Title

Geology, Soils, Water resources radionuclide inventory. Basic for analysis conducted

Author

DOE/NV

101875

Document Date

8/31/96

ERC Index number

05.10.01.042

Document Type

Report

Box Number

1707-1

Recipients

DOE/NV

Geology
Soils
Water Resources
Radionuclide Inventory

Technical Resource Report

for the
Final Environmental Impact Statement
for the Nevada Test Site and
Off-Site Locations in the
State of Nevada

United States Department of Energy
Nevada Operations Office
Las Vegas, Nevada

August 1996

TABLE OF CONTENTS

TABLE OF CONTENTS
(continued)

List of Figures

TABLE OF CONTENTS
(continued)

SECTION **PAGE**

List of Figures (cont.)

List of Tables

GEOLOGY, SOILS, WATER RESOURCES, RADIONUCLIDE INVENTORY
TECHNICAL RESOURCE REPORT
FOR THE
FINAL ENVIRONMENTAL IMPACT STATEMENT FOR THE NEVADA TEST SITE
AND
OFF-SITE LOCATIONS IN THE STATE OF NEVADA

1.0 Statement of Intent/Purpose of Report

The purpose of this report is to document the basis for the discussions and findings presented in the U.S. Department of Energy's Environmental Impact Statement (EIS) for the Nevada Test Site (NTS) and Off-Site Locations in Nevada related to geology, soils, water resources, and radionuclide inventory at the NTS. The baseline data and reference materials that were used as the basis for the descriptions of the affected environments are presented for each of these related areas. The specific methodologies that were used in reaching the findings regarding the impacts of various alternative actions on the geology, soils, and water resources of the potentially affected areas are presented and discussed.

For convenience in finding the information presented in this report, the organization is somewhat different from that used in the EIS. First, an introduction is provided that describes the location of the NTS (and the regions of influence), the proposed alternatives, and the general methodologies that were employed. The next chapter is organized into three main sections regarding the affected environment, the impacts of past actions, and the analysis of expected impacts that may result from the actions that could be taken under each of the proposed alternatives. Supporting references, data sources and sets, and calculations are presented in the appendices to this report and in the Administrative Record for the EIS.

There is redundancy between this document and the text of the EIS. This redundancy is intentional as it allows a reader that is only interested in the NTS to be able to access all the information and evaluations within one report. Thus, duplicate information that is presented in this document is complementary to that presented in the EIS.

There is also information included within this document that is not contained within the text of the EIS. This information includes more detailed discussions of the affected environments and impact evaluations, expanded data presentations, and additional references. Again, the information and discussions are intended to be complementary to those presented in the EIS.

It is not the intent of this document to present all of the information available on the geology, soils, and water resources of the area of interest, nor to present detailed evaluations of every aspect of these technical disciplines. Rather, this document is intended to meet the requirements of a technical support document prepared as part of an overall EIS. As such, the material presented focuses on a succinct presentation of the information that is germane to the potentially affected environments, and the presentation of impact evaluations within the context of only the actions that have been proposed.

2.0 Introduction

This chapter presents general background information concerning the areas that are evaluated and the proposed alternative actions that are covered within the EIS. The approach used in evaluating the impacts, the underlying assumptions, and the specific methodologies used are then presented in more detail.

2.1 General Location and Region of Influence

The area considered under this evaluation include the NTS and the region of influence around the Test Site. Figure 1 shows the location of each of the area included within this evaluation.

In evaluating the geology, soils, water resources and radionuclide inventory, different regions of influence were designated depending upon the location and type of actions that are proposed. For geology, the region of influence includes the entire NTS for most impacts and extends as far as Clark County for some topics, such as seismicity. For soils, the region of influence includes the entire NTS with a special emphasis on areas where soils have been contaminated as a result of past actions.

For water resources, the region of influence is much larger for the NTS, comprising the entire Death Valley flow system (see Section 3.1.2). This large region of influence was defined for water resources because of the location of the NTS within this flow system. For the radionuclide inventory, the region of influence is much smaller, limited to the above ground and underground nuclear testing areas on the NTS, radioactive waste disposal sites, and areas where soils have been contaminated with radionuclides. For presentation however, the radionuclide inventory is reported for the NTS as a whole.

2.2 Identification and Discussion of the Proposed Alternatives

Under the four alternatives, the impacts on the soils, geology, and water resources would vary, depending upon the nature of the actions taken and their consequences. The actions that may cause these impacts are identified and discussed in this section.

Under Alternative 1, the nuclear testing scenario (Continue Current Operations), there would be seismic effects, soil disturbances, and contamination of the deep geologic environment (more than 500 feet below land surface). Ancillary testing operations including construction and maintenance, waste disposal, and other land disturbing activities would also impact the soils, geology, and water resources. Environmental Restoration actions would include intrusive site investigations and potentially, the remediation of contaminated resources. These actions would include a number of site disturbing activities that would impact the resources. Similarly, projects conducted under the Nondefense Research and Development Program have the potential for soil impacts around specific test areas. A number of actions under the Work for Others Program have the potential for impacting the soils and water resources, and to a lesser degree the geologic resources. Finally, Site Support Activities would impact the resources through the use of water, soil disturbing actions, and waste disposal. Under Alternative 1, impacts would be limited to the NTS, TTR, and NAFR and to the off-site locations where historic underground testing was conducted (Project Shoal area and CNTA).

Under Alternative 2 (Discontinue Operations), almost all site disturbing and water consuming actions would be discontinued. Thus the new impacts of continued site operations for Defense Programs under Alternative 1 would not occur. There would be no new impacts associated with the Environmental Restoration, Nondefense Research and Development, and the Work for Others programs. However, much

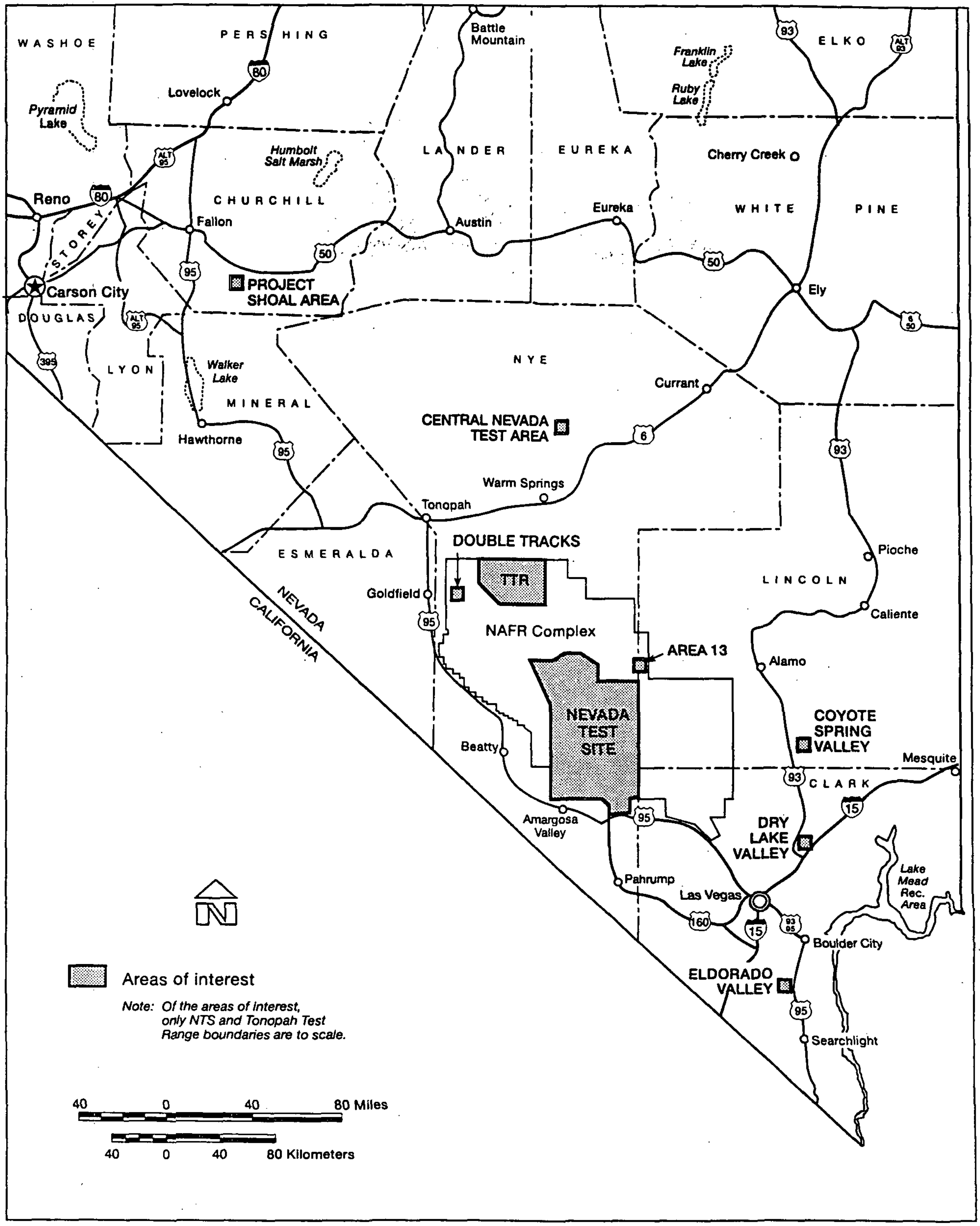


Figure 1. NTS and selected areas of interest

of the work to be conducted under the Environmental Restoration Program is focused on mitigating the impact of past actions at the NTS. If the Environmental Restoration Program is not continued, then the impacts that result from the remaining inventory of radionuclides and other contaminants on the NTS should be considered.

Under Alternative 3 (Expanded Use), the impacts of the Defense, Waste Management, Environmental Restoration, and Nondefense Research and Development programs under Alternative 1 would also occur along with the additive impacts of additional activities. The demilitarization actions would impact the soil resources and the location of a solar enterprize zone on the NTS or offsite locations would result in impacts on soil and water resources. Under Alternative 4 (Alternate Use) the impacts on soils and geology are as described for other alternatives. The impacts on water resources would fall within the range of impacts of the other alternatives.

2.3 Methodology and Assumptions Used - Discussion of Rationale

The methods used in conducting this evaluation included a review of the available literature and data, the definition of resource requirements where published estimates were not available, and the evaluation of impacts. The specific methods employed, qualifications for data and information, and the techniques used in analyzing and evaluating impacts are identified and discussed in this section.

Literature and data review - Information needed for impact evaluation was obtained from existing agency files and published data sources. Agency file data include information provided by the Nevada Division of Water Resources (DWR), the US Geological Survey (USGS), and the US Department of Energy (DOE). The specific references used are cited within the technical discussions of this report and a complete list of references used is provided at the end of this report.

A review of the entire literature base related to the NTS was not conducted. As part of an on-going compilation effort, the DOE has identified more than 2,000 published references on the hydrology and water resources of the NTS. Similarly, there have been thousands of publications and DOE documents

The DWR maintains an up-to-date database of the water right allocations in Nevada. This database includes the location, quantity and status of all water rights and water right applications for each basin within the regions of influence. There is little uncertainty concerning the locations of water right owners in the vicinity of the NTS and other areas potentially impacted by the proposed alternatives. For this evaluation, this information was assumed to accurately portray the current status of water rights in the areas of interest.

Similarly, there is little uncertainty concerning the location of environmentally sensitive areas as these areas have been identified and extensively studied. Detailed information concerning the plants and wildlife and protected species that occur at these sensitive areas is detailed in the biological resources portions of the EIS and corresponding technical support documents. For the purposes of this evaluation, it was assumed that all environmentally sensitive areas have been accurately identified and the biota associated with these sites has been defined adequately for the purposes of this evaluation.

Information concerning boundary conditions is largely based upon the published literature on the hydrogeologic conditions of the region. While in some instances, the scientific literature contains conflicting points of view, the technical areas of conflict do not affect the evaluation of impacts for the purposes of an EIS. For example, the age or exact stratigraphic horizon of a particular rock unit may be open to debate. However, the effects of an underground test do not vary because of the age of the testing media and the conflict need not be considered within the context of the EIS. In general, there is agreement over significant boundary areas (recharge and discharge areas) and it was assumed that the conditions described in peer reviewed technical documents are representative of the existing environment.

Definition of legal water availability - The legal water availability of water was established through the review of records on file with the DWR. Basin water right abstracts were requested from DWR and were used as the basis for the values of perennial yield, committed water resources, and estimated water use that are presented later in this report for each hydrographic basin. There is considerable uncertainty in the approach used to estimate the perennial yield values; however, the published values have been used for many years to guide water resource development and use in Nevada and must serve as the basis for evaluation. There is little uncertainty concerning the committed water resources; again the files of the DWR are current and accurately represent the quantities of appropriated water in each basin under consideration.

Definition of water demand - Water use at the NTS has been metered, providing a reliable baseline of past water use at the facility. Water use estimates for other areas are less certain and are based upon either crude estimates, rudimentary records, or consumptive use estimates made by DWR as part of their annual water use inventories of selected basins in southern Nevada. Nonetheless, the information represents the best available data and is assumed to reasonably represent the existing water use in the areas under consideration.

Water use requirements for most of the actions that are proposed can be estimated based upon historic records for that type of action. For example, the quantity of water required for construction purposes is typically small and can be estimated based upon the records of past construction projets. In other instances, most notably the proposed solar enterprise zone, there is little historical data to base demand projection on. Therefore, phased water demand estimates for the solar enterprise zone were prepared as part of this evaluation. For other alternative actions, water demand was based upon conceptual designs or historic water use. For activities for which no water use data were available, estimates were made by Raytheon Services Nevada, Inc. These estimates served as the basis for water demand projections for many of the proposed actions, and are included in the Administrative Record of the EIS in the form of unit resource tables.

Water demand estimates for the solar enterprise zone were based upon information on cooling requirements for the solar enterprise zone and construction water requirements for a conventional power plant in the region. The Nevada Solar Enterprise Task Force Work Group (1994, p. 4-2, 7-1, 7-10) provides the schedule for deployment of solar enterprise technology and unit water consumption rates for the alternative technologies. The resulting estimated demand is presented in Table 1. There is uncertainty associated with this estimate and the actual demand for water to build and operate the solar enterprise zone may be considerably lower. However, in lieu of more refined estimates based upon the final configuration of technologies, the estimates presented in Table 1 represent reasonable worst case values. By using worst case values, any impacts associated with the solar enterprise zone will be overestimated within this evaluation.

Impact evaluation - The impacts on soils, geology, and water resources were identified on the basis of the historic actions at the NTS and estimates of the areas that would be disturbed under each alternative. The areas where cratering has occurred and where soils have been contaminated have been well defined and provide a reliable characterization of the base case conditions and the likely incremental impacts of continued or new impacts under the alternative actions. There is uncertainty related to the subsurface impacts of past testing on the geologic media. The generic impacts of an underground test are relatively well defined, e.g., the creation of a cavity, chimney, and collapse crater and the release of radionuclides into the deep subsurface environment. The specific impacts of any particular test are not as well defined owing to the classification of specific test related data. For this evaluation, it was assumed that the generic impacts of a typical test are representative and can be used as the basis for defining the overall impacts of all tests that have been conducted.

The impacts of groundwater withdrawals were estimated through the use of standard hydrologic techniques, specifically, through the use of a numerical model developed by the Desert Research Institute (DRI), the Theis non-equilibrium equation, distance drawdown graphs, and image well analyses. The DRI model approach and results are detailed in an unpublished DRI report that was prepared under the sponsorship of the DOE. This report is provided in an appendix to this Technical Resource Report.

A simple 2-dimensional analytical model (King, J.M., 1984, Computing Drawdown Distributions Using Microcomputer, Ground Water, Vol. 22, No. 6. pp. 780-784) was used to perform the calculations and a standard spreadsheet (Quatro Pro for Windows, Version 5.0) was used to generate the distance drawdown graphs. Documentation on this analytical model and model simulations are provided in an appendix to this Technical Resource Report along with the spreadsheets that were developed. Where input data were lacking for some of these analytical methods, reasonable values were selected that resulted in reasonable worst case evaluations. Sensitivity analyses were performed to determine a range of impacts rather than a single value. Best professional judgment was used in the selection of bounding values for these sensitivity analyses and in the interpretation of the results.

There is uncertainty associated with these types of analytical methods. The underlying mathematical equations are based upon assumptions that the aquifer is heterogeneous, laterally extensive, and of uniform thickness, there is no recharge from any source, the pumping well fully penetrates the aquifer, and all water removed from storage is discharged instantaneously. The aquifers at the NTS (and elsewhere for that matter) seldom meet all of these assumptions fully. As noted previously, the values for key hydraulic

Table 1. SOLAR ENTERPRISE ZONE WATER USE ESTIMATES

WATER CUNSUMPTION UNIT RATES	AFY/MW
TROUGH (SEGS)	10.6
TROUGH (ISCCS)	3.5
TOWER	11
DISH	neg.
FLAT PLATE	neg.
CONCENTRATOR	

POWER DEVELOPMNENT PROFILE (MW)

	YEAR							
FACILITY TYPE	1996	1997	1998	1999	2000	2001	2002	2003
TROUGH		80	200					
TOWER				200				
DISH			1	5	25	40	50	70
FLAT PLATE		5	5	10	20	20	20	20
CONCENTRATOR		5	10	15	20	30	40	70
TOTAL		90	216	230	65	90	110	160

POWER GENERATION (MW)

	YEAR							
FACILITY TYPE	1996	1997	1998	1999	2000	2001	2002	2003
TROUGH		80	280	280	280	280	280	280
TOWER				200	200	200	200	200
DISH			1	6	31	71	121	191
FLAT PLATE		5	10	20	40	60	80	100
CONCENTRATOR		5	15	30	50	80	120	190
TOTAL		90	306	536	601	691	801	961

PRODUCTION OPERATING WATER USE WITH SEGS Trough (ACRE FEET/YEAR)

	YEAR							
	1996	1997	1998	1999	2000	2001	2002	2003
TROUGH		848	2968	2968	2968	2968	2968	2968
TOWER				2200	2200	2200	2200	2200
DISH								
FLAT PLATE								
CONCENTRATOR								
TOTAL		848	2968	5168	5168	5168	5168	5168

SEGS - Solar Electrical Generating System
ISCCS - Integrated Solar Combined Cycle System

PRODUCTION OPERATING WATER USE WITH ISCCS Trough (ACRE FEET/YEAR)

	YEAR					
	1996	1997	1998	1999	2000	2001
TROUGH		280	980	980	980	980
TOWER				2200	2200	2200
DISH						
FLAT PLATE						
CONCENTRATOR						
TOTAL		280	980	3180	3180	3180

CONSTRUCTION WATER REQUIREMENTS (ACRE FEET/YEAR)

	YEAR					
	1996	1997	1998	1999	2000	2001
DUST CONT	22	66	66	22	22	22
SEWAGE	9	18	26	26	18	18
BATCH PLA	92	184	184	184	92	92
MISCELLAN	12	27	28	23	13	13
TOTAL	135	295	304	255	145	145

TOTAL WATER USE (ACRE FEET/YEAR)

	YEAR					
	1996	1997	1998	1999	2000	2001
SEGS OPTIC	135	1143	3272	5423	5313	5313
ISSCS OPTI	135	575	1284	3435	3325	3325

REFERENCES & ASSUMPTIONS

1. Unit water use rates are from Ref. A, page 7-2.
2. Power development profile is from Ref. A page 2-5 (Table 2-3)
3. Power generation is assumed constant after development.
4. Dust control water assumes 30,000 gal/day during peak construction phase.
5. Sewage assumes 35,000 gal/day & 240 days/year at peak per Ref.B, page 3.1.7.
6. Batch plant peak water use is 250,000 gal/day & 240 days/year per Ref. B, page 3.1-7.
7. Miscellaneous water use at 10 percent of total annual use.
8. Assumes all potable water will be derived from off site.

REFERENCES:

A. Nevada Solar Enterprise Zone Development Study
September, 1994
B. Environmental Assessment, Allen-Warner Valley Energy System
Volume III, Harry Allen Station, September, 1975

parameters such as transmissivity and storativity are only order-of-magnitude estimates. Therefore, some judgment is necessary in the application of these techniques to a particular hydrogeologic environment.

For this reason, a reasonable worst case evaluation was performed that assumed that the water supply wells all operate continuously while in reality the wells on the NTS only operate periodically and different water supply systems operate independently of each other. This assumption results in the models predicting more drawdown of the water levels than would actually occur and a corresponding over estimation of the impacts of the wells. Not accounting for natural recharge also results in the overestimation of the impacts of the water withdrawals. By taking an approach that overestimates, rather than underestimates, the impact of pumping wells on water levels in the region, the results are considered conservative and adequate for the purposes of evaluating the potential future impacts of the proposed alternatives.

3.0 Nevada Test Site

This section focuses on the presentation of materials related to the existing conditions of the geologic, soils, and water resources of the NTS and adjoining areas. First the baseline conditions are presented in

a detailed discussion of the existing environment. Then the impacts of past activities at the NTS are defined and discussed. These observed and studied impacts serve as the basis for assessing the potential impacts of future actions.

3.1 Existing Environment

In this section, information on the baseline conditions of the geology, soils, and water resources of the NTS is presented and discussed. This information serves as the basis for the identification and evaluation of environmental impacts that might result from the actions taken as part of the proposed alternatives. Each discussion is focused on that part of the environment that is of significance with respect to those alternatives. For some discussions, for example soils, the area of interest is limited to only the NTS while for other topics, such as water resources, the area of interest encompasses a much larger geographic area that includes much of southern Nevada and portions of eastern California.

As noted in the introduction, it is not the intent of this section to present all of the information available on the NTS, nor to present detailed evaluations of every aspect of the geology, soils, and water resources. Rather, this document focuses on the information that is directly related to the potential impact of the proposed actions and the succinct presentation of that information.

3.1.1 Physiography, Geology, and Soils

In this section, information concerning the topographic conditions on the NTS, the rocks and geologic structures that underlie the region, and the soils that have formed on these rocks is presented and discussed. These aspects of the physical environment are important as the geology and soils have been demonstrably impacted by past actions at the facility. The definition of the impacts of these past actions provides the framework for the evaluation of the impacts of future actions.

3.1.1.1 Physiography

The NTS and surrounding areas are in the southern part of the Great Basin, the northernmost subprovince of the Basin and Range Physiographic Province (Figure 2). The boundaries of the Great Basin can be defined on the basis of geologic history, ethnography, hydrology, and biology. A complete discussion of

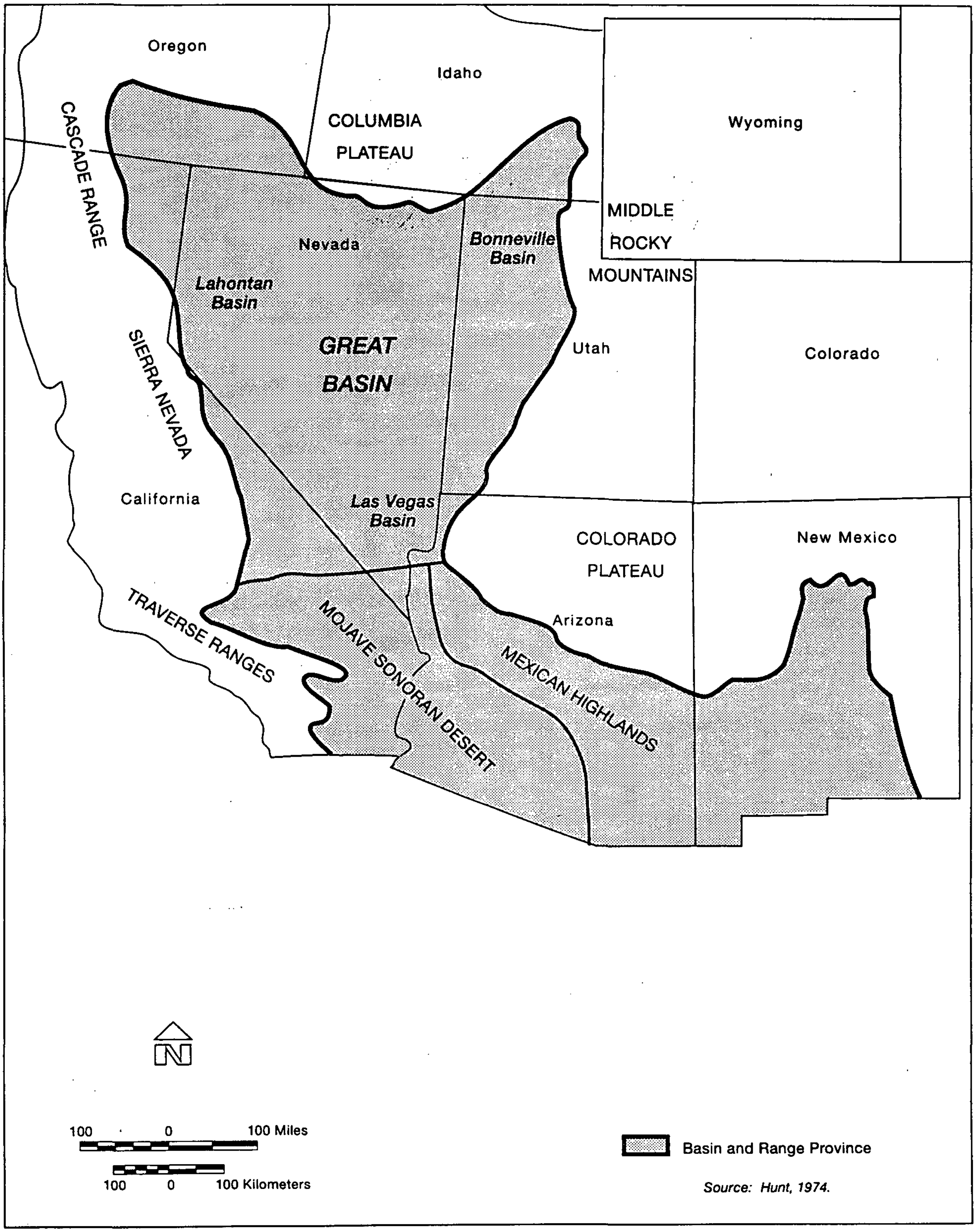


Figure 2 Basin and Range Physiographic Province

basin has no outlet to the Pacific Ocean. The precipitation that runs off the mountainous areas collects in the lowland areas of the valleys of the Great Basin and may be channelled downgradient to lower valleys or may pond on the valley floor. An area in eastern and southern Nevada is tributary to the Colorado River with discharge ultimately to the Gulf of California.

The relief of the NTS is considerable, ranging from less than 1,000 m (3,280 ft) above sea level in Frenchman and Jackass Flats to about 2,340 m (7,675 ft) on Rainier Mesa and about 2,200 m (7,216 ft) on Pahute Mesa. The topography of the eastern and southern NTS is typical of the Great Basin, with broad alluvial basins separated by numerous north-south trending mountain ranges. Figure 3 shows the general topographic expression of the NTS. In general, the slopes of the upland surfaces are steep and dissected, and the slopes in the lowland areas are more gentle and less eroded. The main upland areas of the NTS include Pahute Mesa, Rainier Mesa, Timber Mountain, Shoshone Mountain, the Calico Hills, the Half Pint Range, Skull Mountain, and Little Skull Mountain. In the northwestern portion of the NTS, the physiography is dominated by the volcanic highlands of the Pahute and Rainier Mesas.

There are three primary valleys on the NTS: Yucca Flat, Frenchman Flat, and Jackass Flats. Both Yucca and Frenchman Flats are topographically closed, with playas in the lowest portions of each basin. Jackass Flats is topographically open with drainage off of the NTS via Forty Mile Wash.

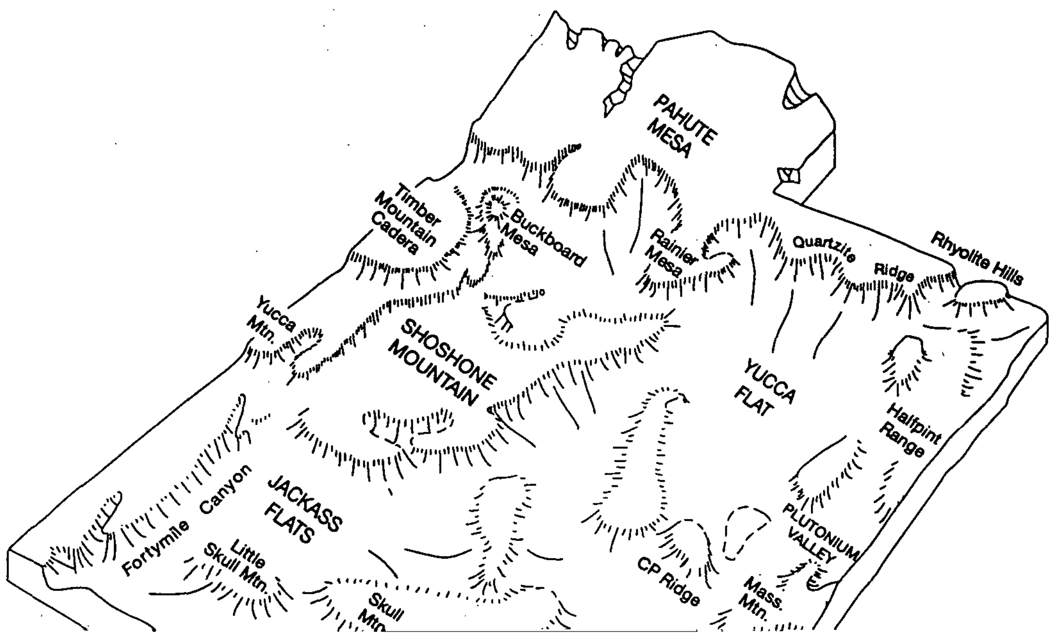
The topography of the NTS has been altered by historic DOE actions, particularly underground nuclear testing. The principal effect of testing has been the creation of numerous craters in Yucca Flat and a lesser number of craters on Pahute and Rainier Mesas. These craters form from the collapse of the overlying rock into the cavity formed by an underground nuclear test. The craters in Yucca Flat are not perceptible from ground level from much of the valley floor. However, when viewed from the bounding uplands or from the air, cratering is evident over a large area of the valley.

Shallow detonations were also performed during Project Plowshare to determine the potential uses of nuclear devices for large-scale excavation. These tests also resulted in localized alteration of the natural topography and drainage features. Lesser alterations of the natural topography of the NTS and adjacent areas have occurred as a result of road building, sand and gravel mining, underground mining prior to the creation of the NTS, and the construction of waste disposal areas, flood controls, and drainage improvements. These types of disturbances are typical of any large facility such as the NTS.

3.1.1.2 Geology

Detailed investigations of the geology of the NTS have been in progress since 1951, shortly after the Test Site was established, and continue to be performed. The geologic studies were expanded in the 1950s and early 1960s as underground testing became the established mode for testing nuclear explosives. Since then, many regional and site studies have been conducted that have included detailed geologic mapping, sitewide geophysical surveys, exploratory drilling and testing, and detailed geotechnical studies. As a result of these many investigations, comprehensive databases are available on virtually every aspect of the geologic conditions on the NTS and surrounding areas.

