph 1).

[57] Kersting et al. (1999; p. 59, first paragraph, last sentence).

[59] McCord et al. (2006; p. ES-17, 6) report "….it is almost certain that flow in the intrusive confining units is very slow, if not nil, which has no effect on the shallower part of the flow system."

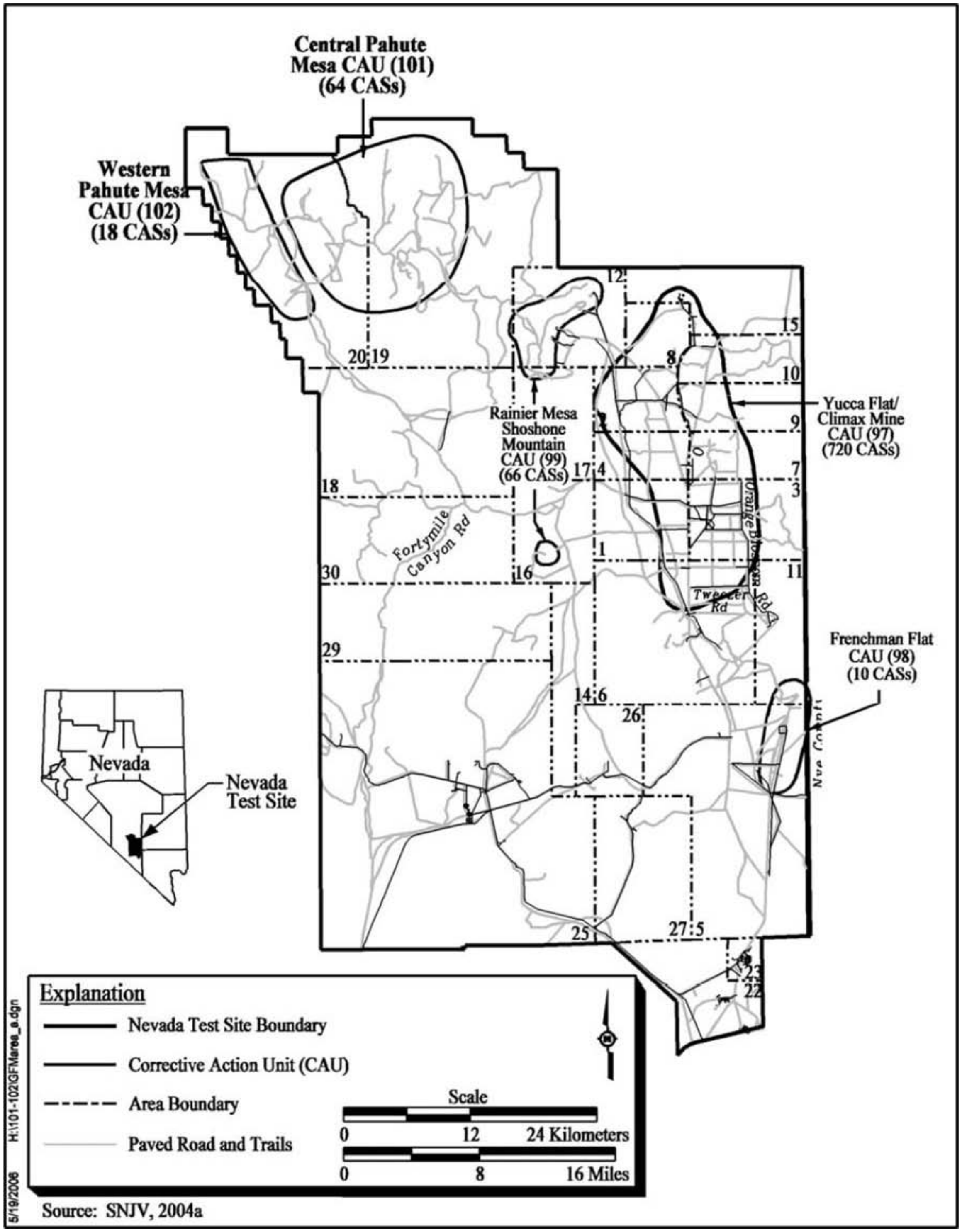
[60] See Appendix I, Table A-1: Summary of References. This reference is an excel spreadsheet of scientific papers, reports, and books the committee has either studied or was given as a reference during presentations and meetings.

[61] This subcommittee of the NTS CAB has been meeting since 1999.

[62] These recommendations appear in a letter from Phillips to Mellington, February 9, 2005. An earlier version of this paper provided details on the wells on pp. 28 – 32.

[63] See Edward A. Mankinen, Hildenbrand, Fridrich, McKee, and Schenkel, Geophysical Setting of the Pahute Mesa-Oasis Valley Region Southern Nevada, Nevada Bureau of Mines and Geology, Report 50, 2003. [64] This estimate of $18 million is based on a personal communication from Kelly Snyder, DOE NSO EM Public Accountability Specialist, and Bill Willborn, DOE NSO EM UGTA Federal Subproject Director, on October, 2006 where the average cost for drilling is $5.726 million (this includes road, pad and drilling depth of 5,000 feet). Well development, testing and sampling averages $711,000. Average total cost for a hot well is $6.437 million.

Figure 1: Location of the Pahute Mesa Corrective Action Units



Source: Stoller-Navarro (2006) Groundwater Flow Model of CAUs 101 and 102: Central and Western Pahute Mesa, Nye County, Nevada, Figure 1-1 Location of the Pahute Mesa Corrective Action Units, p. 1-2.