As noted in the *Final Environmental Impact Statement Nevada Test Site, Nye County, Nevada* (ERDA, 1977), the NTS is probably the geologically best known large area within the United States. This statement is well based on the thousands of technical reports that have been issued not only through DOE publications, but also by such highly respected organizations as the Nevada Department of Conservation and Natural Resources, the Nevada Bureau of Mines and Geology, the USGS, the Geological Society of


PAHUTE MESA
Timber Mountain Cadera
Buckboard Mesa
Rainier Mesa
Quartzite Ridge
Rhyolite Hills
Yucca Mtn.
SHOSHONE MOUNTAIN
YUCCA FLAT
Halfpint Range
Fortymile Canyon
JACKASS FLATS
Little Skull Mtn.
PLUTONIUM VALLEY
CP Ridge
Mass. Mtn.
Skull

America, and the National Academy of Sciences. The wealth of published information is supported by a myriad of data drawn from extensive characterizations of both the surficial geology and the subsurface conditions at the NTS and the adjoining region. In fact, the DOE is considered by many to be at the forefront of investigations into many areas of geologic study because of the detailed investigations and sophisticated testing that have been, and continue to be done under its sponsorship at the NTS. The DOE continues to collaborate with respected practitioners of modern regional structural geology, stratigraphy, and volcanology.

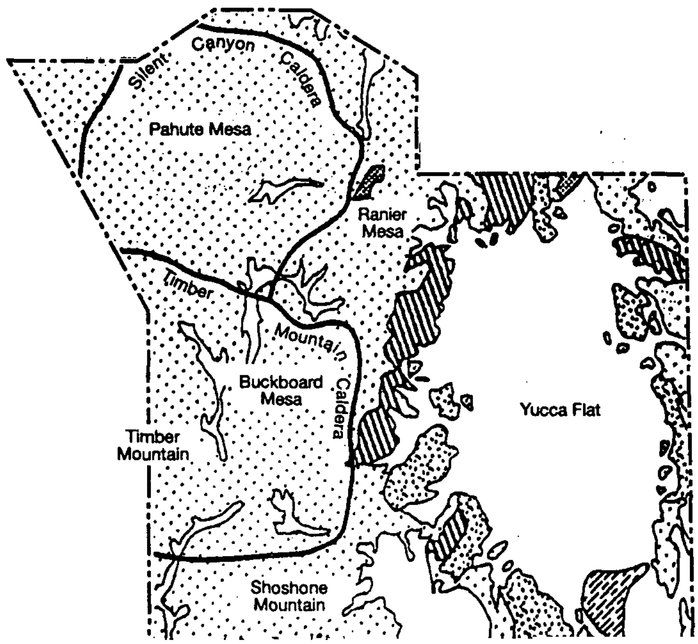
Baseline information on the geology of the NTS is available at a number of scales. Stewart (1980) summarizes the geology of the entire state, including the NTS, in a discussion that accompanies the 1:500,000 state geologic map prepared by Stewart and Carlson (1978). The geology of Nye County is presented in more detailed studies (1:250,000) by Cornwall (1972) and Kleinhampl and Ziony (1985) with a particular emphasis on the occurrence and exploitation of the many mineral deposits in the county. A larger scale geologic map (1:100,000) of the NTS and immediate environs was prepared by Frizzell et al, (1990). More detailed quadrangle maps at a scale of 1:24,000 have been published by the USGS for most of the NTS and for some of the surrounding areas. Even larger scale maps have been prepared for specific projects such as permit applications and facility siting investigations.

The map data is augmented by an extensive database on the subsurface conditions. This database is drawn from the many boreholes that have been drilled at the NTS for weapons tests, water supply wells, and scientific investigations. A comprehensive suite of geophysical logs was run for many of these boreholes and, in conjunction with the surface and airborne geophysical surveys that have been completed, provide additional data on the subsurface conditions. Typical borehole geophysical suites include electric logs, gamma logs, temperature logs, borehole compensated acoustic and density logs, fluid density logs, and for some boreholes, magnetometer logs and tracer surveys. Surface geophysical surveys have been completed using electric, gravimetric, magnetic, and seismic methods and the Test Site has been completely surveyed using aerial magnetic techniques.

Selected samples collected from subsurface drilling have been extensively tested to provide data on the mechanical properties of the rock units underlying the NTS and adjacent areas. Geotechnical tests have included compressive strength, elastic properties, saturation, and petrographic analyses. Analytical tests have also been performed on selected samples to determine the gross chemical composition, the interactions between saturation and rock strength, and the effects of rock type and chemistry on the fate of radionuclides and other contaminants.

General Geologic Conditions

The geology of the NTS consists of a thick section (more than 10,600 m [34,768 ft]) of Paleozoic and older sedimentary rocks, locally intrusive Cretaceous granitic rocks, a variable assemblage of Miocene volcanic rocks, and locally thick deposits of postvolcanic sands and gravels that fill the present day valleys (Frizzell and Shulters, 1990). Figure 4 is a generalized geologic map of the NTS. More detailed stratigraphic information is available from recently updated maps of the NTS (Frizzell and Shulters, 1990) and Pahute Mesa (Minor et al, 1993). Figure 5 shows a generalized stratigraphic column for the area in the vicinity of the NTS. This column shows the many geologic formations and units that have been identified for the region and identifies which of these units belong to the important groundwater aquifers of the area.


Silent Canyon Caldera
Pahute Mesa
Ranier Mesa
Timber Mountain Caldera
Buckboard Mesa
Timber Mountain
Yucca Flat
Shoshone Mountain

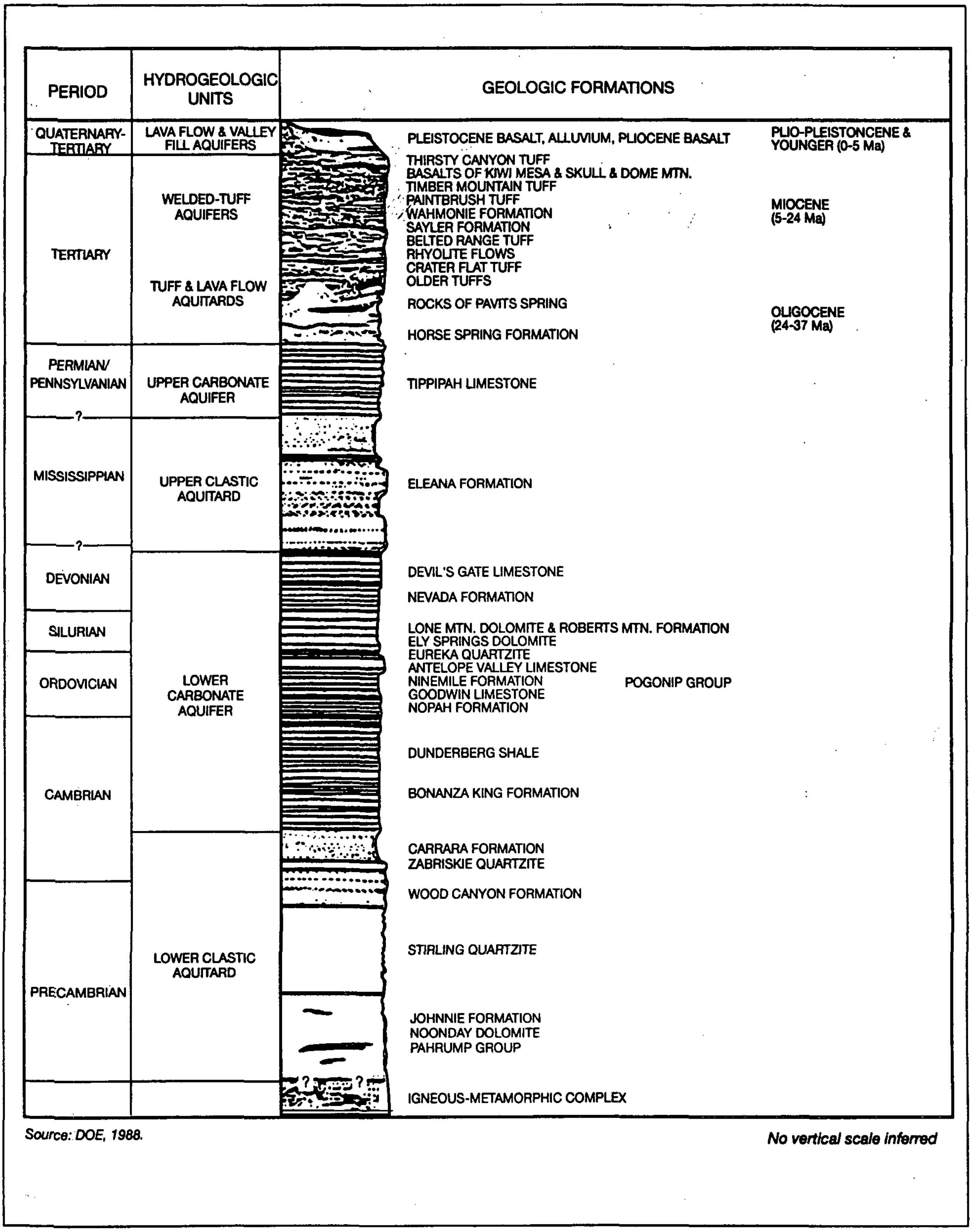


Figure 5 Generalized stratigraphic column

The tectonic history of the Great Basin region is complex. The major mountain forming events that have occurred over geologic time have left their imprint on the rocks of the area. As a result, the sequence of rocks present in many areas is quite different than the sequence that was originally deposited. In many cases, the properties of the rocks have been altered from their original state by the faulting and fracturing that occurred over geologic time. The following discussion briefly summarizes the geologic history of the NTS area and highlights the events that have occurred that have led to the current distribution of rock types and geologic structures that are present under the area.

The part of the western United States that includes the NTS was a stable continental margin until Late Devonian time. At that time, uplift west and north of the NTS resulted in the erosion and deposition of thick sandstones in a foreland basin during Mississippian time (Poole and Sandberg, 1991). Compressional deformation during the Cretaceous, as part of the Sevier orogeny, produced regional thrusts, folds, and wrench faults that fundamentally rearranged the positions of the Paleozoic and older sedimentary rocks (Armstrong, 1968). This episode of deformation juxtaposed these rocks along thrust faults according to Frizzell and Shulters (1990). The Sevier orogenic zone may have been extended with normal faulting prior to late Mesozoic time and the intrusion of granitic rocks (Hodges and Walker, 1992; Cole et al, 1993).

Following erosion throughout most of the Early Tertiary Period, the area in and around the NTS began to pull apart along low-angle normal faults and strike-slip faults associated with the formative stages of the modern basin-and-range structural province (Guth, 1981; Hamilton, 1988; Wernicke et al, 1988; Cole et al, 1989). Eruptions of the southwest Nevada volcanic field occurred in the Middle Tertiary Period (Sawyer et al, 1990; Warren et al, 1989). Successive eruptions produced no less than seven large and partially overlapping calderas, which were filled with lava flows and blanketed by vast deposits of tuff. These volcanic events created the rocks that underlie the upland areas of the northwestern NTS that have been proven to be almost ideally suited for use in underground nuclear testing.

Cenozoic crustal extension formed normal faults that further disrupted the rock sequences. This faulting continued during and after volcanic activity, and caused further tilting and lateral translation of major upper crystal blocks. The modern alluvial basins in the valleys of the NTS were progressively filled with as much as 1,200 m (3,936 ft) of coarse gravels and sands and localized deposits of playa silt and clay. Tectonic extension, wrench movement, and seismic activity continue to the present day.

Yucca Flat and Frenchman Flat

Yucca Flat and Frenchman Flat, where both above ground and underground nuclear testing occurred, are intermontane basins typical of basin-and-range structure. The alluvium- and tuff-filled valleys are rimmed mainly by Precambrian and Paleozoic sedimentary rocks and Cenozoic volcanic rocks. The geology of these test basins is discussed together because of the similar conditions that are present.

In the lowland areas of Yucca Flat and Frenchman Flat, the consolidated rock units are overlain with alluvium. On the alluvial fans, the alluvium comprises interbedded gravel, sand, and silt with varying degrees of cementation. These coarse-grained deposits grade to the predominantly clay deposits under the playa areas. Limited areas of wind-blown sands and silts are also present in portions of the lowland areas. According to information presented in Laczniak, et al (1996) the sequence of rock types in eastern Yucca Flat comprises carbonate rocks overlain by volcanic rocks (tuff) which in turn are overlain by alluvium. In the western part of Yucca Flat, the sequence comprises the Eleana confining unit overlain by volcanics and/or alluvium. Under Frenchman Flat, the alluvium overlies a thinner sequence of volcanic rocks that thins to the east and south. In the southernmost and westernmost part of Frenchman Flat the alluvium may directly overlie carbonate rock.

Mesozoic intrusive rocks are located at the north-northeast edge of Yucca Flat. Precambrian and Paleozoic rocks are regionally extensive and occur under the basins as basement rocks. Under the NTS, the lowermost 3,000 m (9,840 ft) of the pre-Tertiary section consists of Late Precambrian to Middle Cambrian quartzites and siltstones. These rocks crop out along the northeastern portions of Yucca Flat and comprise clastic rocks (quartzite, siliceous siltstone, micaceous quartzite, and shale). These units are of particular significance because they form the basement for the groundwater flow regime under Yucca Flat and Frenchman Flat, referred to as the lower clastic aquitard.

These clastic rocks are overlain by as much as 4,600 m (15,088 ft) of carbonate rocks of Cambrian through Devonian age comprising dolomite, interbedded limestone, and thin, but persistent, shale and quartzite layers. These units make up the lower carbonate aquifer. As noted by Laczniak et al (1996) the total thickness of these rocks can be quite variable because of the extensive faulting that has occurred since their deposition. In general, these carbonate rocks generally dip to the west-southwest under eastern Yucca Flat and are continuous under the underground testing area in Yucca Flat and south into Frenchman Flat. These geologic units are of particular note as Laczniak et al (1996) note that the lower carbonate aquifer is the pathway by which any groundwater contamination in Yucca Flat or Frenchman Flat would migrate beyond the boundaries of the NTS.

The lower carbonate sequence is overlain by the Eleana formation and/or Chainman Shale of Mississippian age. These units form the upper clastic aquitard. The Eleana formation consists of siliceous siltstone and chert-clast conglomerate that may be as much as 2,500 m (8,200 ft) thick along the west side of the basins and thins markedly to the east and south. The formation is extensive in Yucca Flat but is present only in the northeastern portion of Frenchman Flat. In both Yucca and Frenchman Flats, the Eleana formation is thought to be bounded by faults. In some areas, the Eleana formation has been thrust eastward over other rocks disrupting the stratigraphic sequence.

Limestones of Pennsylvanian age depositionally overlie the Eleana formation along the western edge of the basins. These limestones form the upper carbonate aquifer. This upper carbonate assemblage consists of heterogeneous carbonate rocks of the Tippapah Limestone that lie structurally above the Eleana formation or Chainman Shale as a result of thrust faulting of low-angle normal faulting (Cole et al, 1989). A few drill holes in Yucca Flat have penetrated isolated blocks of carbonate rocks overlying the Eleana formation.

Thrust faults have repeated sections of the Paleozoic and Precambrian rocks, and low-angle extensional faulting has created isolated blocks of the Paleozoic rocks out of stratigraphic order. For example, Laczniak et al (1996) note that numerous "dismembered" blocks of older carbonate rock lie above the upper clastic aquitard formed by the Mississippian units. Most of the prominent geologic structures that have caused these disturbances are related to basin-and-range extensional faulting that is younger than the volcanic rocks. In Yucca Flat, fault strikes are mostly north-south; in Frenchman Flat, structure strikes are mostly west-southwest.

Outflow sheets of tuffs from the volcanic centers west of the basins occurred during the Tertiary Period and were emplaced on the irregular paleo-topographic surface of Yucca Flat and Frenchman Flat. According to information presented by Laczniak et al (1996), welded tuffs of the Paintbrush Group and Rainier Mesa Tuff overlie the upper carbonate rocks in southern Yucca Flat and northern Frenchman Flat.

These rocks have been compartmentalized by faulting which has resulted in thousands of feet of offset along the Carpetbag-Yucca and Rock Valley-Cane Springs fault systems.

The youngest sediments in Yucca Flat and Frenchman Flat are the alluvial deposits in the valley areas. These deposits comprise predominantly sands and gravels that were derived from the volcanic and sedimentary rocks in the surrounding highlands. Laczniak et al (1996) note that the alluvium is variably cemented and comprises moderately sorted gravel and sand. The playa deposits in both basins comprise siltstone and claystone deposits.

Underground nuclear tests in both basins have been detonated primarily in the alluvium or in the underlying volcanic rocks. According to information presented in Laczniak et al (1996), a total of 661 underground tests have been conducted at Yucca Flat and 10 tests were conducted at Frenchman Flat. A few larger tests were detonated in the underlying carbonate rocks beneath northern Yucca Flat during the early years of the testing program, and three small tests were detonated in granite just north of Yucca Flat at the Climax stock (OTA, 1989; DOE, 1993b). Testing near or below the water table was common in both Yucca Flat and Frenchman Flat. Of the 671 total underground tests, 77 tests were conducted at depths below the water table in these two basins and there were another 159 tests that were conducted within five cavity radii of the water table (Laczniak et al, 1996).

Pahute Mesa and Rainier Mesa

Pahute Mesa and Rainier Mesa were both the sites of numerous underground nuclear tests. The southwestern Nevada volcanic field, of which both Pahute Mesa and Rainier Mesa are a part, includes a broad volcanic plateau underlain by tuffs and lavas from the Timber Mountain-Oasis Valley caldera complex, the Silent Canyon Caldera Complex, and the Black Mountain caldera north of Timber Mountain (Byers et al, 1989). This Miocene, rhyolitic, eruptive center produced an overlapping complex of fault-controlled calderas in the general area of Timber Mountain and Pahute Mesa and laterally extensive tabular outflow sheets of welded tuff on Rainier Mesa.

The Timber Mountain caldera is listed as a National Natural Landmark by the U.S. Park Service. Recent work indicates that as many as six calderas may be present in the Pahute Mesa area and that the calderas may be ellipsoids bounded by faults related to basin-and-range structure rather than circular collapse structures (Ferguson et al, 1994). Stratigraphic units represent caldera-forming, caldera-filling, and caldera-burying emplacements, depending on their location relative to their originating and successive eruptions (Warren, 1993).

Underlying Pahute Mesa is the Silent Canyon Caldera complex of volcanic rocks with maximum accumulations of more than 4,154 m (13,600 ft) according to Laczniak et al (1996). Although these rocks are predominantly tuffs and lavas, there is a great deal of variability in their properties. Laczniak et al (1996) note that depending upon the degree of welding, zeolitization, fracturing, and mineralization, the same rock type that transmits groundwater in one horizon may be an effective barrier to groundwater flow in another horizon.

The volcanic rocks that underlie Pahute Mesa were not erupted in a single event, rather there were periods of eruption over a six to eight million year timeframe. After each eruption, the central portion of the caldera probably collapsed only to be filled again by a younger eruption. This eruptive sequence has left a complex sequence of volcanic rocks under the region and a number of structures have since disturbed this sequence.

Underlying Rainier Mesa area is a thick section of bedded tuffs that erupted from these calderas. The tuffs are believed to have been deposited in a trough with maximum accumulations of about 1,065 meters (3,500 ft) according to Laczniak et al (1996). These volcanic rocks are underlain by dolomites along the eastern half of the testing area. To the west, older micaceous quartzites have been penetrated by drillholes indicating the presence of a thrust fault through this area.

All underground nuclear tests within Pahute Mesa, as well as Rainier Mesa, have been detonated within volcanic rocks. A total of 85 tests have been conducted at the Pahute Mesa Testing Area and 62 subsurface tests have been conducted at Rainier Mesa. Of these 147 total tests, 34 were detonated below the water table and 48 were detonated within 5 cavity radii of the water table, all at Pahute Mesa. According to Laczniak et al (1996), all underground testing at Pahute Mesa has been conducted within the Silent Canyon caldera complex except for a few events in the northwesternmost portion of the NTS.

Other Testing Areas

The DOE has also conducted a limited number of nuclear tests in areas beyond the four major testing areas already discussed. The limited testing areas include Buckboard Mesa (three tests), Dome Mountain (one test), Shoshone Mountain (six tests), and the Climax stock in Yucca Flat (three tests).

The area of testing in Buckboard Mesa is located in the east-central portion of Timber Mountain, and the Dome Mountain testing area is located along the southern flanks of this caldera. These two sites exhibit the general geologic conditions of the caldera complex, that is, a thick sequence of volcanic rocks, including welded and ash-flow tuffs; volcanic-derived sediments, including sandstone and conglomerate; and basalts. The radial fracturing and faulting typical of a caldera are present at both of these sites.

Shoshone Mountain is located beyond the Timber Mountain caldera, but the volcanic rocks derived from this volcanic center predominate at this site, as well. The predominant rocks include the Ammonia Tanks and Topopah Spring tuffs and ash-flow tuffs. There are also exposures of clastic sediments and carbonate rocks of Paleozoic age, including the Tippipah Limestone and the Eleana formation, on the northwest flanks of the Shoshone Mountain testing area. At this site, the northeast to southwest striking normal faults typical of many portions of the Basin and Range Province are predominant.

The Climax stock, located along the northern flank of Yucca Flat, was used for testing and experimentation. The stock is a granitic (quartz monzonites and granodiorite) intrusion of Late Cretaceous age. The Climax stock occurs at the intersection of two geologic structures, the Tippinip fault and the Halfpint anticline, and intrudes Paleozoic sediments.

Many of the valleys have playas that may hold shallow water after seasonal storms. Playa sediments are bedded sand, silt, or clay and may include salts. Other sediments in the region carried and deposited by wind are typically sand and silt. These aeolian sediments generally are derived from nearby playas or dry river beds, but can be from afar. These deposits can be retransported by streams and redeposited on the alluvial fans or playa areas. The surfaces of relatively stable deposits in the valleys generally have a thin veneer of wind-deposited silt.

Geologic Hazards

Many natural hazards could impact facilities at the NTS (Guzowski and Newman, 1993). Most of these hazards can be discounted on the basis of being physically unreasonable because of the geology and climate of the region. Six natural geologic hazards have been identified that can occur at a scale that could impact large areas. These include seismicity, volcanism, and four geotechnical hazards: soil instability, slope instability, ground instability, and flooding. Each of these is discussed below, except flooding, which is discussed in the water resources section.

Seismicity — Seismic activity in the region has recently been characterized (Vortman, 1991). This analysis was based on 11,988 seismic events that occurred within 200 km (120 mi) of the NTS since 1868. Of these events, 8,161 were natural, and 3,827 were human-induced. The actual number of seismic events may be larger because the emplacement of instruments capable of detecting low-magnitude events is relatively recent. Naturally occurring seismic events are associated with extensional tectonic activity characteristic of the province (Sinnock, 1982; Vortman, 1991).

Three major fault zones in the region may be currently active: Mine Mountain, Cane Spring, and Rock Valley (Figure 6). Small earthquakes recently occurred at or near the Cane Spring Fault zone and the Rock Valley Fault zone, although no surface displacement was associated with either of these earthquakes (Carr, 1974). A fault near Little Skull Mountain in the southwest part of the NTS was the site of a 5.6 magnitude earthquake in 1992. This is the largest earthquake recorded within the boundaries of the NTS and may have resulted from the magnitude 7.5 earthquake near Landers, California, which occurred less than 24 hours earlier. Although there was no surface rupture, the Little Skull Mountain earthquake was the first to cause significant damage to facilities on the NTS (Anderson et al, 1993). These facilities, however, were built prior to the more stringent building codes presently followed on the NTS. The earthquake caused an estimated $40,000 in damage to the Field Operations Center, located in Area 25, a two-story concrete-block structure used by the DOE for studies at Yucca Mountain (Anderson et al, 1993).

Additionally, the Yucca Fault in Yucca Flat has been active in the recent geologic past (Sinnock, 1982; Rogers et al, 1987). This fault displaces surface alluvium by as much as 18 m (60 ft). Displacement of this young surface alluvium indicates that movement on Yucca Fault has occurred within the last few thousand to tens of thousands of years; subsurface displacement along this fault is 210 m (700 ft). The Carpetbag Fault lies west of the Yucca Fault within Yucca Flat. In the subsurface, this fault shows about 600 m (2,000 ft) of displacement in the past 7.5 million years (Sinnock, 1982).

Human-induced seismic events since 1868 include those resulting from: 1) the filling of Lake Mead; 2) high-explosive tests; 3) underground nuclear-explosive tests; 4) postnuclear explosion cavity collapses; and 5) aftershocks from nuclear explosions (Vortman, 1991). Ground-motion studies have played a large role in the weapons testing program. Sandia National Laboratories has developed a program for recording surface and subsurface motions resulting from underground nuclear explosions (Vortman, 1979; Vortman and Long, 1982a and b). There are several factors that influence the level and duration of ground motion from underground explosions, including (1) the yield of the device; (2) ground-coupling at the source of the explosion, which is a function of depth of the device, local geology, and stratigraphy; (3) the geological complexity along the transmission path; and (4) the topography and geology at the location receiving the ground motion. There is always some variation or unknown associated with estimating these factors, but because of the long history of conducting weapon tests, the effects are reasonably predictable and can be expected to fall within the range of observed conditions.

Seismic waves from nuclear explosions are believed to relieve tectonic stress, as manifested by earthquakes deeper than 3 km (1.8 mi) (Rogers et al, 1987), aftershocks, and reactivation of nearby faults in the areas of nuclear-device testing (Rogers et al, 1991). Studies of nuclear explosive tests show that

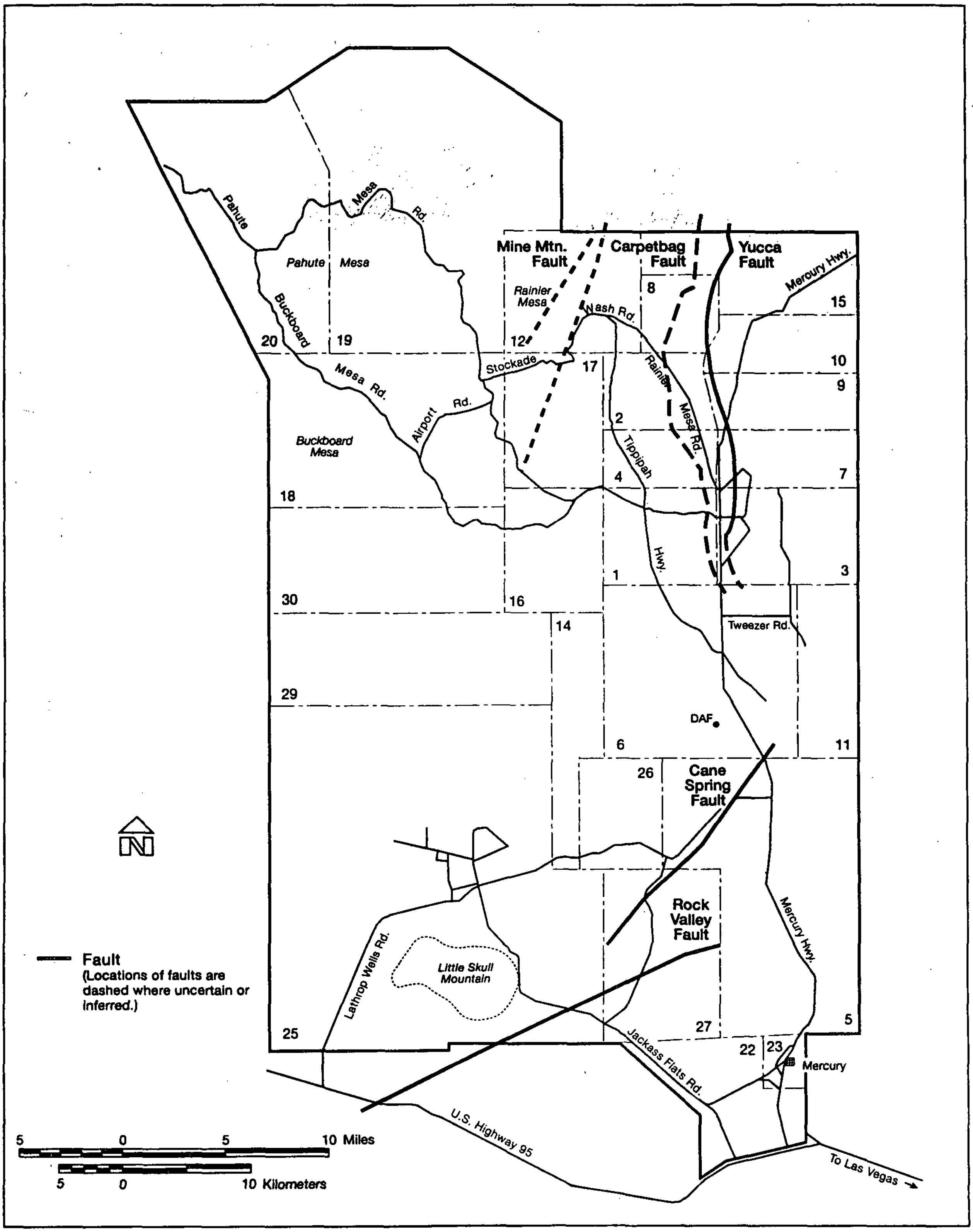


Figure 6 NTS fault map

these events can generate vertical and horizontal displacements on nearby existing faults. As much as 100 cm (40 in.) of vertical displacement and 15 cm (6 in.) of horizontal displacement have been observed (Rogers et al, 1991). Parts of both the Yucca Fault and the Carpetbag Fault have been reactivated from nearby testing of nuclear devices (Frizzell and Shulters, 1990).

The NTS is located within Seismic Zone 2B, as defined in the Uniform Building Code (ICBO, 1991) (Figure 7). Zone 2B is defined as an area with moderate damage potential, and Zone 3 is an area with major damage potential. Current design practices require facilities to be built to seismic Zone 4 standards. The *Final Environmental Impact Statement, Nevada Test Site, Nye County,* (ERDA, 1977) reported that only architectural damage has been sustained in the local communities for tests greater than 100 kt. Since the Threshold Test Ban Treaty, only a few reports of damage to local communities occur each year, and these are of a very minor nature. Beyond about 48 km (30 mi), structures have to be higher than several stories before they would be affected. The closest location where such structures are located is Las Vegas. A smaller number of similar complaints have been recorded from people in Las Vegas high-rise structures.

Volcanism — Several late Cenozoic, silicic caldera complexes occur in an eastward-trending belt between 37 degrees and 38 degree north latitude (Stewart, 1980). A part of this belt, which includes the mesas of the NTS has been termed the southwestern Nevada volcanic field (Byers et al, 1989) (Figure 8). The Stonewall Caldera is the youngest (7.5 million years) major silicic center in the area. Silicic volcanism is characterized by large-volume explosive eruptions.

A transition from predominantly silicic volcanism to predominantly basaltic volcanism, characterized by low-volume mild eruptions, was initiated approximately 10 million years ago (Christiansen and Lipman, 1972). Since 7.5 million years ago, only scattered, short-duration volcanic activity occurred in Nevada. The volcanic rocks are primarily basaltic cinder cones and lava flows (Sawyer et al, 1990; Stewart, 1980). The nearest examples of Quaternary volcanic cones and lava flows are located in Crater Flat, west of the NTS (Crowe, 1990).

Based on analysis of previous basaltic volcanism in the NTS region, there is no evidence of either an increase in the volcanic rate or the development of a large-volume volcanic field (Crowe et al, 1986). According to the information provided by the State of Nevada in comments on the Draft EIS, some researchers have concluded that there is a significant probability of future volcanism activity occurring at the NTS, most likely in the western portions, based upon studies of the most recent volcanic activity in Crater Flat, the Sleeping Buttes volcanic center, and along the west side of the NAFR complex. With the exception of the potential cleanup of some soils, none of the proposed actions under the alternatives under consideration in the EIS would occur in these areas.

The EIS covers a 10-year planning period. Volcanic activity is not considered a significant issue with respect to the proposed actions because the probability of volcanic activity cannot be defined for such a short period for a specific area. Therefore, a complete discussion of the extensive literature that has been written on this subject is not warranted or appropriate. A more detailed discussion of the history of volcanism over the region and the potential effects of volcanism may be found in the Site Characterization Plan for the Yucca Mountain Site (DOE, 1988, Volume I, Part A, pages 1-200 through 1-206). Additional evaluations include Bradshaw and Smith (1994), Connor and Hill (1994), Ho et al (1991), Smith et al (1990 and 1991), and Wells et al (1990). For facilities with siting criteria that include evaluations of volcanic hazards, the DOE will evaluate the volcanic hazards on a case-by-case basis with the documentation prepared to meet the specific requirements of the permitting or licensing authority.

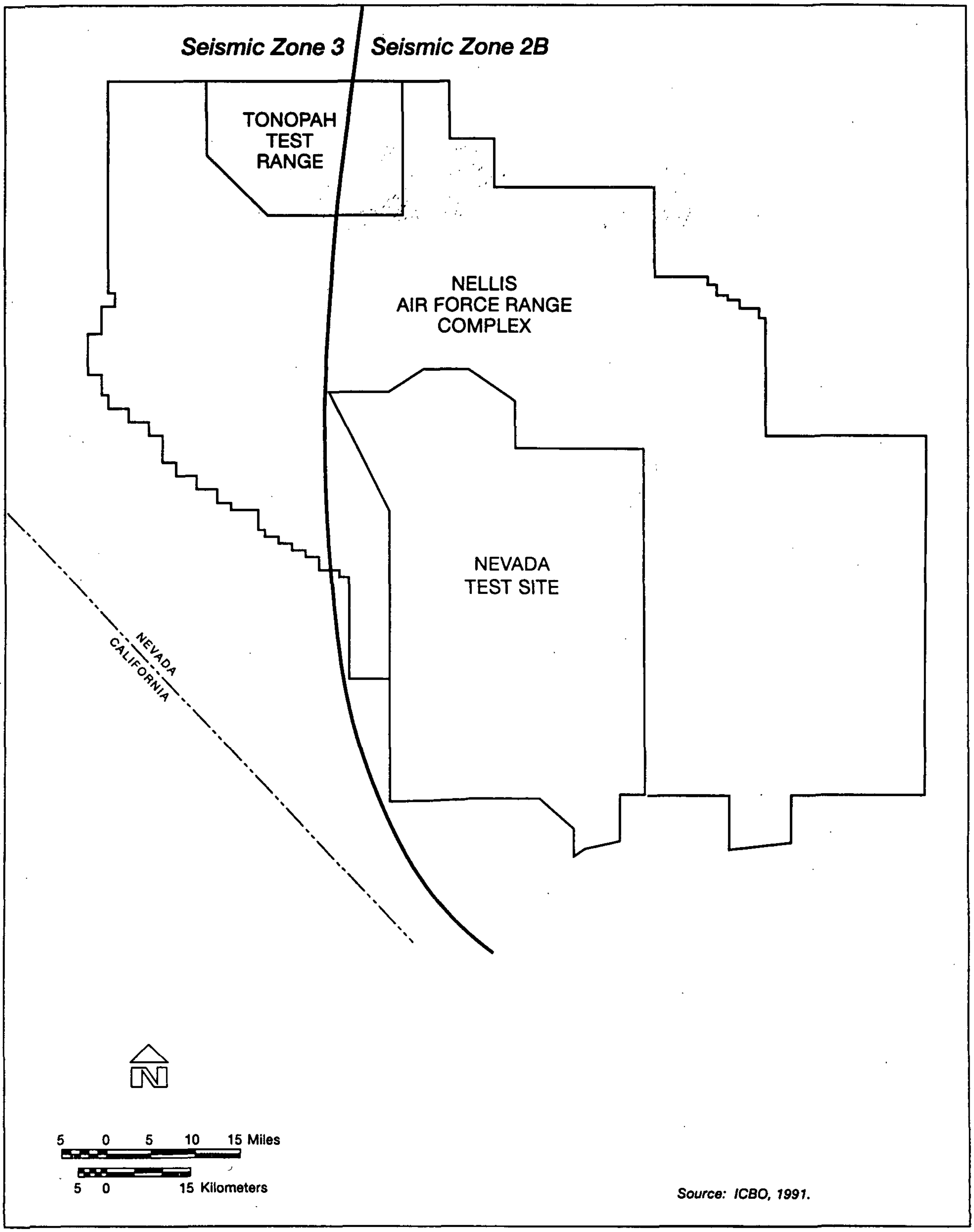


Figure 7 . Seismic zones in the NTS area

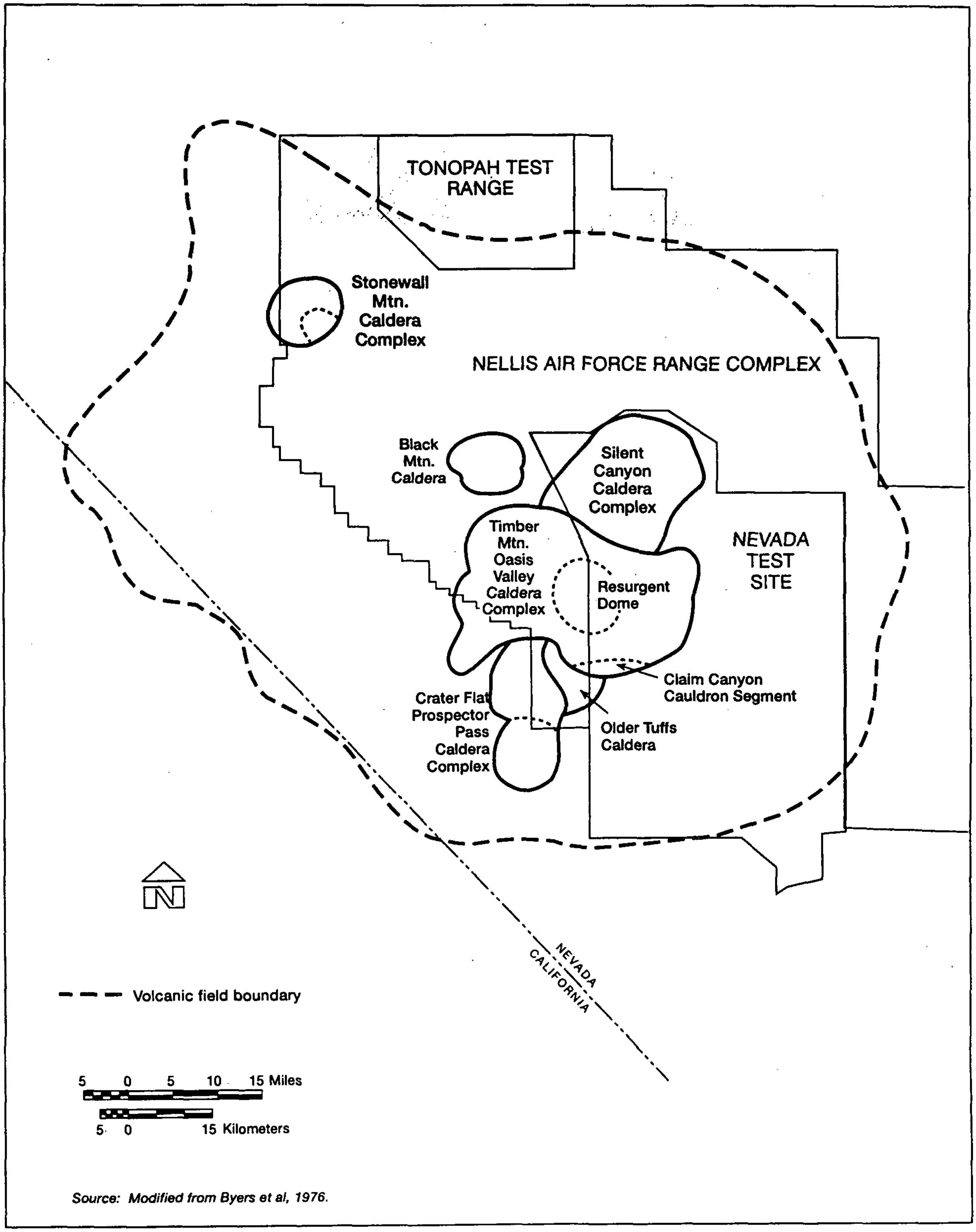


Figure 8. Southwestern Nevada volcanic field

Geotechnical Hazards

Geotechnical hazards are those that present an inherent direct risk to structures. Such hazards relevant to the region fall under the headings of slope stability, soil stability, and ground stability. Although this section primarily discusses hazards to engineering, areas that are particularly stable for certain activities are also noted.

Slope Stability —Within the region, no natural factors have been reported as affecting the engineering aspects of slope stability. External factors that have or could affect slope stability in the region include loading, fracturing, and ground motion associated with nuclear explosions. The slopes of the collapse craters in Yucca Flat and elsewhere on the NTS are generally less stable than the undisturbed slopes. Naturally occurring slope instabilities occur as a result of the physical properties and weathering of the rock units that comprise the upland areas on the NTS.

Historic rock falls have been reported that were caused by the ground motion associated with underground tests but landslides or other mass movements have not been documented. Although not reported as problematic, caution is warranted for certain activities (e.g., construction and drilling) on or near slopes in or near areas of previous nuclear testing. On the NTS, particular caution is warranted on or near slopes that have been tunneled for nuclear testing. Site-specific evaluations of slope stability may be necessary for specific activities, e.g. prior to the construction of large structures in areas of rugged terrain, in playa areas, or in areas formerly used for underground nuclear testing.

Soil Stability—Soils in arid environments are typically rich in montmorillonite, a type of clay. The structure of montmorillonite is conducive to swelling or contraction as water is added or removed. Soils in the region have not been comprehensively mapped nor have the areas of potentially expansive soils identified and mapped. Although not reported as problematic in the region, site-specific evaluations of soil stability and expandable clay may be necessary for specific activities. In playa areas where clays are present and may be interbedded with evaporite deposits, soils may become unstable from the application of fresh water to the surface. The infiltration of fresh water can result in the dissolution of halite or other evaporite minerals and the subsequent catastrophic loss of soil stability and formation of a sinkhole or other collapse structure.

Soil loss is a naturally occurring process that can be accelerated through the activities of man. Areas disturbed by excavation are more quickly eroded by wind and water than the undisturbed desert pavements of the region. Proper drainage controls, grading, compaction, and revegetation of disturbed areas at the NTS has minimized the amount of soil erosion that has occurred over the facility.

Ground Stability—Certain soil-forming processes enhance ground stability through the development of a pavemented surface and the accumulation of calcium carbonate. Ground with these attributes, notwithstanding the absence of factors that would result in instability, may be preferred for certain activities (e.g., waste management and foundations). In general, ground that has not been reworked by the flow of water is more likely to have these attributes. Site-specific evaluations for pavement development, calcium carbonate accumulation, and the absence of detrimental soil conditions may be necessary for certain activities as part of stability assessments.

Ground will tend to be less stable if it is composed of readily weathered and/or fractured rocks, contains void space, or lacks vegetation. The stability of a particular area can be reduced if the area is subjected to flowing water, cycles of freezing and thawing, winds strong enough to cause erosion, ground motion, and, in some areas, the heavy pumping of groundwater from the underlying aquifers. Although not

reported as problematic for the NTS, site-specific or regional evaluations for these factors may be necessary for certain activities.

Certain areas where nuclear devices have been tested may be less stable than other areas. On the NTS, not all rubble chimneys resulting from tests have reached the surface; these areas are considered to be unstable. These areas are not appropriate for any other type of use because of their instability; these areas are structurally fenced and controlled. Planning for actions to be conducted in areas in the region where testing of nuclear devices may be resumed certainly have to take into account ground motion associated with that testing. Evaluations of the suitability of areas for testing indicate that areas that have been used in the past are those most suited for testing (Houser, 1968).

Geologic Resources

Geologic resources in the region are discussed under the headings of economic minerals, aggregate, hydrocarbons, and geothermal resources. The impact that past activities have had on geological resources is also discussed.

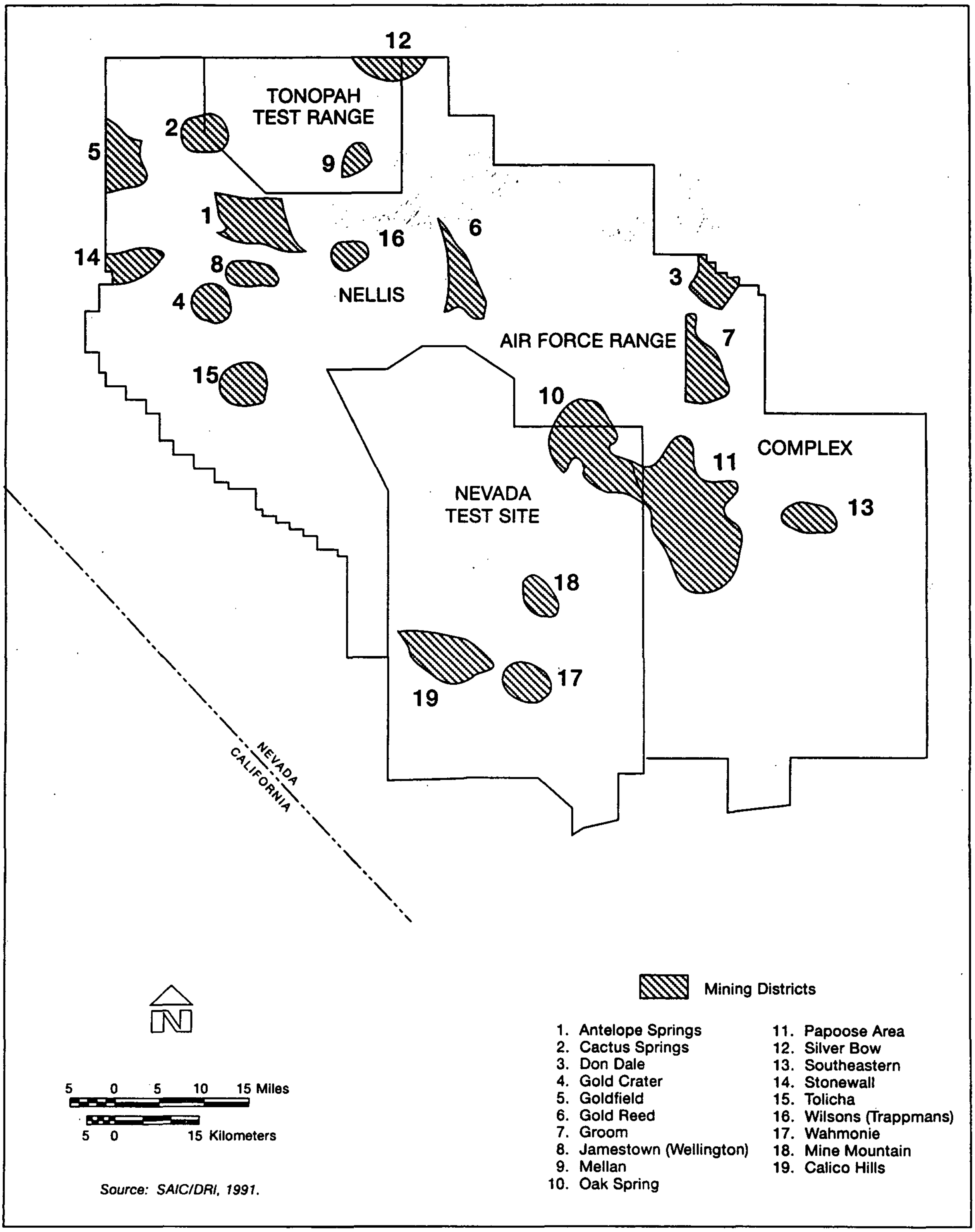
Economic Minerals —Economic minerals are discussed under the headings of precious metals, base metals, ferroalloy metals, and industrial minerals. Important mineral commodities in the NTS region include gold, silver, copper, lead, zinc, tungsten, and uranium (DOI, 1991). Prior to the withdrawals of land for the NTS and the NAFR, the region produced a variety of commodities from a number of mining operations. The historic mining districts of the region are shown on Figure 9. Should the region be opened for public access, areas of previous mining could become important for the collection of mineral specimens and for the development of one or more mining operations.

Precious Metals - Silver may be present in the Oak Spring District at the north end of Yucca Flat and west of Area 13; a significant amount of silver has been taken from the Groom mine in this area (DOI, 1979). A potential economic mineral deposit may remain in the Wahmonie District, located in the south-central part of the NTS.

The NTS has been closed to commercial mineral development since the 1940s (SAIC/DRI, 1991). The reactivation of other gold districts in the region, in response to current gold prices and modern extraction technologies, suggests that the potential for precious metal deposits in the NTS region should be considered moderate to high (SAIC/DRI, 1991).

Base Metals — Copper, lead, zinc, and mercury are known to be present within the region. Economic quantities of copper, lead, and zinc have been recovered from the Groom mine (Humphrey, 1945; Quade and Tingley, 1983; SAIC/DRI, 1991).

Ferroalloy Metals — On the basis of commercial tungsten mining operations in the Oak Spring District during the late 1950s and early 1960s, the NTS region is considered to have moderate potential for the occurrence of tungsten skarn deposits or polymetallic replacement deposits (SAIC/DRI, 1991). Molybdenum is also associated with these deposits (DOI, 1979). Iron (magnetite) is present in the region:



Source: SAIC/DRI, 1991.

Figure 9 . Mining districts located in the NTS, Tonopah Test Range, and NAFR Complex

region. The widespread occurrence of zeolite deposits in the region suggests a low to moderate potential for development. Barite is known to occur in the region in veins associated with quartz and mercury, antimony, and lead mineralization. Barite veins at the NTS are small and impure and do not represent a potential barite resource. Fluorite is also present in the region. Little is known about the occurrence of fluorite, and its resource potential is assumed to be low to moderate (SAIC/DRI, 1991).

Aggregate Resources —Most of the alluvial valleys in the region have aggregate resources at least along the flanks of adjacent mountains. The quantity and quality of the aggregate resources on the NTS are very large and are sufficient to meet any anticipated future demand. The aggregate resources that underlie portions of the NTS do not have any unique value over aggregate occurring in other areas throughout southern Nevada, which are huge by comparison.

Hydrocarbon Resources — Grow et al (1994) indicated that on the basis of rock type and thermal maturity, the northeastern and southern part of the NTS has potential for oil and gas. The thermal maturity acceptable for oil, however, is just within the range of acceptability. The values for both total organic carbon and hydrogen index are regionally continuous; potential source rocks are low. Further, Late Tertiary extensional faulting in the region has likely disrupted any seals or other traps that are required for hydrocarbon accumulation. Based on these findings, the potential for hydrocarbon resources in the region is considered to be low. Previous investigators have also concluded low potential for hydrocarbon resources in the region based on various parameters (Harris et al, 1980) and on reported shows of surface and subsurface hydrocarbons (Garside et al, 1988). Figure 10 shows the relative potential for oil and gas resources in the region. No occurrences of oil and gas, coal, tar sand, or oil shale in the region have been reported.

Geothermal Resources — Hot springs are common in the Great Basin Physiographic Province and the geothermal resources of Nevada have been defined on a statewide basis (Fiero, 1986). If the water temperatures measured near Yucca Mountain are representative (50 to 60 °C [120 to 140 °F]), the water temperatures in the region of the NTS may be insufficient for commercial power development. Current technology requires reservoir temperatures of at least 180 °C (356 °F) for commercial power generation (DOE, 1988).

A preliminary assessment of the geothermal potential of the NTS by the Harry Reid Center for Environmental Studies and Professional Analysis Incorporated (1994) found that there was very good potential for the development of a moderate temperature geothermal resource. This resource potential was judged to be suitable for the development of a binary geothermal power plant.

3.1.1.3 Soils

Soil survey work has been limited on the NTS and surrounding areas to relatively small areas of local interest. A great deal of research has been conducted, however, into the movement of contaminants through the soils of the NTS and the definition of areas where soils have been contaminated.

In general, the soils of the NTS are similar to those of surrounding areas and include aridisols and entisols. The degree of soil development in a given area reflects the age of the soils and the climate, and the soils types and textures reflect their origin. The aridisols (more developed desert soils with a low organic content) are older and form on more stable fans and terraces. Entisols (weakly developed soils typical of desert rockland environments) generally form on steep mountain slopes where erosion is active.

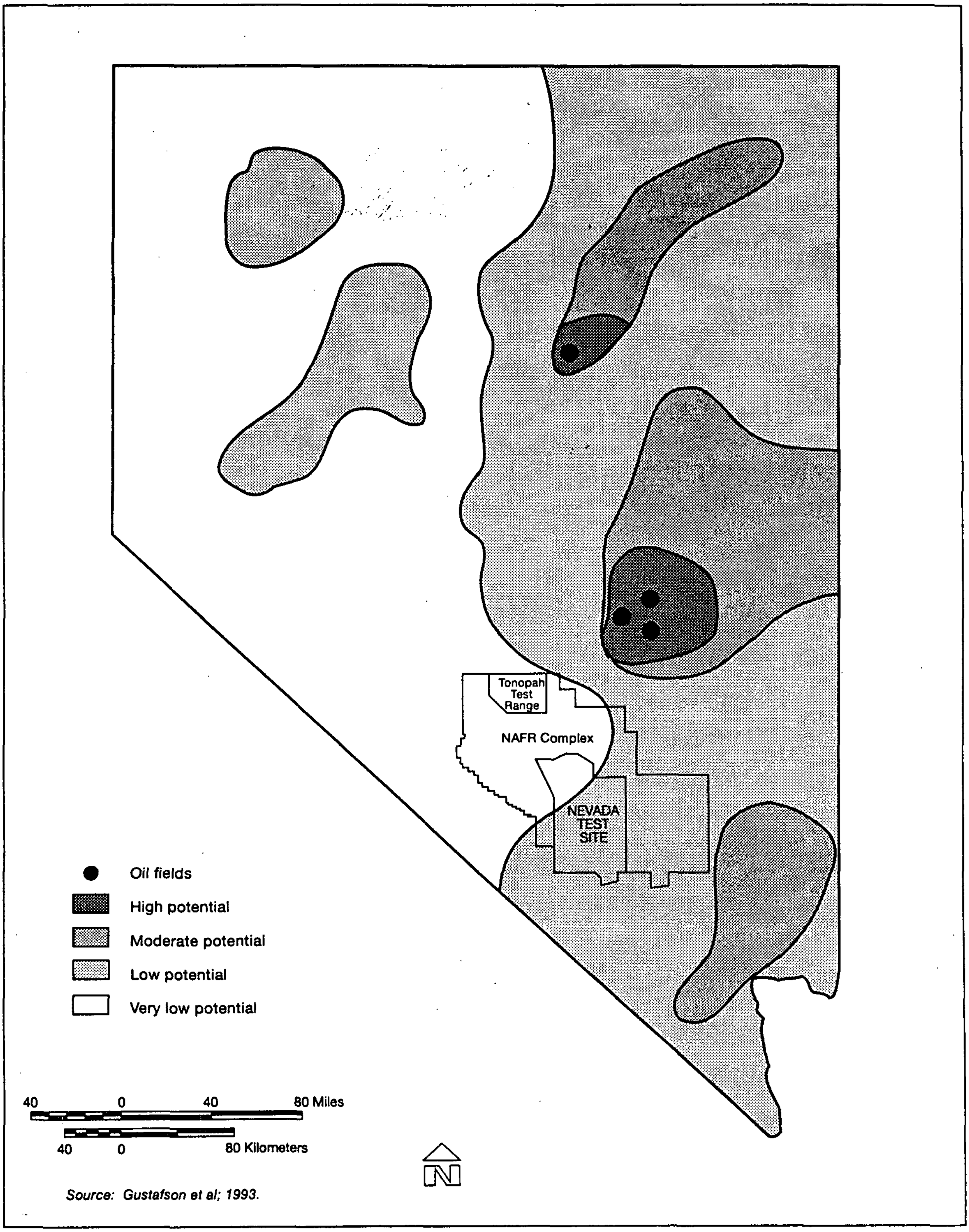


Figure 10 Nevada petroleum potential

Soil loss through wind and water erosion is a natural occurrence throughout the NTS and surrounding areas. The erosion of soils from upland areas and its deposition on the alluvial fans and playa areas are part of the natural processes that have shaped the present landscape of the Great Basin Physiographic Province. Portions of some watersheds on the NTS probably exhibit higher erosion rates, but the erosion conditions and susceptibility of soils on the facility have not been defined. In general, the undisturbed soils of the NTS have well-developed desert pavement surfaces and can be expected to have a low to moderate potential for soil loss to erosion.

There are limited areas of soils that can be irrigated on the NTS according to the State map prepared by the Division of Water Resources (1973), and they occur only in the lower elevations of Yucca Flat, Frenchman Flat, and Jackass Flats. Elsewhere on the NTS, the soils are generally very limited in both thickness and areal extent and are unsuitable for irrigation.

In Yucca Flat, the soils include those soils that can be irrigated with moderate limitations and with moderately low available water-holding capacity, and stony, cobbly soils. In Frenchman Flat, the soils classes present have severe limitations with low available water-holding capacities and soils subject to flooding. The soils that can be irrigated in Jackass Flats have very severe limitations, coarse textures, and very low available water-holding capacities.

According to Romney et al (1973), the soils of the southern NTS reflect the mixed alluvial sediments upon which they form. Soils are generally young in profile development and show only weak evidence of leaching. In general, soil textures are gradational from coarse-grained soils near the mountain fronts to fine-grained soils in the playa areas of Yucca Flat and Frenchman Flat. Most soils are underlain by a hardpan of caliche. Soil salinity generally increases dramatically in the direction of the playa areas, with the highest level of soluble salts having accumulated in the deeper soil profile horizons in Frenchman Flat.

The soils on portions of the NTS have been contaminated during testing and ancillary operations. The largest areas of surficial contamination are in Yucca Flat, Frenchman Flat, and Plutonium Valley and in scattered locations in the western and northwestern parts of the facility. A more detailed discussion of radiological contamination in the soil can be found in the following section. A comprehensive investigation is underway to determine the risks associated with this soils contamination. Actions would be taken as part of the Environmental Restoration Program to reduce these risks, as appropriate.

3.1.2 Water Resources

The discussion of hydrology is divided into separate sections on the surface water resources and the groundwater resources. The surface water resources are discussed in terms of hydrographic basins, whereas groundwater is discussed in terms of hydrogeologic basins and flow systems that comprise two or more individual basins. A hydrographic basin is the area drained by a stream system and bounded by topographic divides (Bates and Jackson, 1987). A hydrogeologic basin is groundwater flow from source areas located either in the bounding mountain ranges or upgradient basins toward discharge areas where groundwater is lost to evapotranspiration, discharge to the surface water regime, or flows underground into downgradient basins. The two types of basins are not necessarily coincident, but the distribution of surface water certainly has an effect on the distribution of groundwater.

The hydrologic conditions of the NTS have been extensively studied, and a very large database is available concerning the surface water and groundwater regimes. In fact, the hydrology of the NTS has probably received more scientific scrutiny than any other area in Nevada. However, the database for areas beyond the Test Site boundaries is not as extensive because of the lack of activities and wells over large portions of the region. The off-site database has been expanded in recent years through a number of regional studies conducted by the USGS, the DRI, and other research organizations. Further, these organizations are continuing to expand the scope of their studies on the NTS as well, thereby addressing uncertainties both on and off the facility.

3.1.2.1 Surface Water Resources

The NTS is located entirely within the Great Basin. The hydrographic basins of the region have internal drainage controlled by topography (Figure 11). Streams in the region are ephemeral. Runoff results from snowmelt and from precipitation during storms that occur most commonly in winter, and occasionally in the fall and spring and during localized thunderstorms that occur primarily in the summer (DOE, 1988). Much of the runoff quickly infiltrates into rock fractures or into the dry soils; some is carried down alluvial fans in arroyos, and some drains onto playas where it may stand for weeks as a lake (DOE, 1986). These playas emphasize a perennial surface water deficit that has characterized Nevada, at least in historic times (French et al, 1984).

The surface water resources of the NTS are meager and are not considered a resource available for the development of water supplies. Surface water bodies on the facility are limited to a few spring pools; there are no perennial or intermittent streams on the NTS. The ephemeral channels that drain the NTS only contain flow for short periods (usually a few hours or less and very seldom more than a few days) following heavy precipitation events.

Drainage

There are not important perennial or intermittent streams on the NTS. The western half and southernmost parts of the NTS have integrated channel systems that carry runoff beyond the NTS boundaries during the infrequent runoff events. Fortymile Canyon is the largest drainage system, originating on Pahute Mesa in the northwestern part of the NTS and draining into the normally dry Amargosa River channel at the confluence located about 32 km (20 miles) southwest of the NTS boundary. Within the NTS, Fortymile Canyon and its tributaries are restricted to well-incised canyons, but the channel splits into several tributaries beyond the NTS in the Amargosa Desert hydrographic basin.

The other major NTS drainages that discharge to the Amargosa River are Topopah Wash and Rock Valley. Topopah Wash trends southwesterly from Jackass Flats in the south-central NTS, and Rock Valley drains from the southernmost NTS westward and then south to Ash Meadows. Both of these drainages are dry throughout most years.

Ground-surface disturbance and craters associated with underground nuclear tests have rerouted parts of natural drainage paths in areas of nuclear device testing. Some craters have captured nearby drainage, and headward erosion of drainage channels is occurring. In some areas of the NTS, the natural drainage system has been all but obliterated by the craters.

The USGS maintains an extensive network for monitoring stream discharge rates on, and in the vicinity of, the NTS. The most recent source of information can be found in annual data summaries presented by the USGS for Nevada (Emmett et al, 1994 and Clary et al 1995). These summaries provide peak discharge data for partial recording stations, precipitation records, and surface water quality data. In 1983, the USGS initiated a comprehensive streamflow and precipitation data collection program that is detailed

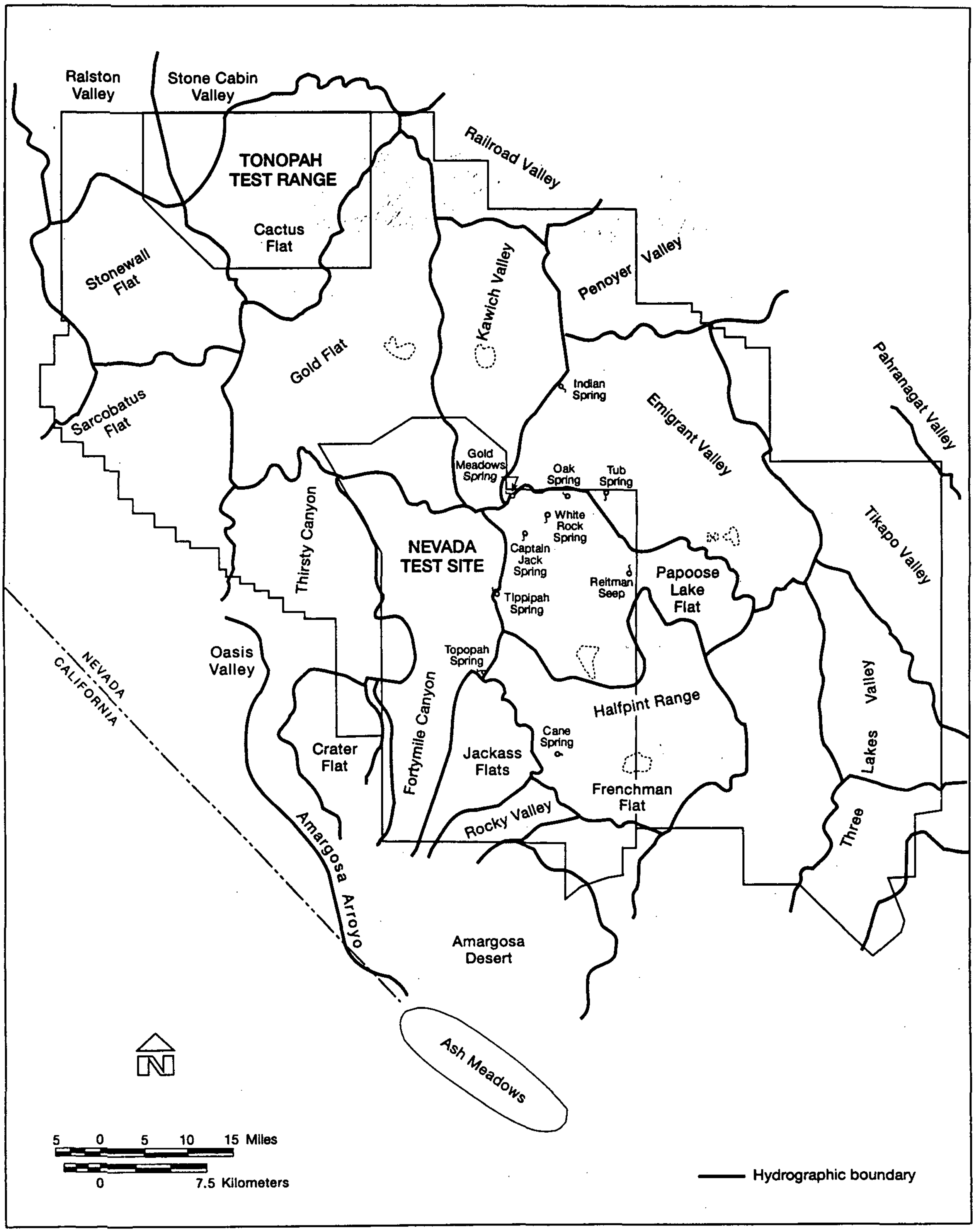


Figure 1-1 . Hydrographic basins of the NTS, NAFR Complex, and Tonopah Test Range area in Pabst et al (1993). Additional information can be found in Christensen and Spahr (1980), and Squires and Young (1984).

In general, the data available from these sources establishes that surface water flows are infrequent with no flow in some years, while in other years, flow occurs for only a few days. For example, Fortymile Wash, the major channel draining the western part of the Test Site, did not have any measurable flow at the Test Site boundary during water years 1991 through 1994. (A water year runs from October 1 through September 30). At a monitoring station location 16 miles to the north in Fortymile Wash, there was flow one day in water year 1992 and two days in water year 1993.

Flooding

Flash flooding does occur in response to heavy precipitation events, especially during summer thunderstorms. The runoff from these storms is typically of short duration and, as a consequence, does not represent an adequate resource for development. The flash floods do result in large peak discharge rates, however, and are of concern with respect to worker safety and the stability of any facilities or structures that are located within the flood plains of the major drainages. Standard engineering practices and worker education offer effective means to lessen the potential damages from the infrequent flash flood events on the NTS.

Floods on the alluvial fans and playas of the NTS are most likely to have an impact on DOE facilities or activities. The potential exists for sheet flow and channelized flow through arroyos (desert channels that are usually dry) to cause localized flooding throughout the lowland portions of the NTS. Because of the size of the NTS, no comprehensive floodplain analysis has been conducted to delineate the 100- and 500-year floodplains. However, existing DOE Orders and environmental regulations dictate that the design of many facilities and actions on the NTS adhere to specific standards with respect to flood (see Tables 2 and 3).

A rise in the surface elevation of any standing water on a playa creates a potential flood hazard. Playas are located in Yucca Flat and Frenchman Flat and collect and dissipate runoff from their respective watersheds. Control Point and News Knob arroyos (informal names), and Gap Wash, Red Canyon Wash, Tongue Wash, and the Aqueduct arroyos in Yucca Flat pose a potential flood hazard to existing facilities. Control Point and News Knob arroyos have been assessed for flood hazard (Miller et al, 1994c).

Arroyos in Frenchman Flat that pose a potential flood hazard to existing facilities are Barren Wash, Scarp Canyon, Nye Canyon, and Cane Spring. The first three of these arroyos have also been assessed for flood hazard (Schmeltzer et al, 1993a and b; Miller et al, 1994 a and b).

Areas prone to flooding surround Fortymile Wash, and include two watersheds, Fortymile Canyon and Jackass Flat. Peak runoff from these two watersheds has been estimated by Squires and Young (1983). The 100-year peak flow for the Fortymile Canyon watershed is estimated at about 13,000 cubic feet (369 cubic meters) per second and the peak flow for the Jackass Flat watershed is estimated at about 8,200

cubic feet (232 cubic meters) per second. No construction exists on the NTS that would significantly alter these estimated flood rates. Topopah Wash, which runs southwesterly across Jackass Flats from Jackass Divide in the south-central part of the NTS, is a major tributary to Amargosa arroyo. Fortymile Canyon and Jackass Flats hydrographic basins pose a flood hazard to off-site areas (SAIC/DRI, 1991). Rock Valley arroyo trends westward from the southernmost part of the NTS to Ash Meadows in the east-central

Table 2. Flood regulations relevant to waste management and other facilities on the NTS.

Flood Regulations	Title
DOE Order 6430.1A	General Design Criteria
DOE-STD-1020-94	Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities
Executive Order 11988	Floodplain Management
Executive Order 11990	Protection of Wetlands
44 CFR 9	Floodplain Management and Protection of Wetlands
44 CFR 65	Identification and Mapping of Special Hazard Areas
10 CFR 1022	Compliance with Floodplain/Wetlands Environmental Review Requirements
10 CFR 264.18	Hazardous Waste Management Unit - Location Standards
40 CFR 264.193	Containment and Detection of Releases
40 CFR 270.14	Contents of Part B: General Requirements
NAC 444.8456	Location of Stationary Facility for Treatment, Incineration or Disposal of Hazardous Waste

Table 3. Applicable flood events and other information regarding regulations listed in Table 2.

Regulations	25-yr, 6-hr	25-yr, 24-hr	100-yr, 6-hr	500-yr	PMP	Sediment Transport	Notes
DOE Order 6430.1A	X		X	X	X	X Also implied	References: EO 11988, EO 11990, 10 CFR 1022, UCRL 115910
DOE-STD-1020-94					X	X	
Executive Order 11988			X				
Executive Order 11990							Wetlands
44 CFR 9			X	X		Implied by references to other regulations	
44 CFR 65			X	X		X	Also FEMA Design Criteria Chapter 10
10 CFR 1022			X	X			
10 CFR 264.18			X				
40 CFR 264.193		X					
40 CFR 270.14			X			Requirement for flood hazard delineation map and consideration of other "special flooding"	

part of the Amargosa Desert (ERDA, 1977). Arroyos trending southward from Red Mountain pose a potential flood hazard to sewage lagoons that service Mercury.

Springs

Throughout the region, springs are the only sources of perennial surface water. These are restricted to some short reaches of the Amargosa arroyo and pools at some large springs (Figure 12). Most water discharged from springs travels only a short distance from the source before evaporating or infiltrating into the ground (DOE, 1986).

Discharges from springs, seeps, and marsh areas in the western hydrographic basins in the region range between less than one and several thousand gallons per minute; typically, discharges are several tens to several hundreds of gallons per minute in the larger springs. The largest discharge is at Crystal Pool in Ash Meadows (DOE, 1988). Moore (1961) provides data on discharges from springs on the NTS and vicinity. The largest three of the nine springs listed, Indian, White Rock, and Cane Springs, discharge greater than 1 gal/min; all others discharge less than 1 gal/min. None of these springs discharges enough flow to sustain vegetated areas that are large enough to meet the definition of wetlands.

Impoundments

A small lake, locally known as Crystal Reservoir, with a storage capacity of 2.3 million m^3 (1,860 acre-feet) is present in the Ash Meadows part of the Amargosa Desert hydrographic basin. Water for the reservoir is supplied by a concrete flume from Crystal Pool (Giampaoli, 1986). The reservoir was recently drained and cleaned by the U.S. Fish and Wildlife Service.

Many impoundments have been constructed on the NTS for operations there. The impoundments on the NTS do not support any vegetation stands that qualify as wetlands.

Surface Water Chemistry

Little data have been collected on the chemistry of the surface waters of the region because all the streams are ephemeral, and only a few springs have been sampled more than once. Moore (1961) presented results on chemical and radiological analyses for eight springs on the NTS (Table 4). These data suggest that concentrations of chemical and radiological constituents are within naturally occurring ranges.

As part of the DOE NTS Monitoring Program, potable water supply wells, springs, well reservoirs, waste disposal ponds, and sewage lagoons are routinely sampled for radiological substances in accordance with federal, State, and local regulations (DOE/NV, 1994). There is no known human consumption of surface water on the NTS. In fact, no public water supplies are drawn from springs in Amargosa Valley, which is located downgradient from the NTS along the primary pathway for surface water flow. The closest surface water supply that is used for public consumption is Lake Mead, which supplies a large portion of the water demand of metropolitan Las Vegas. Water availability and weather permitting, grab samples from open reservoirs, springs, containment ponds, and sewage lagoons are collected annually on the NTS. Samples are analyzed for alpha and gross beta, tritium, plutonium-238, -239, and -240, strontium-89, and radium-226/228.

The annual average for each radionuclide analyzed in surface waters is presented in Table 5 and Table 6 presents analyses for reservoir water. The annual averages for open reservoirs and natural springs are

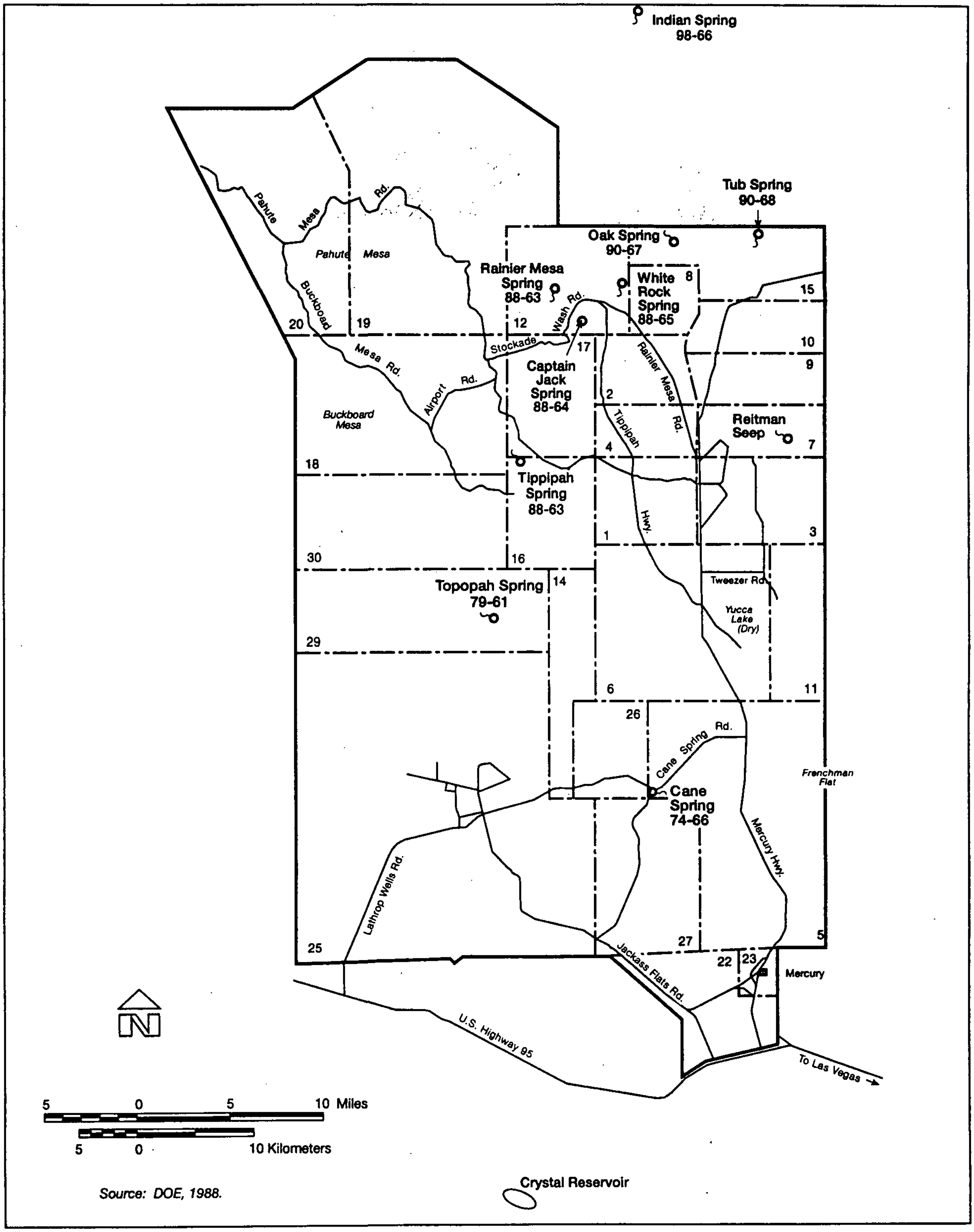


Figure 12 . Location of springs on the NTS

Table 4 Chemical and radiochemical analyses of water from springs on the NTS

Spring No.	Date of Collection	°F	pH	Specific Conductance in Microohms at 25 °C	SiO_2[a]	Al[a]	Fe[a]	Mn[a]	Ca[a]	Mg[a]	Sr[a]	Na[a]	K[a]	HCO_3[a]	CO_3[a]	SO_4[a]	Cl[a]	F[a]	NO_3[a]	PO_4[a]	Total Dissolved Solids (ppm)[b]	Hardness (as $CaCo_3$)		Percent Sodium
																						Total	Noncarbonate	
74-66	9/19/57	66	7.9	425	64	.0	0.10	0.00[c]	32.0	9.2	0.0	37	7.8	163	0	28	20.0	0.5	19.0	0.25	298	118	0	399
74-66	3/24/58	64	8.0	403	63	.0	.00	.00	30.0	9.2	<.1	36	7.6	152	0	30	19.0	.7	18.0	.00	288	113	0	399
79-61	9/17/57	70	6.9	291	71	.2	.08	.00	20.0	3.9	.0	19	18.0	147	0	11	6.0	.7	.1	10	222	66	0	322
79-61	3/25/58	53	6.9	114	50	.3	.44	.00	7.2	1.0	<.1	14	6.4	48	0	15	3.0	.3	2.0	.9	123	22	0	50
83-63	9/17/57	53	7.7	207	53	.6	.31	.00	4.8	.1	.0	40	3.0	88	0	16	7.2	.2	4.6	.45	172	12	0	84
83-63	3/24/58	54	7.4	192	50	.0	.23	.00	4.8	.0	<.1	37	3.2	81	0	19	6.0	.3	4.2	.40	164	12	0	83
88-63	9/18/57	61	8.3	346	65	.2	.04	.00[c]	7.2	1.0	.2	66	4.0	158	2	18	14.0	.6	.6	2.2	256	22	0	84
88-64	5/1/59	56	6.9	188	43	.6	.95	.00[c]	3.2	.0	<.2	47	2.2	95	0	25	4.0	.4	.0	1.2	172	8	0	90
89-65	4/5/57	56	6.9	215	80	1.1	.62	.00	4.8	.0	.0	39	5.4	72	0	23	11.0	.4	4.9	.50	204	12	0	82
89-65	9/18/57	59	7.1	222	52	.1	.03	.00	4.0	.2	.0	42	5.4	78	0	29	8.0	.4	4.8	.65	184	11	0	84
89-65	3/21/58	48	7.2	197	119	.8	.44	.40[c]	6.4	.0	<.1	35	7.4	66	0	32	6.0	.6	4.8	.45	243	16	0	75
89-65	5/19/59	67	8.8	219	48	.7	.30	.00	4.8	.0	<.2	39	4.0	50	13	23	9.0	.6	1.9	.55	167	12	0	83
90-67	4/28/58	55	7.5	241	57	.1	.00	.00[c]	18.0	4.9	<.1	22	6.4	116	0	14	9.0	.3	.0	.10	189	65	0	40
90-68	4/30/59	52	7.1	260	64	.1	.13	.00	16.0	3.9	<.2	31	4.0	118	0	14	11.0	.4	.0	.21	202	56	0	52
98-66	5/1/58	50	7.2	358	61	.1	.08	.00	42.0	7.8	<.2	17	4.8	148	0	36	12.0	.4	.0	.00	254	137	16	211

[a] SiO_2=silica; Al=aluminum; Fe=iron; Mn=manganese; Ca=calcium; Mg=magnesium; Sr=strontium; Na=sodium; K=potassium; HCO_3=bicarbonate; CO_3=carbonate; SO_4=sulfate; Cl=chloride; F=fluoride; NO_3=nitrate; PO_4=phosphate
[b] Dissolved constituents given in parts per million
[c] In solution at time of analysis.

Table 5. Radioactivity in NTS surface waters

(Annual average concentrations in units of picocurie per liter)							
Source of Water	Number of Locations	Gross β	Tritium	^{238}Pu	$^{239+240}Pu$	^{90}Sr[a]	% of DCG[b] Range
Open Reservoirs	15	5.7	-33[c]	0.0011	0.20	0.13	0.069 to 24
Natural Springs	7	9.3	5.4	0.03	0.46	0.24	0.007 to 33
Containment Ponds							
T Tunnel	3	260.0	3.1×10^7	0.028	0.81	ND[c]	([d])
N Tunnel	3	5.3	2.2×10^5	0.00076	0.047	NA[e]	([d])
E Tunnel	2	83	1.7×10^8	0.62	53	5.3	([d])
Decon Facility	1	53	1100	0.0	0.14	NA[e]	([d])
Sewage Lagoons	3	24	67	0.0011	0.0082	0.13	([d])

[a] Strontium-90 values are for one sample
[b] Derived Concentration Guide is based on value for drinking water (4 mrem effective dose equivalent)
[c] Below detection limit
[d] Not a potable water source
[e] Not analyzed.

Source: DOE/NV, 1994a.

Table 6. NTS open reservoir gross beta analysis results

		Gross Beta Concentration (picocurie per liter)				
Location	Number of Samples	Maximum	Minimum	Arithmetic Mean	Standard Deviation	Mean as %DCG*
Area 2, Mud Plant Reservoir	12	9.7	1.4	3.8	2.1	9.5
Area 2, Well 2 Reservoir	12	12.0	4.0	6.4	2.2	16.0
Area 3, Mud Plant Reservoir	12	18.0	2.8	11.0	3.5	28.0
Area 3, Reservoir	12	12.0	0.1	8.2	3.2	21.0
Area 5, UE-5c Reservoir	11	8.9	5.2	7.0	1.2	18.0
Area 5, Well 5b Reservoir	11	15.0	4.8	9.4	3.2	24.0
Area 6, Well 3 Reservoir	2	12.0	9.1	10.0	1.9	25.0
Area 6, Well C1 Reservoir	12	19.0	0.5	9.1	4.9	23.0
Area 18, Camp 17 Reservoir	11	8.7	2.8	4.2	1.6	11.0
Area 18, Well 8 Reservoir	3	6.1	3.8	5.1	1.2	13.0

compared to the derived concentration guides for ingested water. Gamma results for all sample locations indicated that radionuclide levels were consistently below the detection limit except for samples from the containment ponds. The containment ponds were constructed to catch contaminated runoff from the tunnel complexes. With the exception of containment ponds, no annual average concentration in surface waters was found to be statistically different from any other at the 5% significance level. The analytical results from the Area 12 containment ponds showed measurable quantities of radioactivity (DOE, 1993).

These springs are a source of drinking water for wild animals on the NTS. Of the nine natural springs found on the NTS, seven are consistently sampled. The annual average gross beta results for each spring are shown in Table 7 and compared to the strontium-90 Derived Concentration Guide for drinking water; however, the water is not used for drinking. The highest result was for Reitman Seep, which was still below the Derived Concentration Guide (DOE, 1993). Spring discharge samples have also been analyzed for specific radionuclides (tritium, three isotopes of plutonium, and strontium). The average annual concentrations for these radionuclides are also below the Derived Concentration Guides based upon 4 millirem (mrem) effective dose equivalent for drinking water. Tritium averages were low in 1994, below 1.0 picocuries per liter (pCi/L), when eight of the springs were sampled (DOE, 1994b). Open reservoirs have been established at various locations on the NTS for industrial uses. The annual average gross beta concentrations were compared to the Derived Concentration Guides for ingested water, listed in DOE Order 5400.5, even though there was no known consumption of these waters. The corresponding data are shown in Table 8 (DOE, 1993).

Nine of eleven sites related to containment ponds are sampled monthly: five ponds containing impounded waters from the tunnels, three liquid effluents discharged from the tunnels, and a contaminated laundry pond. All active containment ponds are fenced and are posted with radiological warning signs to prevent human access. These ponds are not fenced or flagged so that wildlife access is not restricted. The annual average of gross beta analyses from each sampling location is listed in Table 8 and compared to the Derived Concentration Guide for ingested water; however, the water is not used for drinking by humans (DOE, 1993). Since the closing of the Area 6 Decontamination Facility Pond on November 8, 1992, wastewater has been discharged into holding tanks. Because the water and soil in the former pond are contaminated, grab water samples are collected from the pond monthly when possible (DOE, 1993).

As in the past, samples from the Areas 6, 12, and 23 sewage lagoons were collected quarterly during 1993. During the month of November, sampling was expanded to include all sewage lagoons that are in use, which amounted to an increase of six lagoons located in Areas 6, 12, 22, and 23. Each of the lagoons is part of a closed system used for evaporative treatment of sanitary waste. There was no known contact by the working population during the year. The annual gross-beta-concentration averages for the three lagoons ranged between 2.0 and 3.1 pCi/L. The data for the new lagoons were similar. No radioactivity was detected above the minimum detectable concentrations for tritium and plutonium-238. Levels of strontium-90 slightly above the minimum detectable concentrations were detected in samples collected at the Area 6 Device Assembly Facility sewage lagoon, the Area 6 sewage lagoon, and the Area 12 sewage lagoon. Levels of plutonium-239 and -240 were also detected slightly above the minimum detectable concentration in two samples collected from the Area 6 sewage lagoon. No event-related radioactivity was detected by gamma spectrometry analyses (DOE, 1993).

All water discharges at the NTS are regulated by the State of Nevada under the Nevada Water Pollution Control Act. The State also regulates the design, construction, and operation of wastewater collection systems and treatment works. The NTS maintains compliance with required permits and routinely samples the wastewater effluents that are discharged to sewage lagoons and containment ponds. At some

Table 7. NTS natural spring gross beta analysis results, 1993

Location	Number of Samples	Gross Beta Concentration (picocurie per liter)				
		Maximum	Minimum	Arithmetic Mean	Standard Deviation	Mean as %DCG*
Area 5, Cane Spring	12	24.0	2.0	9.3	6.3	23
Area 7, Reitmann Seep	12	100.0	19.0	36.0	23.0	90

locations, automatic samplers are used to obtain time weighted or flow weighted composite samples of the wastewater. Water-pollution control permits issued by the State are required for industrial and domestic wastewater discharges (DOE/NV, 1993b). Discharge and monitoring requirements imposed by the State serve to prevent degradation of the surface waters (and groundwater) of the NTS. State of Nevada compliance personnel routinely inspect the sewage discharge lagoons and tunnel discharge ponds that are located on the NTS.

3.1.2.2 Groundwater Resources

The groundwater resources of the NTS are large. Groundwater occurs at depth under the entire Test Site, but the physical availability of the water is quite variable, reflecting the types of aquifers present and their water producing capacities. In this section, baseline information on the groundwater resources of the region is presented and discussed.

Regional Hydrologic Conditions

On a regional scale, the NTS is situated within the Death Valley flow system. The Death Valley flow system (Figure 13) is composed of 30 individual hydrographic basins and 41,400 km^2 (16,000 mi^2) of the Great Basin (Harrill et al, 1988). Groundwater within this flow system originates primarily from the infiltration of precipitation over the mountainous areas of the Spring Mountains, Sheep Range and Pahute Mesa and flows toward the regional groundwater depression at Death Valley or smaller depressions in Sarcobatus Flats, Oasis Valley, Ash Meadows, and the Amargosa Desert. The groundwater within the eastern portion of the NTS and within Area 13 of the NAFR flows toward the Ash Meadows discharge area. In the western portion of the NTS, groundwater flows toward the Alkali Flat-Furnace Creek discharge area in Death Valley.

The NTS includes portions of 10 separate hydrographic basins. Table 9 lists these hydrographic basins along with the perennial yields, number of DOE water supply wells, DOE's historic peak water demand rates, and DOE and total water use for each of the basins in 1994. The perennial yield is the quantity of groundwater that can be withdrawn from a basin on an annual basis without depleting the reservoir (Scott et al, 1971). The perennial yield values are estimates used by the Nevada State Engineer for planning purposes and may be significantly greater if recharge is greater than current estimates. Conversely, the perennial yield values could be significantly smaller if one-half of the underflow between some basins is not conisdered a part of the perennial yield of those basins, e.g., Frenchman Flat. For Frenchman Flat, the recharge over the basin is estimated at only about 0.31 million m^3/yr (250 ac-ft/yr) while the perennial yield is almost 20 million m^3/yr (16,000 ac-ft/yr) reflecting the assumed capture of one-half of the underflow from Indian Springs Valley on the east toward Rock Valley on the west. This difference reflects in part, the uncertainties associated with the development of the estimates that are presented in the published literature.

As shown in Table 9, the peak demand associated with historic NTS actions has been a small fraction of the available perennial yield in Gold Flat, Frenchman Flat, Mercury Valley, and Fortymile Canyon. Only in Yucca Flat have the DOE groundwater withdrawals exceeded the published perennial yield. The peak demand of 1.1 million m^3 (912 ac-ft) in 1989 exceeded the perennial yield of 0.4 million m^3/yr (350 ac-ft/yr) by a factor of 2.6. Historic data indicate that annual water withdrawals have exceeded the perennial yield of Yucca Flat since 1962, but only in 1967, 1969, and 1989 were more than about 0.9 million m^3/yr (700 ac-ft) withdrawn.

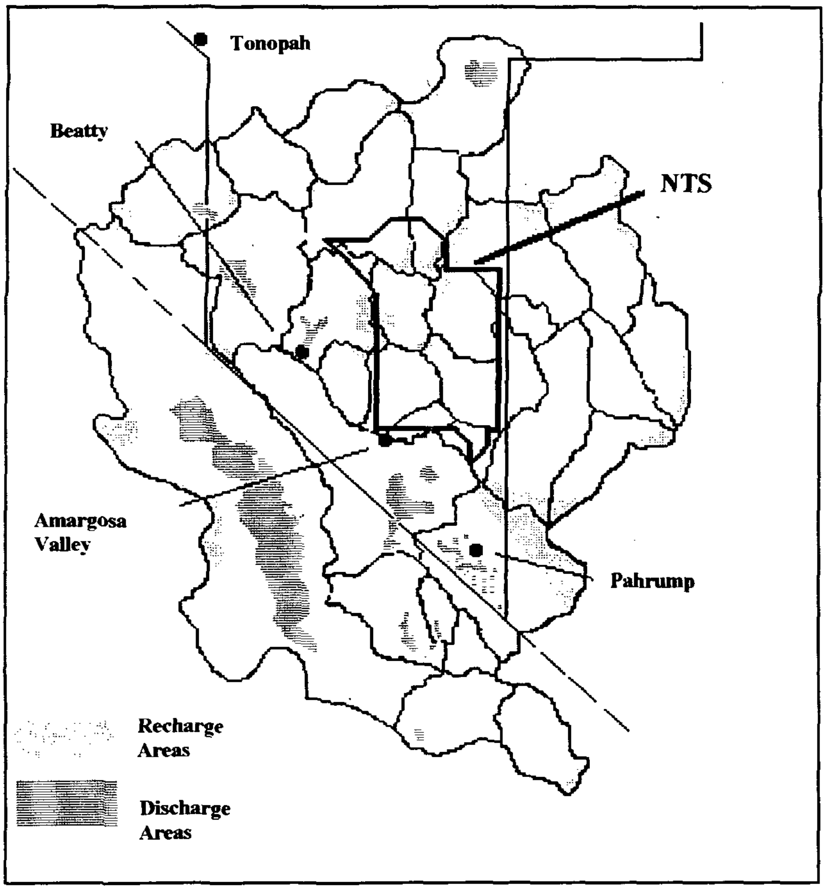


Figure 13. Death Valley Flow System

Table 9 Perennial yield and w[illegible]nds f[illegible]sins on the NTS.

Basin	Perennial Yield acre feet per year	DOE Supply Wells	Hi[illegible] D[illegible]d	[illegible] Y[illegible]	[illegible]94 DOE [illegible]ater Use [illegible]cre feet	1994 Total Water Use
Gold Flat	1,900	1	[illegible]25	1[illegible]	2	385
Kawich Valley	2,200	none	[illegible]one	n[illegible]	none	425
Emigrant Valley	2,500	none	none	n/a	none	no data
[illegible]	350	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]57
[illegible]	[illegible]000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]ercury Valley	[illegible]00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Rock Valley	[illegible]	[illegible]	none	n/a	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	524	1988	[illegible]	[illegible]
[illegible]	[illegible]	2	277	1994	[illegible]	[illegible]
[illegible]	[illegible]	none	none	n/a	[illegible]	[illegible]
Amargosa Valley	[illegible]	none	none	n/a	[illegible]	[illegible]
Total	[illegible]	**18**	**3,096**	**n/a**	[illegible]	[illegible]

[illegible]n 1994, the total water us[illegible]E was less than one-tenth of the [illegible]ndwater wi[illegible] from [illegible]e 10 basins. The DOE [illegible]t 1,460 acre feet in 1994 wh[illegible]al water use i[illegible]ns is [illegible]stimated at 15,255 acre f[illegible] million m^3). Most of the [illegible]r (over 15,000 [illegible]18.5 [illegible]illion m^3]) was used in [illegible]a Valley for agriculture a[illegible]

[illegible]he effects of the DOE's [illegible]hdrawals have includ[illegible]ering of water levels in t[illegible] [illegible]f water supply wells and s[illegible]lized changes in grou[illegible] [illegible]ater levels, spring discha[illegible] or flow directions h[illegible] [illegible]ater withdrawals. Estima[illegible] drawdown in the vic[illegible] made by the USGS (Thordarson, 1983; Young, 1972) and the DRI (Seaber et al, 1995). As part of their Wellhead Protection Program for the NTS, the DOE recently completed capture zone models for each water supply well and mapped the area of influence for each well. The model used was the U.S. Environmental Protection Agency's (EPA) Modular Semi-Analytical Model for the Delineation of Wellhead Protection Areas (EPA, 1991). This model includes three separate modules to simulate two-dimensional steady state groundwater flow in an areal plane and allows for multiple pumping wells, barriers or recharge boundaries, and variations in pumping periods. In simulating the response of NTS wells on the regional hydrologic regime, a very conservative approach was used that assumed that each well was operated continuously for a period of 10 years. In reality, the water supply wells cycle on and off as needed to maintain storage levels in tanks and seldom operate continuously for more than a few days.

The results of the simulations indicate that for each well, the area of influence is limited. In general, the effects of the historic pumping of NTS water supply wells are concentrated within a distance of a few thousand ft (about one kilometer) of the operating wells. Only at Army Well 1, located just inside the Test Site boundary about seven km (five miles) southwest of Mercury, does the capture zone extend beyond the boundaries of the NTS.

Because the extraction rates in Yucca Flat exceed the perennial yield of the basin, the impacts of the water withdrawals in this basin could be more significant and require special consideration. The capture of groundwater in excess of the perennial yield could have removed water from storage or decreased the downgradient subsurface discharge to Frenchman Flat or both. Long-term water-level data for three wells in Yucca Flat are presented in Clary et al (1995) and show variable results. Water levels in Well UE-2ce declined about 24 m (80 ft) between 1977 and 1984, while water levels in Well UE-5n rose about 0.3 m (one foot). At Well UE-2ce, water levels rose almost 8 m (25 ft) between 1984 and 1994. Records for Well TW-7 have been affected by underground nuclear detonations and show an overall trend of rising water levels between 1957 and 1980 and declining water levels from 1980 to 1994.

A recent evaluation of the effects of water withdrawals on the NTS on the regional hydrologic regime was conducted by Avon and Durbin (1994) on behalf of the Las Vegas Valley Water District and by Brown and Lehman (1995) on behalf of the State of Nevada. These studies were specifically focused on water level declines at Devil's Hole in Death Valley National Monument. Both studies concluded that there was little or no evidence that historic water withdrawals on the NTS have an impact on the water levels at Devil's Hole.

Aquifers and Aquitards

The NTS and surrounding regions are hydrogeologically complex, reflecting the geologic history of the aquifers and aquitards that have been deposited and then disturbed over geologic time. There are three principal hydrogeologic systems: 1) the valley-fill deposits of the alluvial aquifer system; 2) the tuffs and ash deposits of the volcanic aquifer system; and 3) Paleozoic and older sedimentary rocks of the regional carbonate system. The alluvial system includes the valley-fill deposits of gravel, sand, and clay as well as interbedded basalt flows and lacustrine deposits. The volcanic aquifer system includes as much as 3,960 m (13,000 ft) of accumulated volcanic deposits. The regional carbonate system comprises more than 10,650 m (35,000 ft) of Paleozoic and older sediments. The general relationship of these hydrogeologic systems in southern Nevada is shown in Table 10. As evidence of the complex hydrogeology, Winograd and Thordarson (1975) identified six major aquifers and four major aquitards in the region. Figure 14 shows the relative positions and characteristics of these aquifers. These units are described in ascending order in the following discussion.

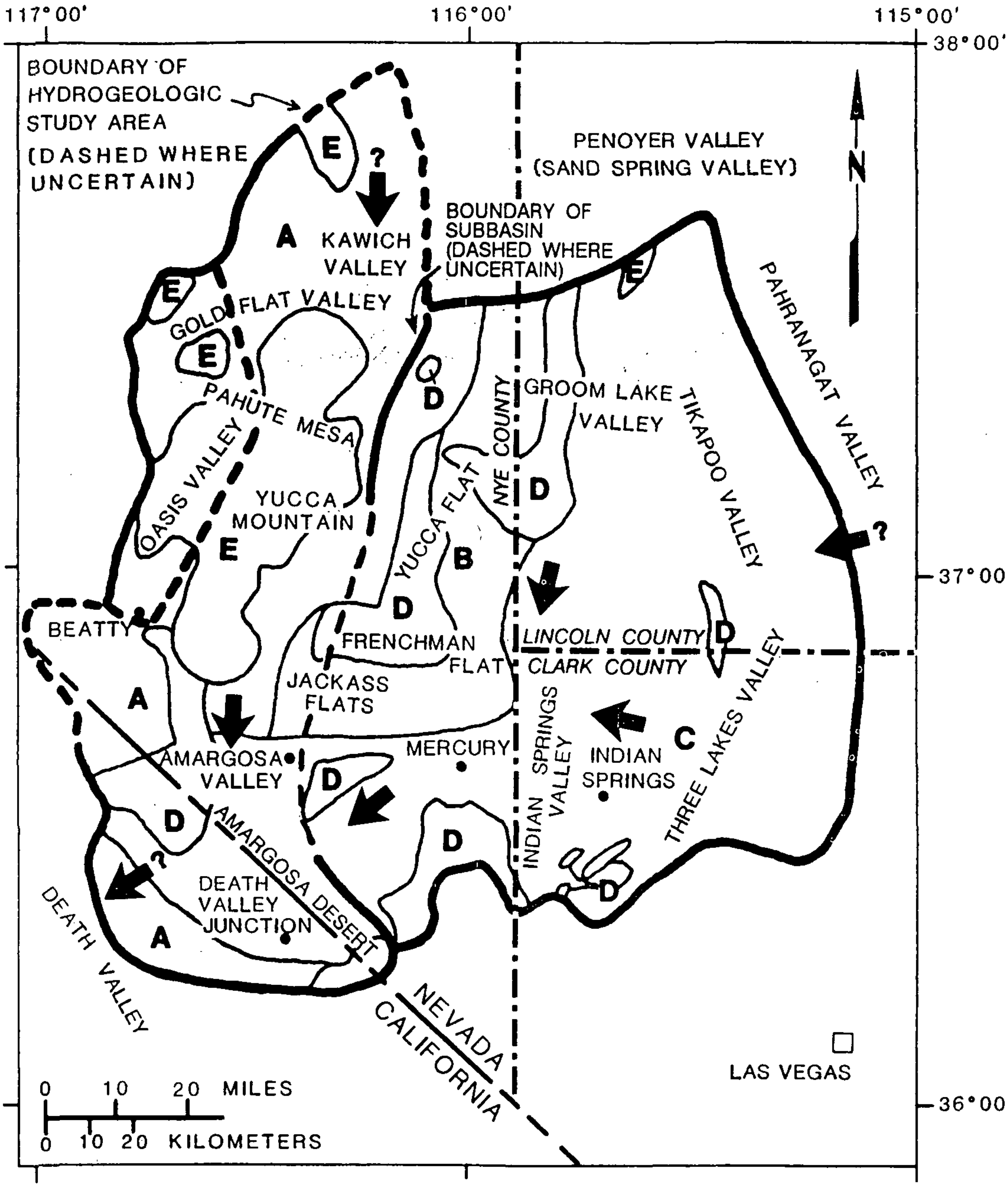
The hydrologic basement, referred to as the lower clastic aquitard, is comprised of low-permeability Cambrian and older quartzite and metamorphic rocks. Even where faulted and fractured, the lower clastic aquitard does not store or transmit large volumes of water and hence is considered as the bottom of the hydrologic system at the NTS. According to information presented in Laczniak et al (1996) and Winograd and Thordarson (1975), the lower clastic aquitard is widespread across southern Nevada. The rocks of this unit are exposed in the northern Halfpint Range on the NTS, in the Groom and Papoose Ranges to the northeast, the Desert and Sheep Ranges to the east, the Spring Mountains and Resting Spring Range on the southeast and south, and the Amargosa Range on the southwest. The lower clastic aquifer is an effective barrier to groundwater flow as evidenced by steep hydraulic gradients across the outcrop areas (Laczniak et al, 1996).

The lower clastic aquitard is regionally overlain by the lower carbonate aquifer, which is comprised of 4,000 to 5,000 m (13,120 to 16,400 ft) of relatively thick permeable limestones and dolostones, with thinner less permeable siltstones, shales, and quartzites. Because of the past geologic history of uplift, erosion, and structural deformation, the lower carbonate aquifer is not present in all areas, and rarely is the entire thickness of the unit present under the NTS or adjacent areas. Regional intrabasin flow in the

Table 10. Major hydrogeologic units of the Death Valley flow system

Hydrogeologic Units	Primary Rock Types	Age	Comments
Valley-fill aquifer			
alluvium	mixtures of sand, silt, gravel, and clay	Late Tertiary to Quaternary	An important source of water for the region
playa deposits	unconsolidated clay and evaporites	Late Tertiary to Quaternary	Characterized by poor well yields and poor water quality
continental deposits	claystone and freshwater limestone	Late Tertiary	Not an important source of water
Volcanic Rocks			
lava flow aquifers	rhyolite lava flows, welded ash-flow tuffs, and nonwelded, zeolitized ash-flow tuffs	Miocene	An important source of water on the NTS
tuff-confining units	lava and rhyolite flows and unwelded to densely welded ash-flow tuffs	Miocene	Characterized by slow groundwater seepage
Carbonates and clastic rocks:			
upper carbonate aquifer	limestone	Permian-Pennsylvanian	Can be very productive
upper clastic confining unit	shales and siltstones	Mississippian	Not productive
lower carbonate aquifer	limestones and dolostones	Cambrian- Devonian	Can be moderately productive
lower clastic confining unit	quartzites and other metamorphics	Cambrian and Younger	Not productive

Source: Modified from Waddell et al., 1984.



GENERAL DIRECTION OF REGIONAL GROUND-WATER FLOW (QUESTION MARK INDICATES UNCERTAINTY)

A. VOLCANIC ROCK AQUIFERS AND AQUITARDS OVERLYING CLASTIC AQUITARDS OR LOWER CARBONATE AQUIFER
B. VOLCANIC ROCK AQUIFERS AND AQUITARDS OVERLYING LOWER CARBONATE AQUIFER
C. LOWER CARBONATE AQUIFER
D. CLASTIC AQUITARDS
E. VOLCANIC ROCK AQUIFER AND AQUITARDS OF CALDERAS

NOTE: FOR CLARITY, VALLEY FILL AQUIFER NOT SHOWN

Source: DOE (1988)

Figure 14. Generalized distribution of uppermost hydrogeologic units in the saturated zone of the region.

vicinity of the NTS is dominated by groundwater movement within the lower carbonate aquifer. Laczniak et al (1996) note that this aquifer is especially important with respect to the movement of groundwater between the underground nuclear testing areas at Yucca Flat and Frenchman Flat toward the discharge areas in Ash Meadows and Death Valley.

Locally at the NTS, the lower carbonate aquifer is overlain by an upper clastic aquitard that consists of low-permeability rocks of the Eleana Formation and Chainman Shale. The upper clastic aquitard is characterized by Laczniak et al (1996) as a major confining unit that separates the Ash Meadow and Alkali Flat-Furnace Creek subbasins of the Death Valley flow system. In places, this unit may be as much as 1,525 m (5,000 ft) thick. The upper clastic aquitard is a major control on groundwater flow directions at the NTS serving as a barrier to westward flow from Yucca Flat.

Pennsylvanian-age limestones that comprise the upper carbonate aquifer overlie the upper clastic aquitard in western Yucca Flat. Flow through the upper carbonate aquifer under the NTS is discontinuous and, therefore, considered less significant than flow through the lower carbonate aquifer. In many areas south and east of the NTS, the upper clastic aquifer is absent and the upper and lower carbonate aquifer are considered part of a single regional system. Elsewhere in southern Nevada in Coyote Spring Valley and the Muddy Springs area, the upper carbonate aquifer has been found to be a very productive aquifer capable of yielding thousands of gallons per minute to properly located and constructed water wells.

Groundwater flow on Pahute and Rainier Mesas is through thick sequences of Tertiary volcanic rock, originating from the calderas of the southwest Nevada volcanic field. The Tertiary volcanic rocks consist of ash flows, lava flows, and air-fall tuffs. Local alteration of units (primarily by zeolitization) in older, deeper parts of the volcanic pile has resulted in lower transmissivities than those of the upper deposits. Thinner sequences of these volcanic rocks overlie the upper carbonate aquifer and upper clastic aquitard within some areas of Yucca and Frenchman Flats. Winograd and Thordarson (1975) classified the upper Tertiary sequence of lava flows, and bedded and welded tuffs as aquifers and the lower Tertiary sequence of welded and nonwelded tuffs, rhyolite, and breccia flows as an aquitard. Lava-flow aquifers (present near volcanic centers) are present in Jackass Flats, Pahute Mesa, Rainier Mesa, Timber Mountain, and associated proximal areas. Tuff aquifers within the volcanic aquifer hydrogeologic unit consist of ash-fall, welded, or bedded tuffs. Welded-tuff aquifers are present in the deepest parts of Yucca Flat, Frenchman Flat, and Jackass Flats. Welded- and bedded-tuff aquifers are also present on the mesas, Timber Mountain, and associated proximal areas. Laczniak et al (1996) characterize the volcanic aquifers and aquitards of the NTS as geometrically complex. Unlike the rocks of the regional carbonate system, the position of a given volcanic unit within the overall stratigraphic sequence does not correlate with its hydraulic properties.

Tertiary- and Quaternary-age alluvium and playa lake deposits fill the intermontane valleys and locally overlie Tertiary and Paleozoic rocks. The valley-fill deposits comprise a sequence of gravel, sand, silt, and clay. The sediments vary widely, with clay predominating in the playa areas and in the gravels and sands under the alluvial fans. The permeability of these alluvial materials is quite variable with very low permeabilities associated with the fine-grained clays and silts, moderate permeabilities associated with poorly sorted mixtures and cemented or consolidated alluvium, and highest permeabilities occurring where the highest proportions of uncemented gravels and sands are located. The valley-fill deposits only form an aquifer where the sediments are saturated. The alluvial aquifer is absent in portions of Yucca Flat where the water table is below the bottom of the valley-fill deposits.

Aquifer Properties

The transmissivity of a water bearing units is defined as the rate at which groundwater flows through a unit width of the aquifer under a unit hydraulic gradient. The porosity of an aquifer is defined as the percentage of the volume of rock that is occupied by connected or void spaces between the individual grains of a rock or soil. The estimated transmissivity and porosity values for the principal hydrogeologic units at the NTS are summarized in Table 11. These values are based upon the results of laboratory tests and aquifer tests as reported by Winograd and Thordarson (1975).

Table 11. Summary of hydraulic properties of major hydrogeologic units

	Approximate Range of Transmissivities		
Hydrogeologic Unit	**m^2 per day**	**ft^2 per day**	**Approximate Range of Porosities (%)**
Limestones and dolomites	0.11to 11,000	1.2 to 118,360	1 to 12
Tuff confining units	0.0016 to 180	0.017 to 1,936	20 to 48
Lava flow aquifers	0.00021 to 5.0	0.002 to 54	32 to 45
Tuff aquifer - welded	0.00024 to 2,300	0.0025 to 24,748	7 to 36
Tuff aquifer - bedded	Not Available	Not Available	20 to 53
Valley-fill aquifer	0.0019 to 340	0.02 to 3,658	10 to 54

In general, groundwater moves most rapidly through the fractured limestones and dolomites of the lower carbonate aquifer and less rapidly through valley-fill alluvium and fractured volcanic rocks. Groundwater moves most slowly through fine-grained playa deposits, unfractured and densely welded volcanic rocks, quartzites, siltstones, and shales. In the limestones and dolostones, the relatively high transmissivities are associated primarily with fractures and dissolution features. In the volcanic rocks, water movement occurs along bedding planes and cooling joints of lava-flow sheets and welded-flow units. In some locations, the overlying unaltered volcanic section is abundantly fractured and has retained its permeability. In the valley-fill deposits, transmissivity is dependent on the amount of clay and mineralization and on the degree of consolidation.

Groundwater Occurrence and Movement

Groundwater occurs at depth under the entire NTS and surrounding region. The depth to the groundwater in wells at the NTS is quite variable, ranging from about 160 m (525 ft) below land surface in portions of Frenchman Flat and Yucca Flat (Winograd and Thordarson, 1975) to more than 610 m (2,000 ft) under the upland portions of Pahute Mesa (Russell, 1994). Perched groundwater is known to occur in some parts of the NTS, mainly in the volcanic rocks of the Pahute Mesa area. The great depth to groundwater under much of the NTS is one of the key factors in the success of the facility as an underground nuclear testing area.

The present conceptual groundwater flow model for the Death Valley flow system is derived primarily from Winograd and Thordarson (1975) and updated by Waddell et al (1984), and by Laczniak et al (1996). Figure 15 shows the approximate elevation of the potentiometric surface under the NTS and surrounding areas. As shown, the groundwater flows generally south and southwest on the NTS from the upland areas of Pahute Mesa and Yucca Flat toward Amargosa Desert and ultimately, Death Valley. Groundwater flows onto the Test Site across the northern boundary and along the eastern boundary and discharges from the Test Site along the southern boundary.

The total thickness of sediments that readily transmit groundwater is not known. As noted previously, the basement of the groundwater flow system can be taken as the lower clastic aquitard where it is present. Under the thick volcanic deposits of Pahute Mesa and Rainier Mesa, this aquitard is absent but the tuff aquitard may limit the depth at which groundwater can flow. For the purposes of most evaluations, the flow system may be assumed to extend from the water table to a depth of about 1,525 m (5,000 ft). At depths greater than this, the transmissivity of the rocks probably becomes much smaller (ERDA, 1977).

The rates of groundwater flow across the region of the NTS are quite variable, reflecting the types of aquifers present, the degree of fracturing (and secondary dissolution of carbonate aquifers), and the hydraulic gradients that are present in a given area. The average flow rates over broad areas were estimated by Winograd and Thordarson (1975) to range from 2 to 200 meters per year (m/yr) (7 to 660 feet per year [ft/yr]), but rates can be much lower or much higher over short distances in certain geologic settings. Significant components of vertical groundwater flow are present in certain areas. For example, in the Frenchman Flat area, large volumes of groundwater recharge derived from Indian Springs Valley on the east and Yucca Flat on the north move primarily downward into the underlying carbonate aquifers. In regional discharge areas such as Ash Meadows, strong vertical gradients are present with water flowing upward from the lower carbonate aquifer into the overlying alluvial deposits.

Water Budget

A groundwater budget is a complete accounting of all of the components of recharge to, and discharge from, a hydrographic basin or a flow system. The components of recharge include the infiltration of rain and snow in the mountainous areas, groundwater flow into an area from upgradient basins, and secondary recharge from the application of water in a basin, e.g., irrigation of farmland. The components of discharge for a basin include direct evaporation and water use by vegetation (collectively termed evapotranspiration), water well withdrawals, and groundwater blow out of the basin. Table 12 presents the estimated water budgets for each of the hydrographic basins on the NTS.

Recharge

Within the NTS region, recharge occurs as underflow from upgradient areas and from the infiltration of precipitation in the northern and eastern mountain ranges. The groundwater underlying the NTS and surrounding areas is derived from two sources, underflow from basins upgradient of the area and from recharge over the upland areas of the Test Site. The total recharge from underflow from adjacent areas is significant. Harrill et al (1988) estimated underflow of 39.4 million m^3/yr (32,000 ac-ft/yr) discharge

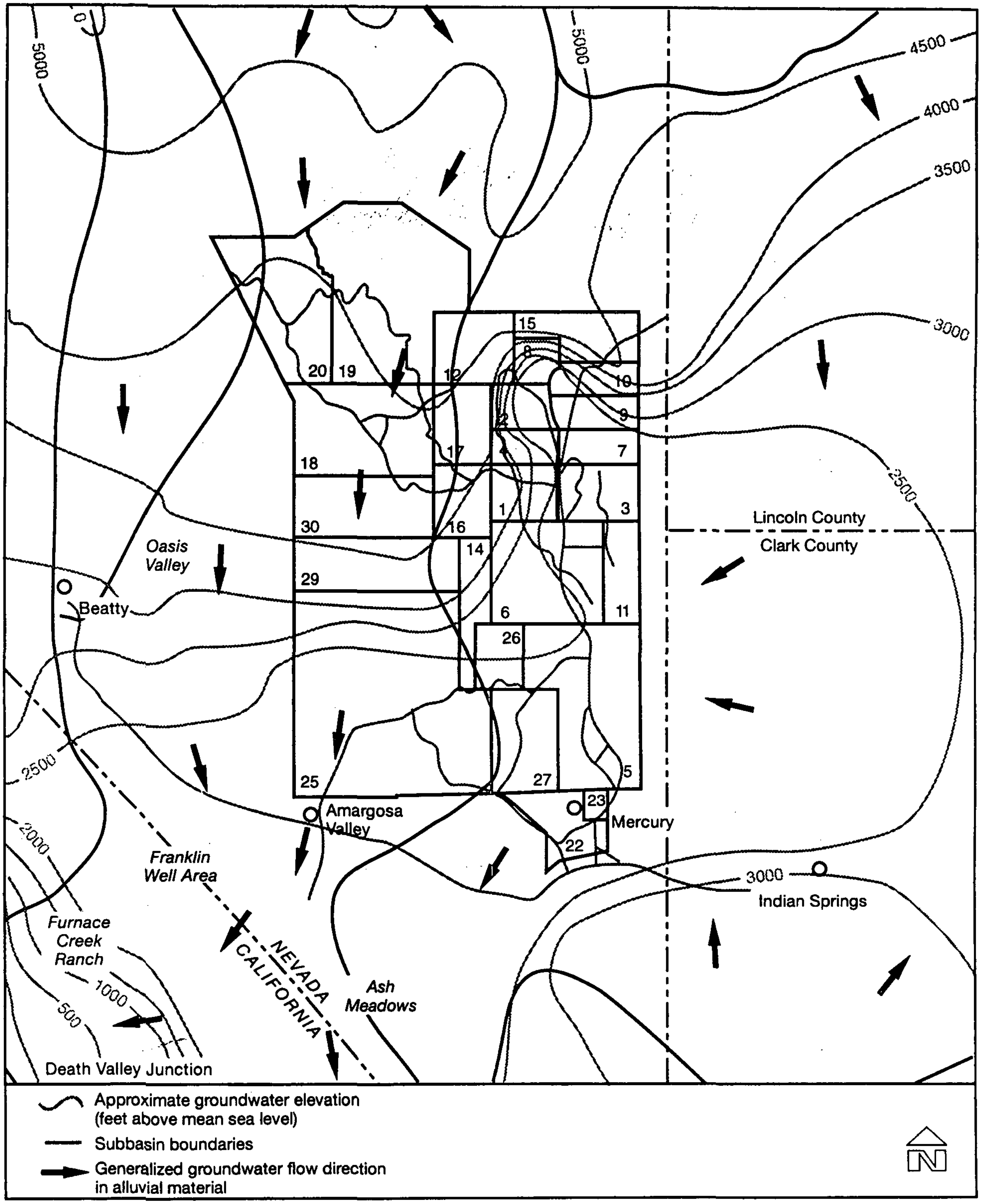


Figure 15 Generalized potentiometric surface and groundwater flow directions

Table 12. Estimates of Groundwater Budget Components for NTS Basins.

Water Budget Parameters in Acre Feet Per Year

Basin	Inflow	Et 1	Et 2	Et 3	Outflow	Recharge 1	Recharge 2	Recharge 3	Perennial Yield
Gold Flat	0	0	0	0	3800	3800	6700	6700	1900
Kawich Valley	*1000*	0	0	0	4500	3500	7500	7500	2200
Groom Lake Valley	0	0	0	0	3200	3200	13000	13000	2800
Papoose Lake Valley	0	0	0	0	<10	<10	(w/158a)	(w/158a)	<10
Yucca Flat	0	0	0	0	700	700	1900	1900	350
Frenchman Flat	*32000*	0	0	0	33000	100	990	990	16000
Mercury Valley	16000	0	0	0	17000	250	340	340	8000
Rock Valley	17000	0	0	0	17000	30	40	40	8000
Jackass Flats	7200	0	0	0	8100	900	6600	6600	4000
Buckboard Mesa	5800	0	0	0	7200	1400	(w/227a)	(w/227a)	3600
Oasis Valley	*2500*	2000	4300	4300	1500	1000	3100	3100	2000
Amargosa Desert	44000	14000	24000	43000	*16000*	600	410	410	24000
TOTAL	35500	16000	28300	47300	16000	15480	40580	40580	72850

Et = Evapotranspiration

Values in italic are totalled independently of other values to avoid double counting of inflows and outflows

Et 1 : State of Nevada (1971)
Et 2 : Pal Consultants (1995)
Et 3: D'Agnese (1994)
Recharge 1 : State of Nevada (1971)
Recharge 2 : Pal Consultants (1995)
Recharge 3: D'Agnese (1994)

Water Budget Imbalances

	Inflow + Recharge	Et + Outflow	% Imbalance
State of Nevada (1971)	50980	32000	-0.37
Pal Consultants (1995)	76080	44300	0.72
D'Agnese (1994)	76080	63300	-0.17

Note: Because this table only includes the 10 basins that occur on the NTS, the totals do not match match those presented in the PAL (1995) and D'Agnese (1994) tables.

Shown above are published estimates of the components of the water budget for the basins of southern Nye County. There is little or no variation in the inflow and outflow estimates so single values were used for these parameters. As shown, there are considerable differences between the earlier State of Nevada estimates and later estimates by D'Agnese and Pal Consultants, Inc. Most of the differences in the more recent estimates can be attributed to the differences in the estimates of evapotranspiration and the different estimates of total recharge to Pahrump Valley.

from Indian Springs Valley westward into Frenchman Flat. They estimated that the underflow of 6 million m^3/yr (5,000 ac-ft/yr) and 1.3 million m^3/yr (1,000 ac-ft/yr) is derived from Kawich Valley and Gold Flat, respectively. Winograd and Thordarson (1975) also estimated that small to moderate volumes of water (0.1 to 7.5 million m^3/yr [80 to 6,000 ac-ft/yr]) may enter the carbonate aquifer in the Ash Meadows groundwater basin by underflow from the northeast. Thus, the total underflow onto the NTS is at least 45.5 million m^3/yr (38,000 ac-ft/yr), based on Harrill et al (1988), and could be as high as 54 million m^3/yr (44,000 ac-ft/yr) if the inflow suggested by Winograd and Thordarson (1975) is considered.

Groundwater flow directions and gradients to the southeast of Army Well 1 and the presence of a faulted sequence of the lower carbonate aquifer through this area (on the southeastern side of Mercury Valley) suggest that there may also be appreciable flow onto the Test Site from groundwater derived from recharge over the Spring Mountains. Flow from Indian Springs Valley may be entering Mercury Valley from the southeast and then discharging from the basin to the southwest, into Amargosa Desert in the area upgradient of the Ash Meadows area.

Recharge in upland areas occurs predominately through the slow percolation of rain and snowmelt through the unsaturated zone (the zone between the land surface and the top of the water table). Most of this recharge is restricted to higher elevations where the precipitation is the greatest, and along canyons and alluvial fans adjacent to upland areas. Recharge from upland areas of the NTS is far more limited than that from underflow, only about 4.2 million m^3/yr (3,400 ac-ft/yr), one-tenth or less of that derived from underflow. Most of the recharge originates over the upland areas of Pahute Mesa, Timber Mountain, and the Belted Range.

There is considerable uncertainty in the recharge estimates for the region. Table 12 lists three different estimates of recharge. The older estimates are based upon the reconnaissance surveys of hydrographic basins and were published by the State of Nevada (1971) as part of the State Water Plan. For the basins of the NTS, the total estimated recharge based on these estimates is only about 19 million m^3/yr (15,500 ac-ft/yr). More recent estimates by D'Agnese (1995) were based on a detailed digital hydrogeologic model and preliminary numerical groundwater flow model of the Death Valley region. Pal Consultants, Inc. (1995), on behalf of the National Park Service, evaluated the results of these models and adopted the same recharge values. These more recent estimates are more than 250% greater than the estimates published by the State of Nevada (1971).

Discharge

Discharge within the NTS region occurs primarily in the southern and western low-lying valleys of Amargosa Desert and Death Valley. The location of discharge areas is controlled by the presence of low-permeability materials that force groundwater to the land surface or by the lower elevations of Death Valley. Most of the natural annual discharge from the Death Valley flow system is transpired by plants or evaporated from soil and playas in the Amargosa Desert and Death Valley.

There is also considerable uncertainty in the estimates of discharge. Discharge from the Ash Meadows area was estimated to be about 21 million m^3/yr (17,000 ac-ft/yr) by Rush (1970). Less than 1 million m^3/yr (a few hundred ac-ft/yr) may continue southward through alluvium of the Amargosa arroyos, and as much as 6.2 million m^3/yr (5,000 ac-ft/yr) yearly may flow westward from the Amargosa Desert to springs in Death Valley (ERDA, 1977). The D'Agnese (1994) study estimated the discharge in Amargosa

The D'Agnese estimate was based upon the analysis of spring discharge data, water use, and phreatophyte water consumption. A detailed regional-scale map of vegetative assemblages was developed using satellite imagery. This map was employed to calculate discharge to evaporation from bare soils and consumption by phreatophytes and agriculture. Based upon the D'Agnese (1994) evaluation, a much greater volume of water appears to be discharged annually from the Ash Meadows area.

Groundwater discharge at Ash Meadows and Oasis Valley is structurally controlled; the presence of the low-permeability rocks of the lower clastic aquitard restricts regional groundwater flow and major faults create a partial barrier to groundwater flow to the southwest. This geologic setting creates high water levels that have resulted in the large spring discharges at Ash Meadows and accompanying evapotranspiration. However, some water may flow across the fault and into the Alkali Flat-Furnace Creek Ranch area, ultimately discharging at the springs near Furnace Creek Ranch.

Within the boundaries of the NTS, groundwater discharge is much smaller and is limited to a few springs in the upland areas and several wells. The springs discharge waters from perched zones in the upland areas of Pahute Mesa and Rainier Mesa. Discharge from the springs is small; three springs discharge between 7 and 31 liters per minute (L/min) (2 and 8 gal/min), while the rest discharge less than 4 L/min (1 gal/min) (DOE, 1988). The springs are important sources of water for wildlife, but they are too small to be of use as a water supply source. Well pumping varies from year to year and ranges between 1.2 and 2.5 million m^3/yr (1,000 and 2,000 ac-ft/yr) (Russell, 1994).

The discharge to springs and wells on the NTS is quite small compared to the natural discharge of groundwater from the NTS through subsurface flow to Rock Valley and the Amargosa Desert. This discharge totals an estimated 51.8 million m^3/yr (42,000 ac-ft/yr) (Harrill et al, 1988). Of this quantity, an estimated 21 million m^3/yr (17,000 ac-ft/yer) discharges from Frenchman Flat under Mercury Valley into the Ash Meadows area of eastern Amargosa Desert, another 21 million m^3/yr discharges from Frenchman Flat under Rock Valley into the central Amargosa Desert, and 10 million m^3/yr (8,000 ac-ft/yr) discharge from Jackass Flats into the central part of Amargosa.

Groundwater Quality

The groundwater quality within the aquifers under the NTS is generally acceptable for drinking water and industrial and agricultural uses. According to EPA guidelines for groundwater classification, all of the hydrologic units that supply drinking water to the NTS are classified as Class II groundwater (Chapman, 1994). Class II refers to groundwater that is either currently being used as a source of drinking water or that could be a source of drinking water.

Recent updates in the interpretation of chemical analyses of groundwater collected at and near the NTS are discussed in Chapman and Lyles (1993). Table 13 presents a summary of water chemistry data for selected wells and compares the results to the EPA Drinking Water Standards. Water chemistry varied from a sodium-potassium-bicarbonate type to a calcium-magnesium-carbonate type, depending on the mineralogical composition of the aquifer source.

Wells producing from the mesas (predominantly the volcanic aquifer system) yielded water containing between 150 and 200 milligrams per liter (mg/L) of total dissolved solids. Ash Meadows groundwater produced higher values of total dissolved solids, ranging from 275 to 460 mg/L. Water from Wells C and C1 in the southern part of Yucca Flat (Figure 16) had about 650 mg/L of total dissolved solids which slightly exceeds the primary recommended limit of 500 mg/L, but falls within the secondary limit of 1,000

Table 13. Summary of 1993 water chemistry data for select wells on the NTS

Well Name	Calcium (mg/L)[a]	Magnesium (mg/L)	Potassium (mg/L)	Sodium (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Nitrate (mg/L)	Sulfate (mg/L)	Alkalinity (mg/L)	Hardness[b] (mg/L)	pH (unitless)	Sp. Cond.[c] (µS/cm)[d]	TDS[e] (mg/L)
Army Well 1	44	22	5	39	261	0	15	1.07	1.9	55	214	201	7.96	542	312
Well 5b	8	2	11	93	161	10	23	0.85	2.7	58	148	28	8.6	496	338
Well 5c	2	1	7	134	278	24	10	1.04	1.5	33	264	9	8.93	572	396
Well 4	24	8	5	48	149	7	12	0.8	6.8	42	134	93	8.26	401	288
Well 4a	22	6	6	55	159	5	9	0.81	NA	35	138	80	8.22	385	283
Well C	74	29	14	125	576	0	33	1.09	1.6	66	472	304	7.38	1,070	639
Well C1	73	28	13	121	578	0	34	1.14	0.6	66	474	298	7.47	1,070	639
Well 8	8	1	3	30	71	5	7	0.81	1.3	14	66	24	8.28	196	149
UE-16d	79	24	7	30	356	0	11	0.56	0.6	58	292	296	7.89	645	401
J-12	15	2	5	41	120	0	8	1.8	2	25	98	46	8.15	277	209
J-13	12	2	5	44	124	0	7	2.26	2.2	18	102	38	7.97	280	209
EPA[f] DWS	NS[g]	NS	NS	NS	NS	NS	250	2.0	10.0	250	NS	NS	6.5 to 8.5	NS	500

NOTE: The following elements are present in trace quantities below Safe Drinking Water Act limits: arsenic, boron, chromium, iron, manganese, selenium, silver, barium, cadmium, copper, lead, mercury, silica, and zinc.

NA=not applicable.

[a] Milligrams per liter = parts per million
[b] Hardness is expressed as calcium carbonate
[c] Specific conductivity
[d] Microsiemen per centimeter
[e] Total dissolved solids
[f] EPA Drinking Water Standards
[g] No standard exists.

Source: REECo, 1991.

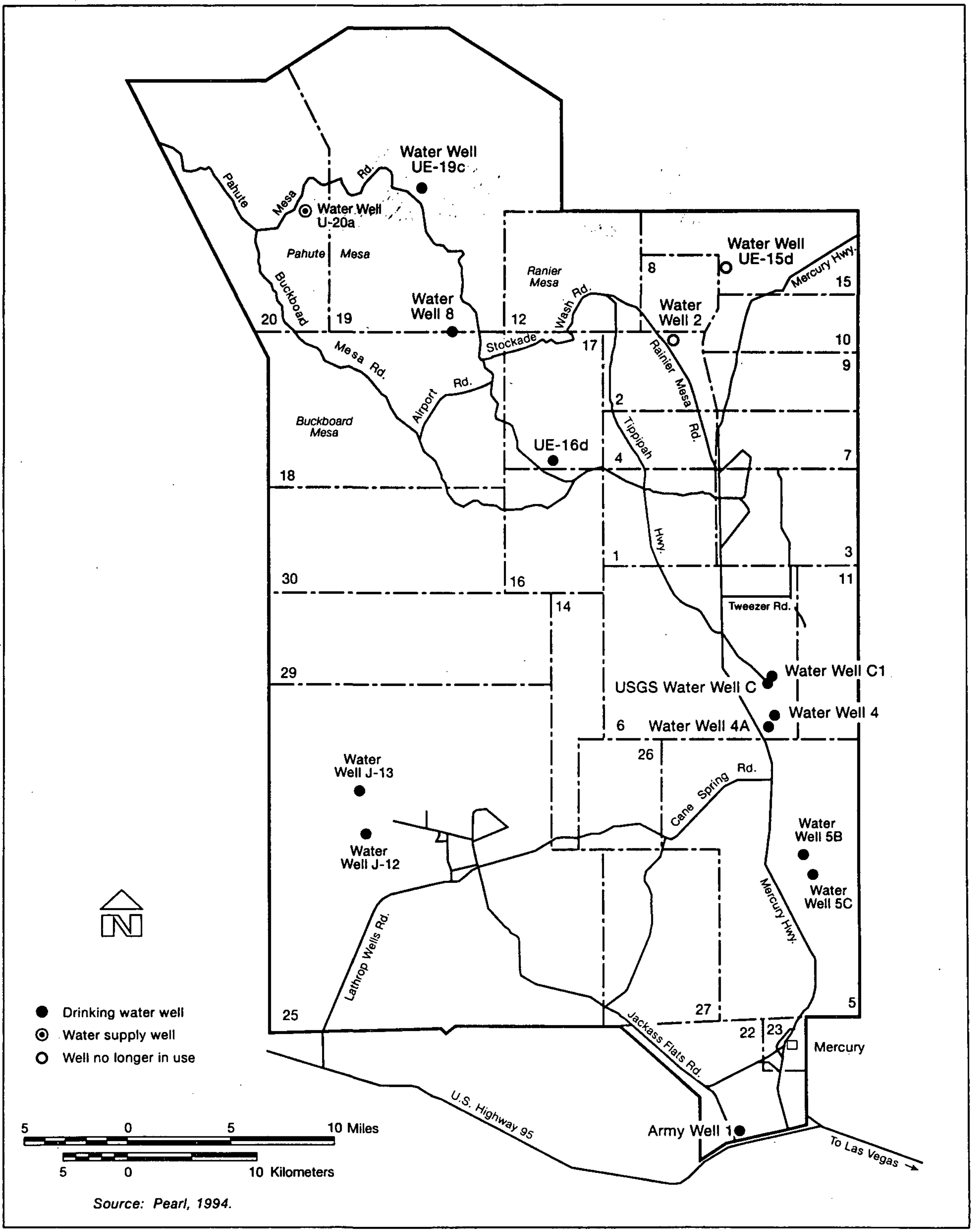


Figure 16 . Groundwater quality sampling locations on the NTS

mg/L of total dissolved solids (EPA, 1992). Additionally, Wells 5B and 5C had pH values of 8.6 and 8.9, respectively, which slightly exceed the primary EPA drinking water standard for pH of 8.5. One well on the NTS produces water with fluoride concentrations that equal or exceed guidelines for continuous use (ERDA, 1977). Periodic groundwater monitoring for volatile organic compounds is performed at the NTS. Results from groundwater monitoring indicate that, except for one occurrence in 1992, no volatile organic compounds are present. In 1992, one volatile organic compound, 1,1,1,-trichloroethane, was detected in a sample collected from Area 6 Well 4a at a concentration of 2.1 µg/L (2.1 parts per billion), which was well below the drinking water standard of 200 mg/L (200 parts per million) (DOE/NV, 1992b). At that time, Well 4a had been recently developed and had not yet been connected to a distribution system. Samples for analysis from Well 4a were taken in May 1992. These analyses did not indicate the presence of volatile organic compounds, (DOE, 1993). Trends from recent analysis indicate no further presence of volatile organic compounds is expected to be detected in potable water wells (DOE/NV, 1992b, 1993, 1994a, and 1995b).

Water Supply

There are physical, environmental, legal, and administrative limitations on the availability of the water resources from the NTS and surrounding regions for development of water supplies. The physical limitations are due to the water-yielding properties of the aquifers present. In general, well yields are poorest in volcanic rocks of Pahute Mesa and in the fine-grained playa sediments of Emigrant Valley and Cactus, Yucca, and Frenchman Flats.

Well yields are moderate to high in the fractured volcanic rocks of the southwest part of the NTS, in the fractured carbonate rocks that underlie the eastern part of the facility, and from the alluvium where adequate saturated thicknesses are present. The production capacities of the existing water supply wells range from about 640 to 2,650 L/min (170 to 700 gal/min) with a total capacity of about 11,350 L/min (3,000 gal/min) or about 6.0 million m^3/yr (4,840 ac-ft/yr).

Beyond the physical availability of the water, there are water chemistry limitations that render portions of the NTS unsuitable for groundwater development. As will be discussed a later section, more than 230 nuclear tests have been conducted below or in close proximity to the water table (Bryant and Fabryka-Martin, 1991). These tests have resulted in contamination of the near test environment with radionuclides (Borg et al, 1976), and localized contamination of groundwater has occurred as a result of some tests (Nimz and Thompson, 1992). Because of these underground tests, much of Yucca Flat, portions of Frenchman Flat, and portions of Pahute Mesa may require restrictions to additional groundwater development. The remaining inventory of radionuclides and other potential contaminants is discussed in detail in a later section of this Technical Resource Document.

There are sensitive environments downgradient of the NTS, including Death Valley, Devil's Hole, and the wetland environment at Ash Meadows. A number of state and federal laws prohibit the development of water supplies that will adversely impact these environments (Dudley and Larson, 1976). As part of DOE's groundwater investigations being conducted through the Environmental Restoration Program, regional numerical models of groundwater flow and tritium transport are being developed. These models include the NTS and Ash Meadows area as well as other areas of environmental concern. The models will be of use in evaluating the effects of past DOE water withdrawals and radionuclide releases. The models will also be of use in predicting the effects of future DOE water withdrawals and in evaluating various remedial strategies. The DOE is also working with the National Park Service in evaluating water level fluctuations that have been observed historically at Devil's Hole, the sole habitat for the endangered Devil's Hole Pupfish.

Water-resource use in support of the primary missions of the NTS is not subject to State water appropriation laws. The NTS, under the Federal Reserve Water Rights doctrine, is entitled to withdraw the quantity of water necessary to support the NTS missions. Water used for other activities may require the appropriation of the water in accordance with Nevada water law. Presently, the water resources of the Alkali Flat-Furnace Creek Ranch subbasin of the Death Valley flow system are fully appropriated, and it may not be legally possible to develop or use water in the western part of the NTS for purposes beyond the missions of the facility. Unappropriated groundwater is available in the Ash Meadows subbasin and is subject to the rights of the senior water rights holders.

Administrative limitations on the groundwater resources are primarily related to ongoing tests and activities. Extensive site characterization activities are in progress by both the Environmental Restoration Program and Yucca Mountain Projects, and experiments are being conducted by the Hydrologic Resources Management Program. Some consideration may need to be given to water withdrawals from wells in the vicinity of these on-going and planned experiments and tests.

A considerable quantity of groundwater is in storage in the sediments and rocks underlying the NTS and surrounding regions. An estimated 2.7 billion m^3 (2.2 million ac-ft) of groundwater are held in storage in the upper 30 m (100 ft) of the saturated zone in Yucca Flat, Frenchman Flat, Mercury and Rock Valleys, and Fortymile Canyon (Scott et al, 1971). With certain limitations, this groundwater is an available resource for development of water supplies at the NTS. Well water is produced from the upper carbonate, volcanic tuff, and valley-fill aquifers.

Historically, domestic, industrial, and construction water supplies were provided by 15 water wells dispersed across the NTS, as shown in Figure 16. In the past several years as nuclear testing activities declined and the demand for water decreased accordingly, the total number of water wells supporting NTS operations has decreased to 12; a list of active water wells on the NTS is given in Table 14. Drinking water on the NTS is currently provided by 11 wells and is supplemented by bottled water in remote areas. Construction and fire control water are supplied by other wells in addition to the potable water supply

Table 14 . Summary of 1993 water well and discharge information for the NTS

Well Name	Aquifer	Depth		Static Water Level (depth)		Pump Setting (depth)		Yield		[a]Annual Pumpage ($Mm^{3\,b}$)	Annual Pumpage ac-ft
		m	ft	m	ft	m	ft	m /min	yd^3/min		
Army Well 1	Carbonate	593.14	1,945	210.31	690	289.86	951	2.01	2.6	0.4178	338.7
Well 5c	Alluvial	361.80	1,187	211.23	693	238.96	784	1.23	1.6	0.2393	194
Well 5b	Alluvial	274.32	900	208.48	684			1.02	1.3	0.1126	91.31
Well 4	Volcanic	450.80	1,479	286.82	941	387.40	1,271	2.46	3.2	0.2856	231.51
Well 4a	Volcanic									0.4172	338.22
Well C	Carbonate	518.46	1,701	470.61	1,544	473.35	1,553	1.02	1.3	0.2390	193.78
Well C1	Carbonate	520.29	1,707	471.83	1,594	484.94	1,591	1.06	1.4	0.0357	28.95
Well 8	Volcanic	1,673.35	5,490	327.05	1,073	374.29	1,228	1.51	1.9	0.1185	96.11
UE-16D	Carbonate	914.40	3,000	230.12	755	330.10	1,083	0.73	.94	0.1813	146.95
J-12	Volcanic	347.17	1,139	225.25	739	250.55	822	3.09	4.0	0.0945	76.64
J-13	Volcanic	1,063.14	3,487	283.16	929	350.82	1,151	2.57	3.4	0.1584	128.38
UE-5c[c]	Alluvial									0.0278	22.52
UE-19c[d]	Volcanic									0.0269	21.79
U-20a[c]	Volcanic									0.1058	85.80
									Total Usage	**2.4606**	**1994.66**

[a] Well yields calculated from controlled pump tests are typically within one order of magnitude of driller's estimates
[b] Million cubic meters
[c] *Construction water well*
[d] No longer in use.

Monitoring Programs

The DOE sponsors several monitoring efforts by NTS contractors, the USGS, and the EPA on and around the Test Site. The objectives of the monitoring are: 1) to provide a network for the detection of radionuclide migration from underground nuclear tests; 2) to assure that the potable water supply systems on the NTS provide safe drinking water; 3) to demonstrate compliance with waste disposal permit requirements and environmental regulations; and 4) to provide data for aquifer characterization studies and research into the mechanisms of radionuclide migration.

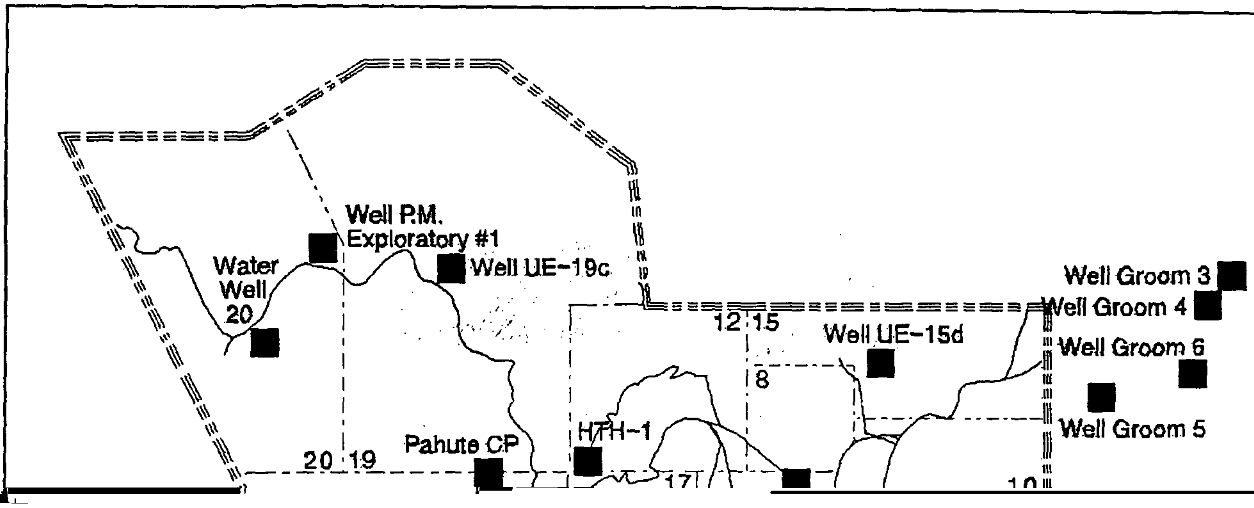
The DOE conducts extensive monitoring of on-site water wells and selected off-site wells in accordance with the Safe Drinking Water Act and the Nevada Administrative Code regulations (REECo, 1991). Concurrently, the DOE monitors on-site wells and select off-site wells for select radionuclides that are not regulated by the Safe Drinking Water Act (DOE/NV, 1993). Additionally, the State of Nevada performs independent monitoring. The analytical results for these monitoring programs are published in *Annual Site Environmental Reports* (DOE/NV, 1993). The following section provide an overview of the six existing NTS groundwater monitoring programs.

Environmental Surveillance Program - The DOE performs routine radiological and nonradiological monitoring in compliance with the Safe Drinking Water Act and DOE Order 5400.1. Under the provisions of the Drinking Water Act, the potable water supply systems at the NTS are monitored for residual chlorine content and coliform bacteria on a monthly basis. Less frequent monitoring is also done for volatile organic compounds, inorganic compounds, and other water quality parameters. In addition, off-site municipal and private water supply wells are monitored as a courtesy to assure that no radionuclides related to underground testing are present.

USGS Water-Level Monitoring Program - The USGS monitors the depth to water in 55 wells located on the NTS and another 43 wells located off the Test Site. This monitoring is done for compliance with DOE Order 5400.1 and includes monthly water level measurements at all wells and the collection of continuous water level data for seven wells and piezometers located on the NTS. The monitoring results are used to help determine the effects of water usage on water quantity, for groundwater flow modeling, and to predict the occurrence of water in new wells and emplacement holes.

EPA Long-Term Hydrologic Monitoring Program - The EPA's Environmental Monitoring Systems Laboratory performs radiological monitoring of nonwater supply wells on the NTS, in off-site areas, and in each of the off-site areas where underground nuclear testing was conducted in Nevada, Colorado, New Mexico, Mississippi, and Alaska through the Long-Term Hydrologic Monitoring Program (LTHMP). The LTHMP was initiated in 1972 to consolidate and expand monitoring that was previously done by the U.S. Public Health Service. Samples are collected monthly from some wells located on the NTS and semi-annually from others. The samples are analyzed for gamma emitters and tritium and any new sampling locations are analyzed for strontium, uranium, plutonium, and radon. The locations of the LTHMP monitoring wells on the NTS are shown on Figure 17, and Figure 18 shows the locations of the off-site LTHMP monitoring wells. Summary results from the lastes monitoring efforts are presented in *Environmental Data Report for the Nevada Test Site* (DOE/NV/11432-176).

Radioactive Waste Management Site Assessment Program - Groundwater monitoring is done at the Areas 3 and 5 disposal site in support of DOE's Resource Conservation Recovery Act Part B permit applications. Wells were installed at the Area 5 site in 1992 to provide information on water quality, flow gradients, and flow directions. Water level and water chemistry monitoring were initiated in 1992 and continues.


Well P.M.
Exploratory #1
Water
Well
20
Well UE-19c
12 15
Well UE-15d
8
Well Groom 3
Well Groom 4
Well Groom 6
Well Groom 5
20 19
Pahute CP
HTH-1
17

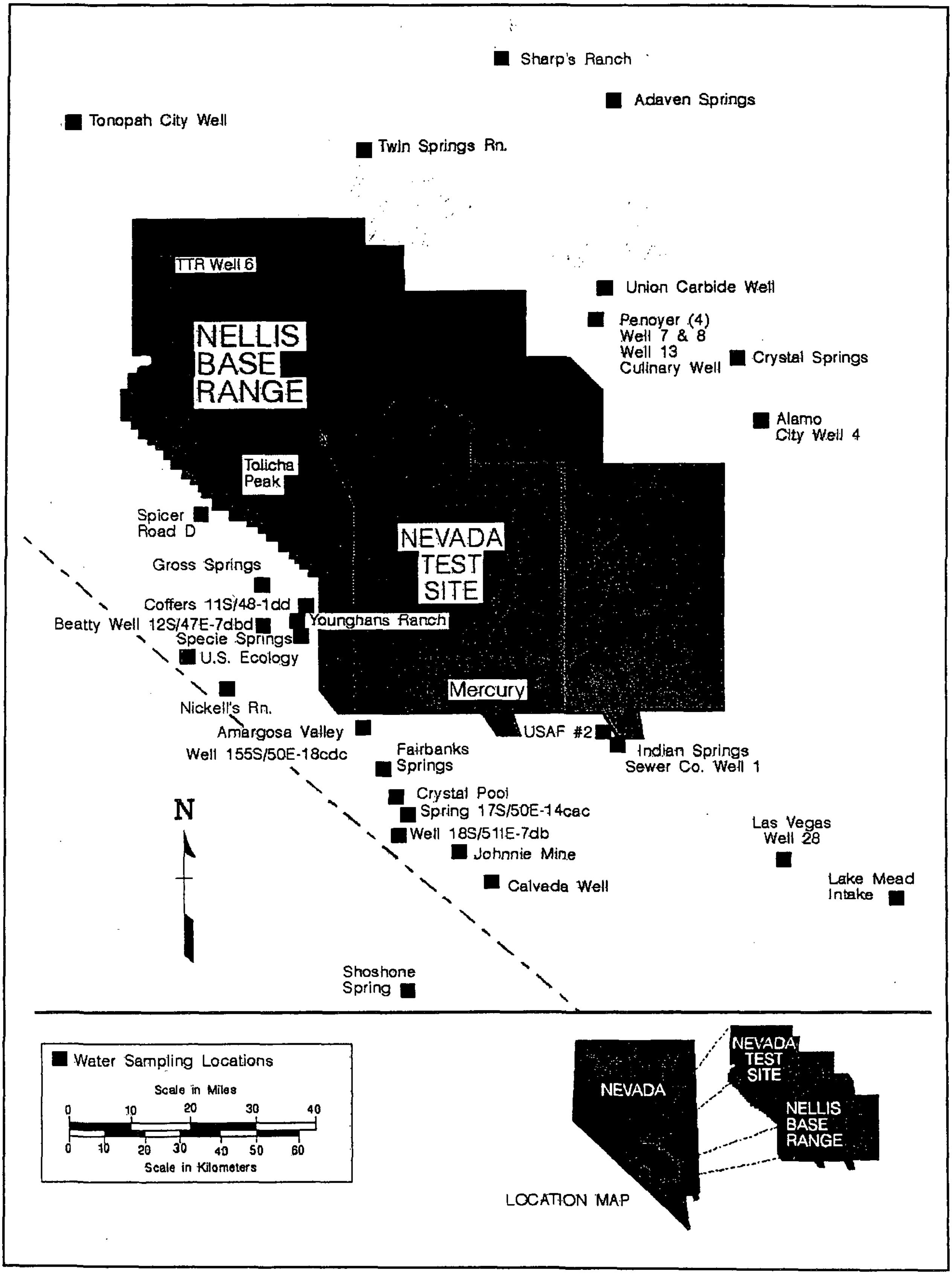


Figure 18 Wells Outside the NTS Included in the LTHMP

Underground Test Area Corrective Action Unit Monitoring Program - Monitoring of far-field and near-field wells for specific groundwater quality parameters is conducted as part of DOE's on-going studies of underground nuclear testing areas on the NTS. As part of their overall investigations, DOE has recompleted a number of wells at the NTS for monitoring and has drilled new monitoring wells at selected locations on the NTS. About 50 wells are presently in use to characterize groundwater conditions regionally or near specific underground nuclear tests. These wells are part of the Underground Test Area project and the Hydrologic Resources Management Program. Some wells are monitored on a regular basis, and many of these wells may be incorporated into the long-term monitoring network in the future.

of underground testing on the hydrogeology, hydrochemistry, and radiochemistry of the NTS. Under the Hydrologic Resources Management Program, the DOE has sponsored research by the Desert Research Institute, the USGS, and the national laboratories to help understand the groundwater flow directions and

3.2 Effects of Past Actions

The effects of past actions on the geology, soils, and water resources of the NTS have been well documented. The most significant effects have, of course, resulted from the nuclear testing that was conducted at the facility. Other impacts occurred as a result of activities at the site that were not related to testing. In this section, the documented effects that are known to have occurred are described and discussed. The recognition of the effects from past activities is a key to the prediction of future impacts from the proposed alternative actions.

3.2.1 Historical Activities

Based upon the more than 40 years of operations at the NTS and information that has been gathered during many the many detailed studies that the DOE has sponsored, many of the consequences of past weapons testing and other activities are well understood and documented. Many of the consequences described in this report were previously presented in the *Final Environmental Impact Statement, Nevada Test Site, Nye County, Nevada* (ERDA, 1977). While not all of the consequences of historic actions at the NTS and adjacent areas have been fully defined, this section presents an overview of their resulting constraints and establishes a baseline of current conditions. The baseline serves as a basis for evaluating the potential effects of future actions. Because of the complexity of some aspects of underground nuclear testing, a full understanding that removes all uncertainty may never be achieved. Nonetheless, the DOE continues, through many of the programs and actions described in this EIS, to address the remaining data deficiencies and uncertainties.

For the purposes of discussion, the past activities at the NTS have been grouped into eight categories. These categories encompass the actions that have impacted the physiography, geology, soils, and water resources of the NTS. In this section, a brief historical overview of these activities is provided, and the known consequences and resulting constraints on use of the physical environment are presented. The relationship between these categories of activities is shown schematically on Figure 19. As shown, certain activities resulted in only surficial consequences while other activities had long-term consequences on the deep geologic media. The information presented in Table 15 summarizes the key environmental characteristics of the activities including the environmental media of concern, the principal contaminants, the depth horizons at which the contamination occurs, and the best available estimate of the remaining inventory of radionuclides.

Atmospheric Weapons Testing—A total of 100 atmospheric detonations were conducted before the Limited Test Ban Treaty was signed in August 1963. Atmospheric tests include tests conducted at ground level, from towers or balloons, or by airdrops. Of the 100 atmospheric tests, 16 were safety tests. By design, these safety tests produced little or no nuclear yield. These tests resulted in contamination of surficial soils and structures. Because of the decay of the radionuclides since the cessation of atmospheric testing, the remaining radionuclide inventory is small, an estimated 20 curies.

Underground Nuclear Testing—A total of 828 underground nuclear tests have been conducted at the NTS. The types of tests conducted include deep underground tests used to study weapons effects, designs, safety, and reliability, and shallow borehole tests used to study the peaceful application of nuclear devices for cratering. The 70 underground safety tests conducted on the NTS, by design, produced little or no nuclear yield. Shallow borehole tests (tests conducted at depths of less than 61m, or 200 ft) resulted in the contamination of both surficial soils and the geologic media. The deep underground tests resulted in the contamination of the deep geologic media underlying large portions of the NTS.

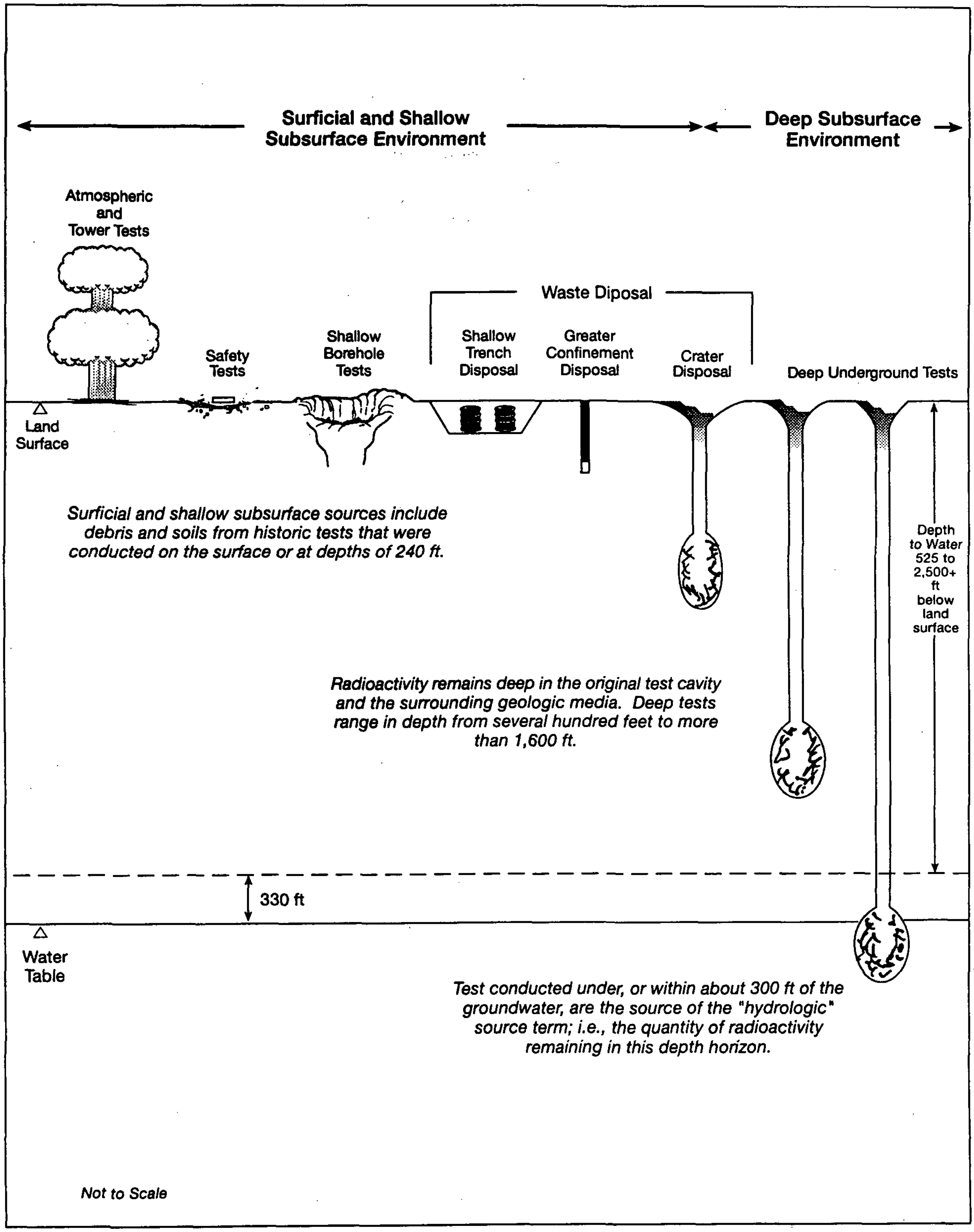


Figure 10. Types and depth horizons of radioactivity that remains on the NTS

Table 15. Summary of radioactivity on the NTS as of January 1996

Source of Radioactivity	Type of Area	Environmental Media	Major Known Isotopes or Wastes	Depth Range	Amount (curies)
Atmospheric & Tower Tests	Above Ground Nuclear Weapon Proving Area	Surficial Soils & Test Structures	Americium Cesium Cobalt Plutonium Europium Strontium	At Land Surface	Approximately 20
Safety Tests	Above Ground Experimental Areas	Surficial Soils	Americium Cesium Cobalt Plutonium Strontium	Less than 0.9 m (3 ft)	Approximately 35
Nuclear Rocket Development Area	Nuclear Rocket Motor, Reactor, & Furnace Testing Area	Surficial Soils	Cesium Strontium	Less than 3 m (10 ft)	Approximately 1
Shallow Borehole Tests	Underground Nuclear Testing Areas	Soils & Alluvium	Americium Cesium Cobalt Europium Plutonium Strontium	Less than 61 m (200 ft)	Approximately 2,000 at land surface; unknown at depth
Shallow Land Disposal	Waste Disposal Landfills	Soils & Alluvium	Dry Packaged Low-level & Mixed Wastes	Less than 9 m (30 ft)	Approximately 500,000[a]
Crater Disposal	Test induced subsidence crater with sidewalls, cover, & drainage	Soils & Alluvium	Bulk contaminated soils & equipment	Less than 30 m (100 ft)	Approximately 1,250[a] (About 205,000 m^3 [7,250,000 ft^3])[b]
Greater Confinement Disposal	Monitored Underground Waste Disposal Borehole	Soils & Alluvium	Tritium Americium	37 m (120 ft)	Approximately 9.3 million[a] (About 300 m^3 [10,000 ft^3])[b]
Deep Underground Tests	Underground Nuclear Testing Areas	Soils, Alluvium, & Consolidated Rock	Tritium, fission, & activation products	Typically less than 640 m (2,100 ft), but may be deeper	Greater than 300 million

[a] Inventory at time of disposal (not corrected for decay)
[b] Amount of waste that was considered for inventory.

The inventory of radionuclides that remains contained within the deep geologic media under the testing areas is estimated to be on the order of 300 million curies, which is, by far, the largest remaining inventory from any of the historic activities conducted on the Test Site. Shallow borehole tests contribute another 2,000 curies to the inventory associated with contamination of the surficial soils. The remaining inventory of radionuclide contamination, the physical disruption of the geologic media that resulted from the detonations, and the introduction of radionuclides into the groundwater regime are the most significant consequences of past actions at the NTS.

Safety Tests—Between late 1954 and June 1963, 16 tests were conducted aboveground to test the vulnerability of certain weapon designs to possible accidents. At a location in Area 5, 24 experiments, utilizing relatively small quantities of plutonium, were conducted between 1954 and 1956. These experiments, known as the GMX Project, were so-called "equation-of-state" studies where "instantaneous" changes in the physical properties of plutonium materials subjected to detonations from conventional explosives were measured. By design, these experiments produced little or no nuclear yield. Safety tests are no longer conducted aboveground; all such tests are performed underground in emplacements that are designed so that radioactive materials will not reach aboveground environments (AEC, 1972; AEC, 1973a; ERDA, 1976; ERDA, 1977). These tests resulted in contamination of surficial soils over a large area. The remaining inventory of radionuclides is small however, only about 35 curies.

Nuclear Rocket Development Station—Twenty-six experimental tests of reactors, nuclear engines, ramjets, and nuclear furnaces were conducted between 1959 and 1973. These tests were conducted in Jackass Flats (in Area 25). A very small (1 curie) inventory of radionuclides remains as a result of the testing station.

Shallow Land Radioactive Waste Disposal— Some wastes generated during the testing program, and as a result of nuclear projects, were disposed of in shallow cells, pits, and trenches. Because of the site's characteristics, notably the absence of a groundwater pathway, shallow burial continues to be an important testing on the terrain of the NTS and was one of the unavoidable adverse impacts identified in the *Final Environmental Impact Statement, Nevada Test Site, Nye County, Nevada* (ERDA, 1977) (see Plate 7, entitled Aerial View of the Many Craters Within Yucca Flat, of the *Framework for the Resource Management Plan* [Volume 2]).

In addition to the subsidence crater, pressure ridges and small displacement faults may occur at the surface. The surface fracturing and faulting are the result of the sudden uplift of the earth at the time of detonation and the collapse during the formation of the chimney and crater. Another permanent consequence of testing has been vertical displacement along existing faults, particularly along Yucca Fault and Carpetbagger Fault in Yucca Flat. Vertical displacement of as much as 2 m (8 ft) has occurred along portions of the Carpetbagger Fault. Cratering has occurred on Pahute Mesa but, because of the greater competency of the rocks in that area and the depths of most tests, cratering in this test area has been infrequent. Fracturing has occurred on the top of Rainier Mesa as a result of the loss of strength in the rocks in that area.

Shallow detonations conducted as part of Project Plowshare also impacted the natural topography of portions of the NTS. Sedan was the largest of these detonations. A 104 kt nuclear device was detonated at a depth of about 194 m (635 ft). The explosion displaced about 12 million tons of soil and created a crater 390 m (1,280 ft) in diameter and 100m (320) ft deep.

Lesser impacts have occurred as a result of the many site-support activities including road construction and maintenance, mining of sand and gravel, grading of building pads and disposal sites, and the construction of ponds, flood controls, and drainage improvements. These impacts are typical of any large facility. Mining activity before the creation of the NTS has also left its "footprint" on the natural topography of the Test Site through tailings piles, prospect pits, and mine roads.

3.2.1.2 Effects on Geologic Resources

As discussed in the *Final Environmental Impact Statement, Nevada Test Site, Nye County, Nevada* (ERDA, 1977), underground nuclear testing has resulted in unavoidable adverse impacts to the natural geologic resources that render the resources unusable for most purposes. Underground nuclear testing was begun in June 1957, and through 1992 there were approximately 800 underground tests conducted at the NTS. The yields of these tests range from zero to 1,000 kilotons (kt). Underground testing, for the purposes of discussion, can be divided into three broad categories: shallow borehole tests, deep vertical tests, and tunnel tests.

Shallow borehole tests were conducted between 1960 and 1968. These tests were generally conducted at depths of 61 m (200 ft) or less although some tests, such as the Sedan event described above, were emplaced at greater depths. Some of these tests were safety-related, others were conducted as part of Project Plowshare to determine whether nuclear detonations could be used as a method for excavation. The shallow tests resulted in two significant impacts: 1) the development of some large ejection craters, most notably the Sedan Crater in the northern end of the Yucca Flat testing area; and 2) the dispersion of radionuclides over the surficial soils in the vicinity of the craters.

McArthur (1991) estimated that the remaining inventory of surficial radioactivity at the Sedan Crater is 344 Ci. The total estimate for all releases from shallow borehole tests to the surficial soil horizon at the

Table 16 Estimated Inventory of Radioactivity in NTS Surface Soils as of 1 JAN 1990. Modified from McArthur (1991). All values are in curies.

Total Radionuclide Inventory

NTS Area	Am 241	Pu 238	Pu 239,240	Co 60	Cs 137	Sr 90	Eu 152	Eu 154	Eu 155	Total
1	4.2	6.5	24	1.1	8.8	15	15	0.1	0.5	**75.2**
2	2.9	8.6	22	1.2	24	46	14	0	0.4	**119.1**
3	4.6	3.1	37	1	12	33	18	0.1	0.5	**109.3**
4	6.6	13	40	1.6	12	13	9.1	0	0.2	**95.5**
5	0.6	0.1	4.8	0.6	0.4	0.9	10	0.2	0	**17.6**
6	1.7	3.3	8.4	0.2	2.8	3.5	0	0	0	**19.9**

of remaining inventory from safety tests in Plutonium Valley, atmospheric tests on Frenchman Lake, and the Nuclear Rocket Development Station in the southwestern part of the Test Site in Jackass Flats. The McArthur estimates were part of the DOE's Radionuclide Inventory and Distribution Program (RIDP) which was initiated in 1981. The RIDP was established to estimate the distribution and the total inventory of important man made radionuclides of NTS origin in the surficial soils of the NTS. Important radionuclides are considered as those with half lives of several years or more and are listed in Table 17. The RIDP took five years of field work and another three years of analysis to complete. The field work included aerial surveys, soil sampling for laboratory analysis, and in situ spectrometry.

Table 17. Important Man Made Radionuclides in the Surficial Soils of the NTS. Modified from McArthur (1991)

Radionuclide	Half-life (years)	Decay Products & Probable Chemical State in the Subsurface
Cobalt-60	5.26	Niobium-60, stable metal salt
Strontium-90	28.1	Yttrium-90 to Zirconium-90, metal oxide or silicate salt
Rhodium-101	3.1	Ruthenium-101, stable
Rhodium-102	2.9	Ruthenium-102, stable
Antimony-125	2.7	Tellurium-125, stable
Barium-133	10.7	Cesium-133, stable, univalent cation
Cesium-134	2.05	Barium-134 (stable), Ba^{2+} salt
Cesium-137	30.2	Barium-137 (stable), Ba^{2+} salt
Europium-152	13	72% Samarium-152 (stable), Sm^{3+} w/rare earth element behavior, 28% Gadolinium-152 to Sm-148, Gadolinium salt w/rare earth element behavior
Europium-154	16	Gadolinium-154, $Gadolinium^{3+}$ salt
Europium-155	1.81	Gadolinium-155, $Gadolinium^{3+}$ salt
Lutetium-174	3.6	Ytterbium-174, stable, $Ytterbium^{3+}$ salt
Plutonium-238	86	Uranium-234, uranium series ending in Lead-206
Plutonium-239	24,400	Uranium-235, uranium series ending in Lead-207
Plutonium-240	6,580	Uranium-234, uranium series ending in Lead-206
Americium-241	458	Neptunium-239, to Uranium-233 series ending in Bismuth-209

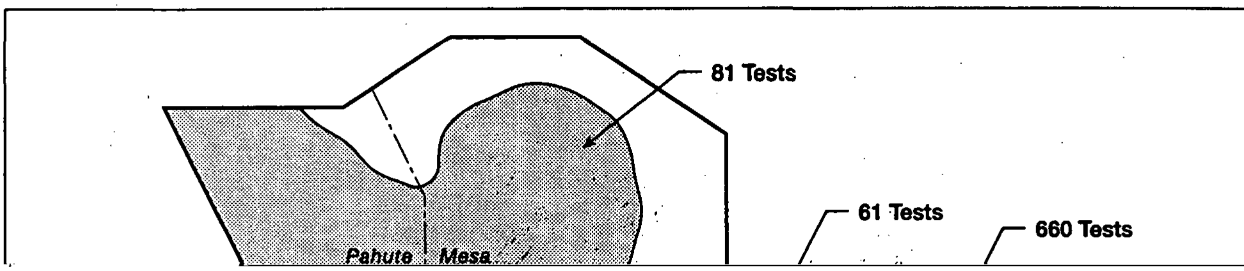
Because of the methodologies employed and the terrain constraints on the NTS, there is uncertainty in the estimates of remaining radionuclides in the shallow subsurface at the NTS. As noted by McArthur (1991), "the process by which the inventory estimates are produced are complex, and uncertainty enters it at a number of points." Sources of uncertainty include counting errors in the measurement of activity levels in the soils, variations in air and soil density and soil moisture content, the use of average inverse relaxation lengths and radioisotope ratios, and sampling errors. Other uncertainty is introduced for areas of rugged terrain that could not be physically surveyed during the RIDP field work. Estimates for these areas were made using average radionuclide concentrations that were defined on the basis of measurements taken in nearby areas that were accessible. In spite of these uncertainties, the estimated values from the RIDP surveys compare well with other survey result. The RIDP estimates provide the best available information on the remaining radioactivity from the shallow borehole tests that were conducted at the NTS.

Deep underground nuclear tests have been completed in Frenchman Flat, Yucca Flat, Pahute Mesa, Rainier Mesa, Shoshone Mountain, Buckboard Mesa, and Dome Mountain. Yucca Flat was the site of 660 underground tests, 80% of all the underground tests conducted at the NTS while the Pahute Mesa and Rainier Mesa testing areas were the sites for another 17% (142 underground tests). The tunnel complex at Rainier Mesa has been extensively used for special experiments and tests that require access to materials and monitoring equipment left near the point of detonation. Figure 20 shows the locations of the underground testing areas on the NTS. The historic tests have left their mark on the NTS both in terms of the physical disruption of the geologic media and a large subsurface inventory of remaining radioactive isotopes.

The major effects of an underground nuclear test on the physical environment are ground motion, the disruption of the geologic media, surface subsidence for tests conducted in Yucca Flat, and the contamination of the subsurface geologic media and surficial soils. Ground motion is a temporary phenomenon that, with the exception of rockfalls and minor land displacements, has not resulted in permanent effects on the NTS. The cratering, the disruption of underground geologic media, and the release of radioactivity into the environment have been the most significant impacts to the physical environment as a result of historic testing operations at the NTS. The effects on the topography of the NTS were discussed in the preceding section on physiography. The other physical impacts of vertical underground tests can perhaps be best described through a discussion of the events that occur after a nuclear detonation.

Figure 21 shows the sequence of events after an underground detonation. Within tens of milliseconds following detonation, the nuclear device and surrounding rock are vaporized, creating a "bubble" of high pressure steam and gas. Some rock may be melted or disaggregated as well. An underground cavity that is more or less spherical is formed by the pressure of this gas bubble and the explosive momentum that is imparted to the host rock. As the cavity continues to expand, the pressure decreases and, usually within a few tenths of a second after detonation, equalizes with the pressure from the overlying rock. At this point, the cavity has reached its greatest dimensions. Concurrent with this pressure decrease, the shock wave from the detonation travels outward, crushing and fracturing the rock in the near-test environment and causing slip along the pre-existing fractures.

As the hot gases cool, the molten rock begins to collect and solidify on the cavity sidewalls and in a puddle at the bottom of the cavity. Some melt may also be injected into the zone of pervasive fracturing that is separated from the cavity by a zone of intensely crushed rock. When the gas pressure declines to


81 Tests
61 Tests
660 Tests
Pahute Mesa

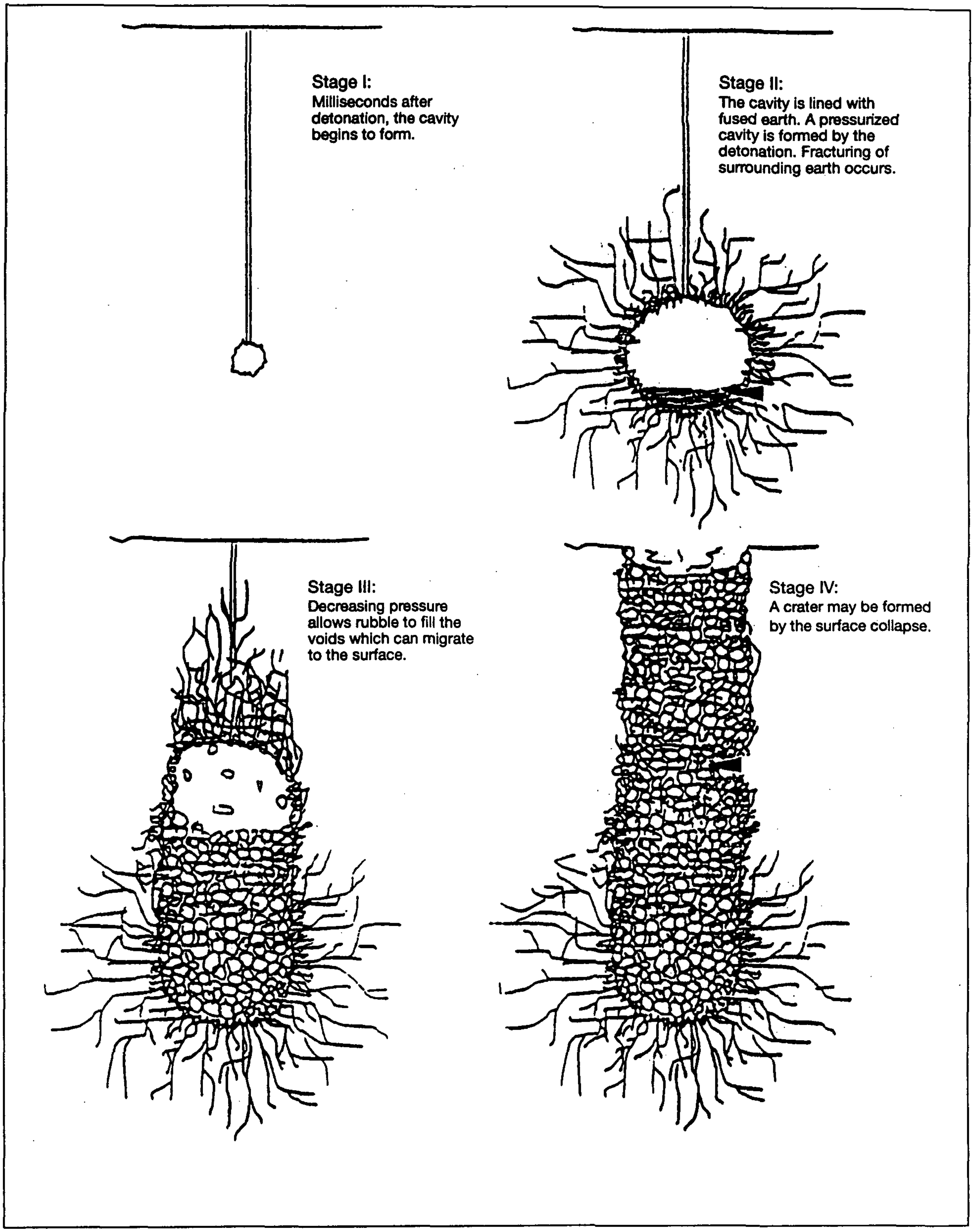


Figure 21. Formation of an underground nuclear explosive test cavity, rubble chimney, and surface subsidence crater

the point where it can no longer support the overlying rock and soil, the cavity may collapse, forming a chimney upward from the cavity. The collapse occurs as the overlying rock breaks into rubble and falls into the cavity void. This process continues until either the cavity completely fills with rubble, the chimney reaches a level where the strength of the rock can support the overburden, or, as usually happens, the chimney reaches land surface. When the chimney reaches the surface, the ground sinks, forming a saucer-like subsidence crater. The crater usually forms within a few hours after the detonation but may, in some cases, take several hundred days depending upon the remaining strength of the geologic media and the depth of the cavity.

Although nuclear tests may have long-term physical consequences on the physical environment, effects of the tests are not synergistic, i.e., the sum of the effects of multiple tests does not produce unexpected consequences. For example, the use of Pahute Mesa for future underground testing will not lead to the collapse of the mesa area. Site selection factors that are essential to ensuring both containment and the integrity of test data have also ensured that widespread subsidence and other failures within the test areas have not and would not occur.

The fracturing of the rock in the near-test environment may have resulted in some alteration of the natural permeability of the rocks underlying portions of the NTS. The shock wave and compressive forces from the tests can, on one hand, increase the permeability by creating more fractures near the test while, on the other hand, decrease the permeability by opening and closing fractures at greater distances from the test. According to the Office of Technology Assessment (OTA, 1989), post-test measurements of rock samples taken from tunnel complexes generally show that the properties of the host rock are unchanged at a distance greater than 3 cavity radii from the point of detonation. At this distance and beyond, no fracturing occurs from the detonation, but the preexisting fractures are opened as the shock wave propagates through the host rock and are closed after the shock wave is past. In some instances, the closing of the fractures may have reduced the fracture aperture and may have resulted in some permanent reduction in the gross permeability of the rock mass. Also, the effects of the shock wave and chimney collpase may cause a reduction of permeability in sandy alluvial deposits through a process of settling and packing of sand grains.

Another consequence of past underground testing has been the formation of pockets of radioactive contamination surrounding each underground test. The total amount of radioactivity released into the underground environment during a test is called the radionuclide source term. The source term includes numerous isotopes that are both short- and long-lived. For example, for a test of a 1-kt nuclear weapon, an initial release of 41 billion curies decays to about 10 million curies in just 12 hours. According to information presented in Borg et al (1976), the quantity of radioactivity remaining from a 1-kt underground detonation 180 days after detonation is about 45,000 Ci (including 18,570 Ci of tritium), or about 1 millionth the original activity. It should be noted that there is considerable uncertainty concerning these estimates. For example, Borg et al (1976) indicate that the actual tritium activity after 180 days (expressed in the EIS on a per-kiloton-basis) could range from 5,570 to 55,770 Ci.

The radionuclide inventories are an order of magnitude estimate to illustrate the dominance of short-lived radionuclides soon after a nuclear detonation and the effect of radioactive decay in reducing that inventory. More precise estimates of the radionuclide inventory for geologic media are discussed in the following text. Estimates of the remaining inventory that may be available for transport via groundwater are presented in the section on water resources.

Declassification of the summed inventory (by radionuclide) that remains in or near the water table has allowed an updated, unclassified estimate of the total radionuclide inventory remaining in the subsurface as a result of underground testing at the NTS. This estimate was based upon two key references: Borg et al (1976) and a Los Alamos National Laboratory memorandum from T. Benjamin to M. Pankrantz (Benjamin, 1995). This memorandum, which in turn was based upon Goishi et al (1995), listed the remaining radionuclide inventory under, or within 100 m (328 ft) of the water table (as of January 1994) for Los Alamos National Laboratory-only fission products as well as Los Alamos National Laboratory and Lawrence Livermore National Laboratory unfissioned fissile materials, neutron-activated radionuclides, and tritium.

Because the fission products table provided by Los Alamos National Laboratory addressed just the Los Alamos National Laboratory events, it was necessary to first project the radionuclide inventory for all tests. This adjustment was based upon the percentage of Los Alamos National Laboratory tests relative to all tests. Table 18 lists the projected total fission products that were calculated on the basis of this adjustment. No adjustment was necessary for the unfissioned fissile materials, activation products, and tritium as the table provided by Los Alamos National Laboratory included all events.

This estimate represents the radionuclide inventory exclusively for the tests that were detonated in or near (within 100 m [328 ft]) of the water table, with a total of about 112 million curies, but does not include the inventory between 61 m (200 ft) below the land surface and 100 m (328 ft) of the water table. Therefore, a further adjustment was needed to estimate the remaining inventory from tests conducted above this depth horizon. To estimate this value, the number of announced tests and the distribution of tests in proximity to the water table (as published by Bryant and Fabryka-Martin [1991]) was used. Their work indicates that 38 percent of the tests were conducted under or within 75 m (246 ft) of the water table; thus, the total hydrologic source term for the NTS, as defined previously, represents 38 percent of the total inventory. It is noted that the number of announced tests published by these authors has since been updated, but it was assumed that the relative proportion of shallow and deep events does not vary much from the information presented in their report. Based upon these relative percentages, the total inventory from all tests was estimated to be 295 million curies. This value was rounded to the 300 million curies that is listed in Table 15. Table 19 lists the individual fission and other products and the values used in the summary calculations.

There is some uncertainty regarding this estimate, including: the uncertainties in the estimation techniques used by Goishi et al (1995), in the actual proportions of Los Alamos National Laboratory tests and water table tests, and in the assumption that the inventories per test are similar for tests in or near the water table as compared to those above the water table. Nonetheless, the estimate serves as a useful reference until declassification efforts allow the release of a more refined estimate. Insofar as the intent of this estimate is to provide a basis for comparison with the remaining inventories which can be measured (e.g., surficial soils, waste disposal units, greater confinement disposal), the estimate is considered appropriate.

3.2.1.3 Effects on Soils

The soils on portions of the NTS have been contaminated as a direct result of various testing and ancillary operations. The largest areas of surficial contamination are in the Yucca Flat weapons test basin, Frenchman Flat, Plutonium Valley, and in scattered locations in the western and northwestern parts of the

Table 18. Projection of Total Remaining Inventory of Fission Products on the NTS.

	LANL TESTS		ALL TESTS (PROJECTED)	
FISSION PRODUCT	NOT ON PAHUTE MESA	ON PAHUTE MESA	NOT ON PAHUTE MESA	ON PAHUTE MESA
KRYPTON-85	3.58E+04	3.04E+04	6.88E+04	1.49E+05
STRONTIUM-90	4.65E+05	3.75E+05	8.93E+05	1.84E+06
ZIRCONIUM-93	1.62E+01	1.26E+01	3.11E+01	6.17E+01
NIOBIUM-94	4.30E-03	2.94E-03	8.26E-03	1.44E-02
TECHNETIUM-99	1.16E+02	8.82E+01	2.23E+02	4.32E+02
PALLADIUM-107	5.28E-01	3.41E-01	1.01E+00	1.67E+00
CADMIUM-113	3.21E+02	2.81E+02	6.17E+02	1.38E+03
TIN-121	1.26E+03	1.05E+03	2.42E+03	5.14E+03
TIN-126	1.50E+01	1.23E+01	2.88E+01	6.02E+01
IODINE-129	3.39E-01	2.64E-01	6.51E-01	1.29E+00
CESIUM-135	1.21E+01	9.14E+00	2.32E+01	4.47E+01
CESIUM-137	5.67E+05	4.39E+05	1.09E+06	2.15E+06
SAMARIUM-151	1.92E+04	1.41E+04	3.69E+04	6.90E+04
EUROPIUM-152	4.18E-02	3.88E-02	8.03E-02	1.90E-01
HOLMIUM-166	6.35E-03	3.83E-03	1.22E-02	1.88E-02
TOTAL FISSION PRODUCTS	**1.09E+06**	**8.60E+05**	**2.09E+06**	**4.21E+06**

Table 19. Summary Calculations of Radionuclide Inventory Remaining in Deep Geologic Media Under the NTS.

	FISSION PRODUCTS	
FISSION PRODUCT	NOT ON PAHUTE MESA	ON PAHUTE MESA
KRYPTON-85	6.88E+04	1.49E+05
STRONTIUM-90	8.93E+05	1.84E+06
ZIRCONIUM-93	3.11E+01	6.17E+01
NIOBIUM-94	8.26E-03	1.44E-02
TECHNITIUM-99	2.23E+02	4.32E+02
PALLADIUM-107	1.01E+00	1.67E+00
CADMIUM-113	6.17E+02	1.38E+03
TIN-121	2.42E+03	5.14E+03
TIN-126	2.88E+01	6.02E+01
IODINE-129	6.51E-01	1.29E+00
CESIUM-135	2.32E+01	4.47E+01
CESIUM-1`37	1.09E+06	2.15E+06
SAMARIUM-151	3.69E+04	6.90E+04
EUROPIUM-152	8.03E-02	1.90E-01
HOLMIUM-166	1.22E-02	1.88E-02
TOTAL FISSION PRODUCTS	**2.09E+06**	**4.21E+06**

Percentage of LANL to Total Tests

	Not On Pahute Mesa	On Pahute Mesa
Total Yield	18130	9292
LANL Yield Only	3703	4836
Percent LANL	0.20	0.52

Adjustment to Include Tests >100 m Above Water Table

Total Source Term Under/Near Water Table (1)	1.12E+08
Announced Tests (2)	616
Test Under/Near Water Table (2)	235
Percentage Source Under/Near Water Table	38
Percentage of Tests at Lower Depths	62
Total Source Term (1.12E+08/0.38)	2.95E+08

UNFISSIONED FISSILE MATERIALS, ACTIVATION PRODUCTS, AND TRITIUM		
ISOTOPE	NOT ON PAHUTE MESA	ON PAHUTE MESA
HYDROGEN-3	3.07E+07	6.99E+07
CARBON-14	8.60E+02	5.55E+02
ALUMINUM-26	4.17E-02	8.94E-03
CHLORINE-36	2.27E+02	2.14E+02
ARGON-39	9.61E+02	1.85E+03
KRYPTON-40	2.47E+02	4.69E+02
CALCIUM-41	1.70E+03	1.64E+03
NICKEL-59	4.23E+01	3.99E+01
NICKEL-63	5.14E+03	4.21E+03
KRYPTON-85G	5.40E+04	9.54E+04
STRONTIUM-90	7.26E+05	1.19E+06
ZIRCONIUM-93	2.63E+01	4.17E+01
NIOBIUM-93M	6.35E+03	7.59E+03
NIOBIUM-94G	1.95E+02	1.73E+02
TECHNETIUM-99	1.90E+02	3.07E+02
PALLADIUM-107G	9.70E-01	1.57E+00
CADMIUM-113M	4.83E+02	1.16E+03
TIN-121M	1.95E+03	4.31E+03
TIN-126	2.35E+01	4.92E+01
IODINE-129	5.50E-01	9.45E-01
CESIUM-135G	2.00E+01	3.17E+01
CESIUM-137	9.15E+05	1.51E+06
SAMARIUM-151	3.23E+04	5.71E+04
EUROPIUM-150	8.86E+01	1.11E+03
EUROPIUM-152	6.40E+04	3.29E+04
EUROPIUM-154	4.84E+04	1.55E+04
HOLMIUM-166M	5.06E+01	4.48E+01
THORIUM-232 DEVICE	4.01E-04	5.84E-02
THORIUM-232 SOIL	1.77E+01	3.38E+01
URANIUM-232	3.65E+02	2.55E+02
URANIUM-233	1.50E+02	1.71E+02
URANIUM-234 DEVICE	1.41E+02	1.23E+02
URANIUM-234 SOIL	8.85E+00	1.67E+01
URANIUM-235 DEVICE	3.79E+00	1.66E+00
URANIUM-235 SOIL	4.15E-01	7.94E-01
URANIUM-236	3.42E+00	4.73E+00
URANIUM-238 DEVICE	7.00E+00	2.19E+00
URANIUM-238 SOIL	8.83E+00	1.67E+01
NEPTUNIUM-237	1.10E+01	3.65E+01
PLUTONIUM-238	1.18E+04	7.16E+03
PLUTONIUM-239	2.88E+04	1.93E+04
PLUTONIUM-240	7.42E+03	6.20E+03
PLUTONIUM-241	1.03E+05	9.00E+04
PLUTONIUM-242	4.52E+00	3.36E+00
AMERICIUM-241	6.83E+03	4.67E+03
AMERICIUM-243	3.42E+00	1.79E-01
CURIUM-244	2.35E+03	2.97E+03
TOTAL ACTIVITY	**3.27E+07**	**7.30E+07**
FISSION PRODUCTS	**2.09E+06**	**4.21E+06**
TOTAL SOURCE	**3.48E+07**	**7.72E+07**
NTS TOTAL	**1.12E+08**	

(1) LANL Estimate JUN, 1993, Benjamin to Pankratz
(2) Bryant & Fabryka-Martin, 1991

The historical impacts on soils as a result of past Defense Program actions have been considerable and, in some instances, these impacts are considered significant. Lesser impacts include excavation of soils for roads and structures, alteration in natural drainages and erosion regimes, and the contamination of soils. This section describes the baseline condition of contaminated soils on the NTS as documented previously in the *Final Environmental Impact Statement, Nevada Test Site, Nye County, Nevada* (ERDA, 1977) and the more recent RIDP studies that have been completed since that time. As with the deep underground testing, an understanding of the events that occur during a nuclear explosion or safety test are important in defining the baseline soil conditions.

Atmospheric Testing

Aboveground nuclear weapons tests were initiated at the NTS on January 27, 1951, with the detonation of a 1-kt air-dropped weapon over Frenchman Flat. A total of 100 tests were conducted at Frenchman Flat and Yucca Flat prior to the signing of the Limited Test Ban Treaty in August 1963. Atmospheric testing included weapons that were dropped by planes, those detonated from towers constructed to heights of 30 to 213 m (100 to 700 ft), tests conducted on, or slightly above land surface, and tests where the weapon was lofted using helium-filled balloons 137 to 457 m (450 to 1,500 ft) above the ground.

Depending on the proximity of the explosion to the ground surface and the size of the yield, surface disturbances from atmospheric testing at the NTS varied widely. The greatest surficial disturbances typically occurred when an air-dropped weapon penetrated the ground surface to a shallow depth (about 15 m [50 ft]) before detonation. According to information presented by Glasstone (1962), such a test with a yield of 100 kt would result in a crater about 36 m (120 ft) deep and about 219 m (720 ft) in diameter.

Radioactivity from atmospheric tests was dispersed by three primary mechanisms: throwout, base surge, and fallout. Throwout occurs at the time of detonation when the fireball propels large volumes of rock and soil upward. Base surge refers to the settling and outward movement of the throwout. Fallout is the portion of material that does not settle, but rises and merges with the radioactive weapons residues. These materials subsequently descend to earth over the next few hours or longer as fallout. The extent and distribution of contamination from an atmospheric test was quite variable depending on the height of detonation, the yield and type of device, the nature of the ground surface, the mass of inert material surrounding the device, and weather conditions at the time of, and following, the test (DOE, 1988). Glasstone (1962) documented the chronology of a shallow penetration air-dropped test. Typical isotopes formed during the historic atmospheric testing included strontium, cesium, barium, tritium, and iodine. Of these, strontium-90 and cesium-137 are of the most concern because of their longer half-lives of 28 and 29 years, respectively.

The vast majority of radioactivity released during atmospheric testing decayed very quickly after each test was conducted. For example, for a 1-kt atmospheric test, the initial release after 1 minute is about 4.1×10^{10} Ci. This activity is reduced to 1.0×10^{7} Ci just 12 hours after the detonation. If the activity remaining after 12 hours is used as the basis for estimates, then about 6.0×10^{10} Ci were released during atmospheric testing between 1951 and 1963 at the NTS (OTA, 1989).

Many of the fission products released during the detonations were dispersed into the atmosphere, and much of the residual radioactivity has decayed in the more than 30 years since the last atmospheric test. Nonetheless, some of the longer-lived radionuclides remain in the soil and physical structures. The primary radioactive isotopes that remain on the NTS from historic atmospheric testing include americium, plutonium, cobalt, cesium, strontium, and europium. According to the Desert Research Institute (1988), the remaining radioactivity in NTS soils within 1,829 to 3,048 m (6,000 to 10,000 ft) of the Able test (a 1-kt airdrop) totaled almost 15 Ci. Based on the most recent estimates for Frenchman Lake (McArthur, 1991), about 20 Ci of radioactivity remain in this area. Most, if not all, of this remaining activity can be attributed to historic atmospheric testing. Residual contamination from atmospheric testing may also be present in Yucca Flat in Areas 1, 2, 3, 4, 7, 8, 9, and 10 of the NTS and in Buckboard Mesa in Area 18. However, because of the number of underground tests that were conducted in these areas, it is not possible to discriminate what residuals are remaining from atmospheric tests. Contamination remaining from the atmospheric tests in these areas is included within the inventory for shallow borehole tests, discussed previously.

Safety Tests

Portions of the NTS were used between 1954 and 1963 for a series of safety tests, chemical explosion tests of plutonium-bearing materials. The safety tests, or subcritical events, were conducted to evaluate the safety of nuclear weapons in accident scenarios. Two series, the GMX Project and Project 56, were conducted on the NTS in Areas 5 and 11, respectively. The GMX Project Site was used for 24 specific equation of state studies or experiments using fissile materials. Project 56 was comprised of four discreet surface safety tests. Between 998 and 1, 588 g (2.2 and 3.5 lbs) of plutonium were spread during the test. The recent work has shown that contamination of 200 pCi/g or higher, affects approximately 2.5 acres. Figure 22 shows the locations of the safety tests that were conducted on the NTS. Figure 23 shows the approximate areas of plutonium contamination exceeding 10 pCi/g.

The safety tests used mixtures of plutonium and uranium that were subjected to detonations of conventional explosives. Concurrent with and after these detonations, extensive studies were conducted to understand the dispersal and transport of these isotopes in the environment, including uptake by plants and animals. These studies were documented in a benchmark series of papers by the Nevada Applied Ecology Group, a panel of scientists chartered by the DOE to investigate the effects of testing at the NTS.

The immediate effects of the tests included the dispersal of plutonium and uranium over significant areas. To determine the area impacted by these tests, inventories were conducted by the Nevada Applied Ecology Group. These inventories were later augmented by extensive field-sampling efforts conducted under the RIDP. These studies resulted in the delineation of affected areas and the contamination remaining in each area. Figures 24 and 25 show the limits of the affected areas and the distribution of radioactivity within those areas.

The areas that were contaminated and the remaining inventory of radionuclides are summarized by McArthur and Mead (1989) and McArthur (1991) for areas on the NTS and in the *Final Environmental Impact Statement, Nevada Test Site, Nye County, Nevada* (ERDA, 1977) for the off-site locations. The GMX Project ion Area 5 resulted in the contamination of about 240 acres, with estimates of the total remaining inventory ranging from 1.7 to 2.5 Ci.

The Project 56 tests resulted in the contamination of about 2,200 acres, with estimates of the remaining inventory ranging from 34 to 39 Ci. On the NAFR Complex, the two disturbed areas total slightly under 1,000 acres, with an estimated remaining inventory of about 50 Ci. On the Tonopah Test Range, almost 670 acres were contaminated, with an estimated remaining inventory of about 65 Ci. The ranges in values given are all approximations and reflect the limitations in field sampling of large areas, detection equipment, and laboratory analyses.

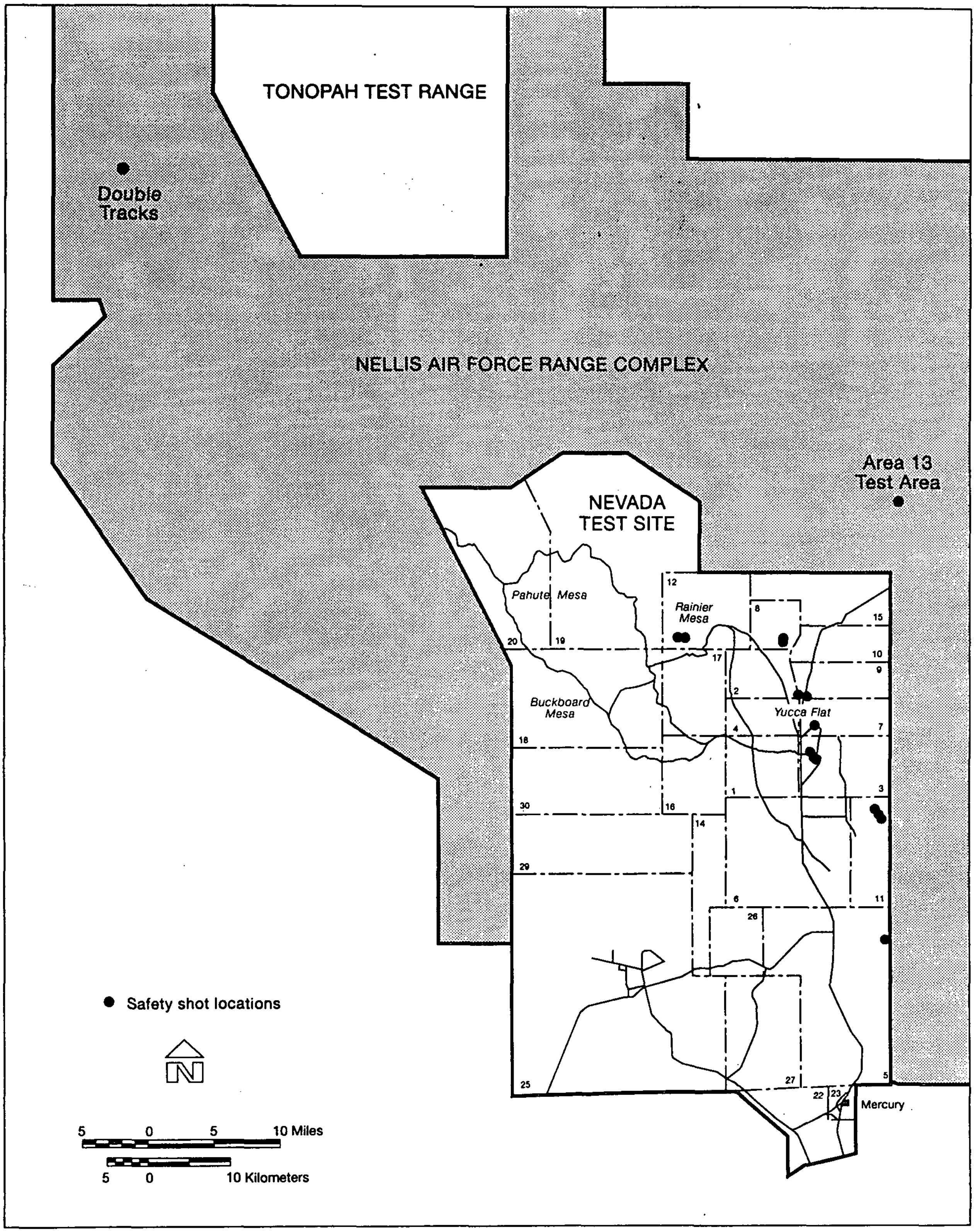


Figure 22 . Locations of safety tests on the NTS and NAFR Complex

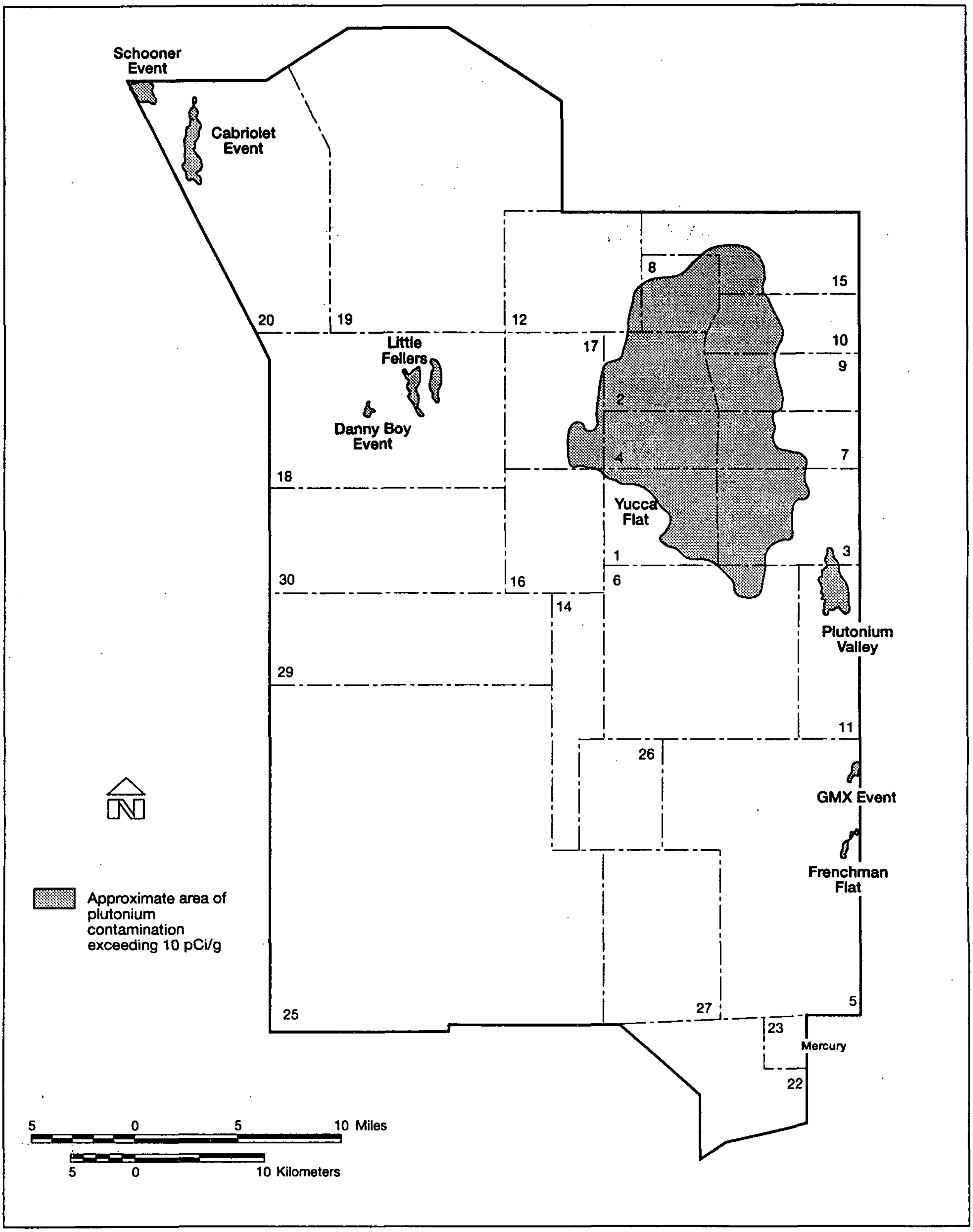
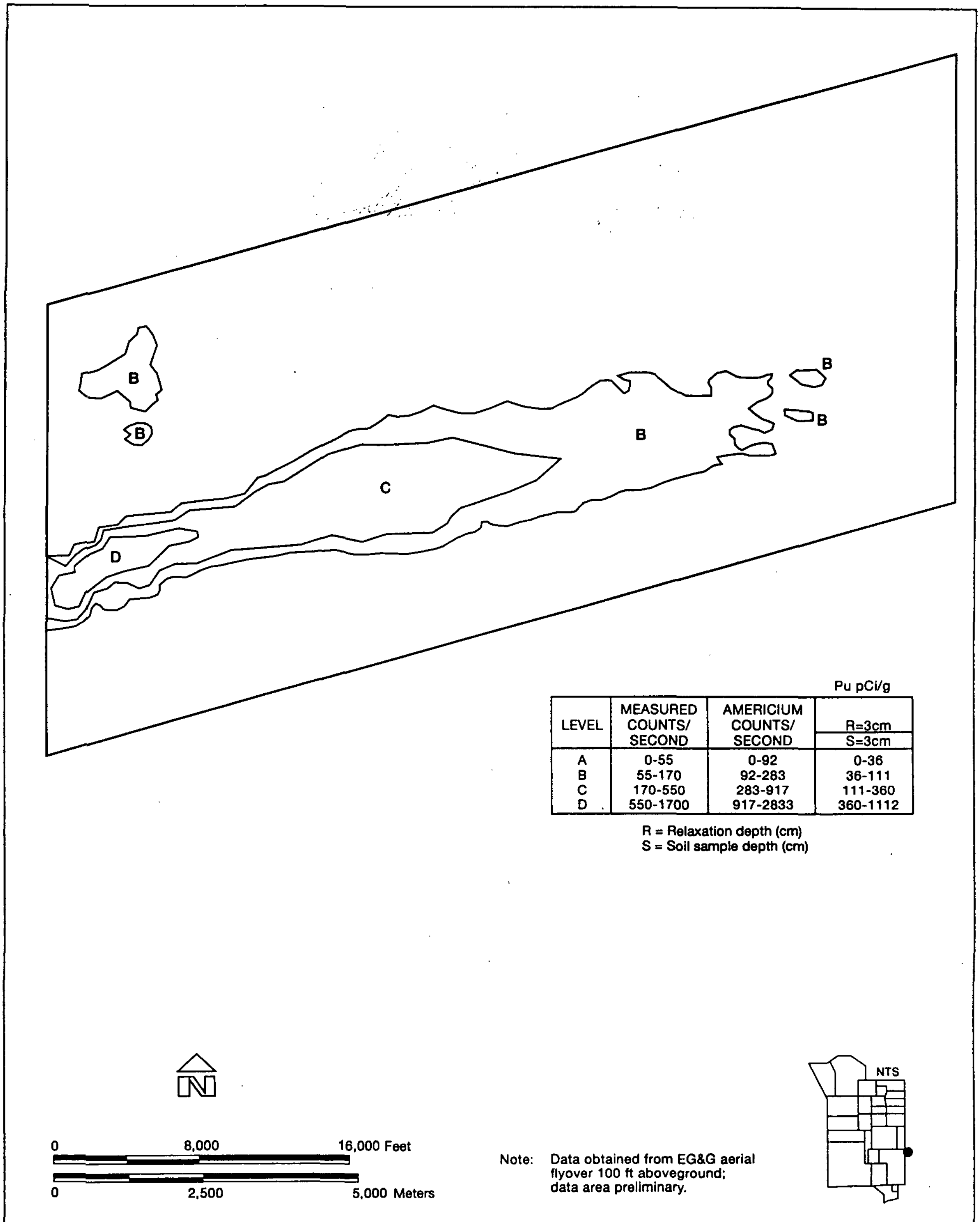


Figure 23 . Approximate area of plutonium contamination exceeding 10 pCi/g on the NTS



Pu pCi/g

LEVEL	MEASURED COUNTS/ SECOND	AMERICIUM COUNTS/ SECOND	R=3cm / S=3cm
A	0-55	0-92	0-36
B	55-170	92-283	36-111
C	170-550	283-917	111-360
D	550-1700	917-2833	360-1112

R = Relaxation depth (cm)
S = Soil sample depth (cm)

Note: Data obtained from EG&G aerial flyover 100 ft aboveground; data area preliminary.

Figure 24 . Approximate area of plutonium contamination plume east of Smallboy site

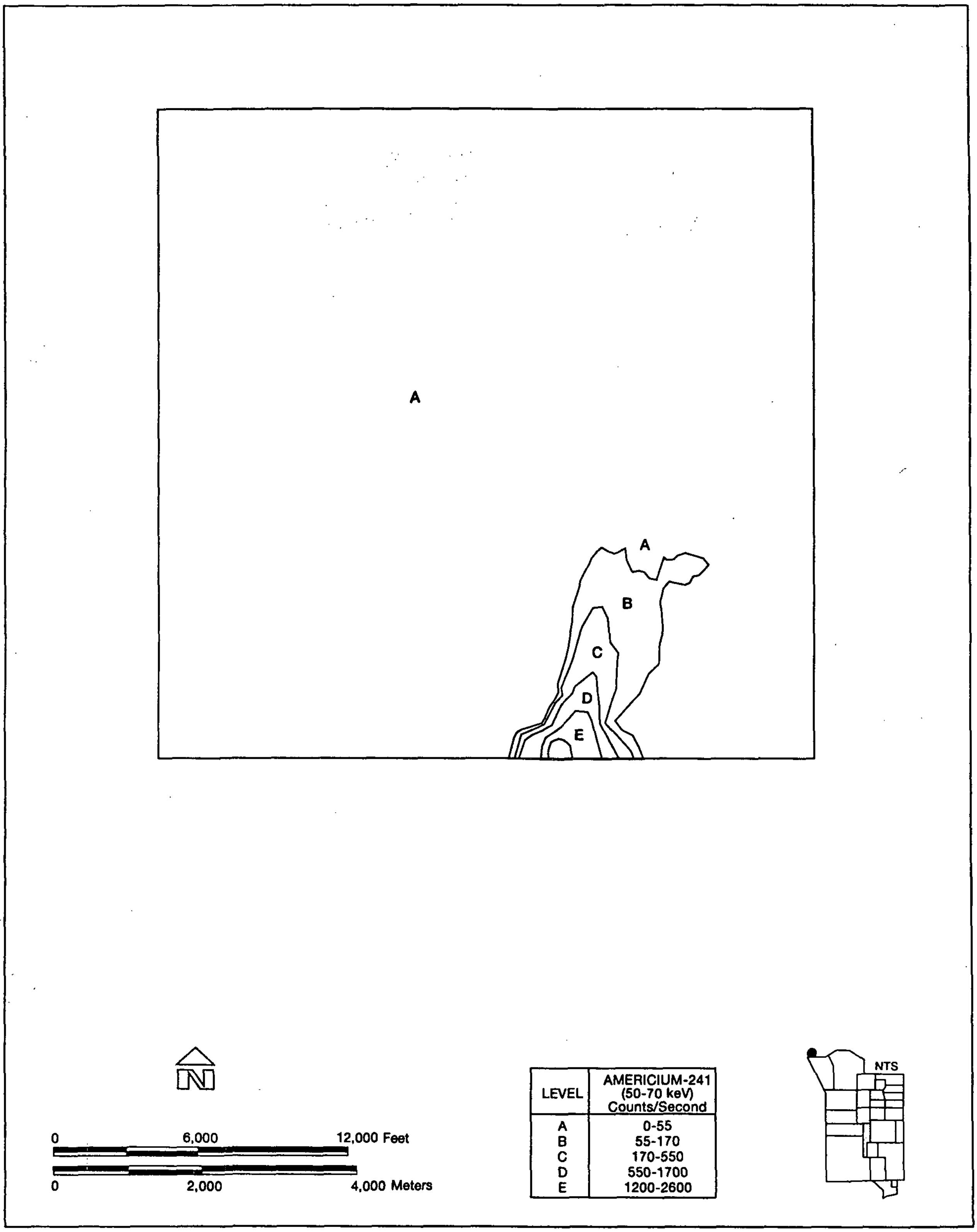


Figure 25 . Approximate area of plutonium contamination plume north of Schooner site

The primary isotopes that were released as a result of the safety tests are plutonium, uranium, and americium, with lesser amounts of cesium, strontium, and europium. These long-lived radionuclides remain today in the surficial soils in the vicinity of the test areas and are available to be transported by wind and uptake by plants and animals. Extensive research into the mobility of the isotopes has found that wind can transport the contaminants and concentrate them in mounds around desert shrubs, and water can cause plutonium to migrate deeper into the soils with time. The isotopes are now relatively immobile unless the soils are disturbed.

The uptake of plutonium by plants can vary widely, with large intakes as a result of plutonium dust settling on the leaves of a plant, while the quantity of uptake is almost negligible for movement from the soil via the plant's root system. In total, the inventory of plutonium in plants is small compared to the inventory in soils. In a comprehensive study of a contaminated area in Area 13 of the NAFR Complex, 44 Ci of plutonium were estimated to be in the soils while only 0.000264 Ci were estimated to have entered the foliage. Research has indicated that this trend may be as accurate for americium, however, which is much more easily taken into the root systems of plants. Similarly, the radioactivity levels in animals has been found to vary widely depending on the species, their habitats, and time spent in the contaminated area.

One of the actions being evaluated in this EIS is the characterization and remediation of the contaminated soils on the NTS. Over the past two decades, the DOE has conducted many different types of surveys and research projects concerning these soils. A long-term data baseline has been established, the areas of contamination have been delineated, air monitoring and radiological surveying continue for key indicator parameters (plutonium, noble gases, and tritiated water vapor), and an extensive research and development project has evaluated alternative methods for cleaning up the soils. The final disposition of the remaining isotope inventory in these soils will be determined as part of the Soils Corrective Active Unit of the Environmental Restoration Program.

Nuclear Rocket and Related Tests

A number of activities were conducted at the Nuclear Rocket Development Station in Areas 25 and 28. From 1959 through 1973, the area was used for a series of open-air nuclear reactor, nuclear engine, and nuclear furnace tests and for the High Energy Neutron Reactions Experiment. Equipment and facilities remain from some of these activities, and there are some limited areas of contaminated soils. The total estimated inventory of isotopes remaining in the soils in this area of the NTS has been estimated to be about 1 Ci (McArthur, 1991). The primary soil contaminants in this area are isotopes of strontium, cesium, cobalt, and europium. The disposition of this contamination will be addressed as part of the Soils Corrective Action Unit under the Environmental Restoration Program.

Other Sources of Soil Contamination

Actions taken as part of the ancillary testing operations has resulted in isolated areas of contaminated soils around former injection wells, lagoons, septic systems, and areas used for experiments in radionuclide transport. These areas of contamination are also being addressed as part of the Environmental Restoration Program. Soils in this areas will be evaluated, sampled and analyzed as necessary to define the extent and magnitude of contamination, and the appropriate remedial actions will be implemented as required by the appropriate regulatory authority.

3.2.1.4 Effects on Water Resources

The effects of past DOE actions on the water resources of the NTS and surrounding regions have generally been limited to effects on a few springs located on the facility and effects on the groundwater resources of the underground testing areas. As with the geologic and soil resources, the most significant effects on the water resources have occurred as a result of the underground nuclear testing program. In this section the effects of past actions on the NTS on the water resources of the region are described and discussed.

Effects on Surface Water

Because of the overall lack of surface water resources, there have not been measurable impacts on natural surface water bodies except for springs. The DOE routinely collects and analyzes samples from the surface water bodies on the NTS. In 1994, surface water sampling was conducted quarterly at 12 well reservoirs, eight springs, one containment pond, and nine sewage lagoons (Black et al, 1995). A grab sample was taken from each of these surface water sites for analysis of gross beta, tritium, gamma-emitters, and plutonium isotopes. Strontium-90 was analyzed once per year for each location. Water samples from the springs, reservoirs, and lagoons contained background levels of gross beta, tritium, plutonium, and strontium. Samples collected from the containment pond contained detectable levels of

Concentration Guide (DCG). One sample from Gold Meadows Spring was 70% of the DCG; the samples

Ruggeieri, et al (1988) and Davisson et al (1994). In general, the effects on the groundwater regime from underground nuclear tests fall into one of two categories: changes in the natural properties of the aquifers; and the release of radionuclides and other materials into the hydrologic environment.

Physical Effects on Aquifer Properties and Water Levels

As discussed previously, an underground nuclear explosion results in the formation of an underground cavity, fracturing of the rock near the cavity, and a rubble filled collapse chimney that may extend to the surface of the land. These physical effects can alter the natural permeability of the rock or alluvium in the vicinity of the cavity. Near the cavity (within about 3 to 5 cavity radii) the permeability and storativity of the aquifer can be increased substantially. At greater distances, the opening and closing of natural fractures as the shock wave moves through the aquifer may result in smaller fracture apertures and lesser permeability in the aquifer.

The vertical permeability of the rock or soils of the chimney is increased as a result of the fracturing and subsidence of the rock. Some increase in recharge from the surface may occur as a result of the greater permeability. Tyler et al (1986) conducted a study on the effects of surface collapse structures at the NTS on infiltration and moisture redistribution. These workers estimated that at least 13% of the precipitation falling on the catchment area of a crater may infiltrate deeply enough to recharge the water table. This value is appreciably greater than that for undisturbed areas.

In some areas of the NTS, water level monitoring has shown that groundwater levels may be significantly impacted by underground detonations. Laczniak et al (1996) reported that water levels in the chimney formed from tests detonated below the water table may be hundreds of feet lower than pre-test levels. These declines are believed to be related to the increased drainage through the rubble chimney into the cavity area after all the water was either vaporized or ejected into the surrounding geologic media. Water levels measured in the area outside of the chimney of some tests have been hundreds of feet higher than levels before the tests. After the drop in water levels in the cavity and the corresponding rise in water tables in an annular mound around the cavity, the groundwater levels begin to equilibrate. Groundwater flows into the chimney and cavity region and away from the annular mound which tends to migrate outward with time. The near cavity effects on water levels can be persistent. Depending upon the permeability, recharge, groundwater flow rates, and other factors, the equilibration of water levels to their natural levels can take days, months, or years.

The effects on water levels discussed above are of large magnitude but are restricted to the area in the vicinity of the test. The effects on water levels at greater distance are much less pronounced and of shorter duration. Laczniak et al (1996) noted that while minor water-level oscillations have been measured at distances in the tens of miles away from a detonation, the actual water level changes are of small magnitude, short-term, and are of minor significance in terms of regional groundwater flow. These authors also note that a sustained area of groundwater mounding is situated in northern Yucca Flat where both vertical and lateral groundwater flow directions and rates have been altered through testing. Because impacts of the tests could have resulted in an overall increase in recharge and groundwater flow rates in the basin.

Effects on Water Chemistry

Beyond the effects on the physical properties of the aquifers and aquitards that underlie the NTS, past underground testing has significantly affected the water chemistry of the testing areas. The mechanisms by which radionuclides can enter the groundwater include: 1) injection into fractures outside the cavity during the first milliseconds after a detonation; 2) interactions between gaseous species and the groundwater; and 3) leaching from the melt glass and condensation in the cavity and chimney over time. The following discussions are based primarily upon Glasstone (1962), Borg et al (1976), and Laczniak (1996), and describe the physical release of radionuclides into the groundwater regime at the time of an underground nuclear test, the remaining inventory of radionuclides left from historic testing, and the subsequent mechanisms that influence the migration of these radionuclides after their release.

Releases to the Near Test Environment

Releases from underground testing operations comprise four major categories of radioactive and hazardous substances: 1) source term and fission products; 2) activation products; 3) stemming materials; and 4) ancillary operations that use radioactive or hazardous materials or substances. The exact quantity of radionuclides and other materials released from a given test are unknown because the nature of the test device and the location vary. The total that has been released from all tests can be approximated, however, on the basis of similarities in the materials used and the overall testing procedures.

The fuels that are released during testing are the original nuclear material that did not undergo reaction during the detonation. The fission products are those direct products generated as a consequence of splitting uranium and plutonium. About 80 different fission products result from the fission of a given nuclear species, e.g., Uranium-235 or Plutonium-239, and about 200 different isotopes of 36 elements can be formed through their decay into a complex mixture of daughter products. There are three specific source term radionuclides (tritium, plutonium, and uranium) and 24 specific fission products that result from a typical underground detonation which are significant because of longevity and abundance.

During an underground nuclear detonation, large quantities of neutrons are released. Naturally occurring materials in the host rock surrounding the detonation (such as iron, lead, and zinc) capture some of these neutrons. The result is the formation of unstable (radioactive) nuclei. Borg et al (1976) identify 22 specific activation products of significance that result from testing operations.

Fracture injection is an important pathway for the introduction of radionuclides into the hydrogeologic regime. Water vapor discharged from the cavity immediately following the detonation is seismically pumped into the fractures that are formed by the test and through other fractures that are opened by the shock wave. As discussed previously, the area over which this phenomenon occurs is believed to be about 3 cavity radii from the cavity. Thus, for a cavity with a diameter of 610 m (2,000 ft), the injection of radionuclides into rock fractures is expected to occur outward to a distance of 914 m (3,000 ft) from the cavity. Following the achievement of equilibrium conditions, radionuclides that have been injected into fractures under the water table are available for transport through groundwater flow.

Borg et al (1976) summarize the release of gaseous phase radionuclides following an underground nuclear detonation. Immediately after the detonations, all or nearly all of the radioactive species produced by the explosion are held in gaseous form in the superheated gas "bubble" of the forming cavity. Once the cavity has reached its maximum dimensions, the temperature and pressure decrease. As the melt forms and flows to the bottom of the cavity, the walls of the cavity begin to spall and gas may escape. By this time, the temperature in the cavity has decreased enough to allow the condensation of the species with higher boiling points (refractory nuclides). Refractory species include plutonium, rare earth elements, zirconium, and alkaline earth elements; the volatile species include alkali metals, ruthenium, uranium, antimony, tellurium, and iodine. These radionuclides either condense into the melt glass or are deposited as fine droplets in the remaining vapor.

As the roof of the cavity collapses and the chimney begins to form, the escaping gases move upward through the chimney. With continued cooling, the radionuclides with lower boiling points condense onto the surface of the chimney rubble. The gaseous species may also escape laterally into the fractured region around the cavity and chimney. These radionuclides may condense directly into the groundwater or may be sorbed onto soils or rock particles in the zone directly above the groundwater. The most mobile isotopes are the gaseous species, including argon, krypton, and xenon, which tend to rise through the chimney and may ultimately seep out to the surface.

For almost all tests, significant quantities of nonradioactive materials are emplaced underground along with the nuclear device. Collectively, these materials are referred to as stemming materials. For a typical underground test, at least 230,000 pounds of rack and stemming materials are placed underground. Table 20 lists the materials that are introduced into the subsurface as part of the actual testing and during post-detonation drillback operations. The nonradioactive species include numerous metals, organic compounds, and drilling products. Following the detonation, most of the metals are either vaporized or undergo neutron activation and are accounted for in the radionuclide inventory. The fate of the organic compounds and drilling fluids is not fully understood. No estimates are available concerning the total quantity of these materials that may still remain in the subsurface at the NTS.

Underground nuclear testing is a sophisticated operation that requires the coordinated efforts of large teams of scientists, engineers, and highly-skilled workers. To support the past testing operations, the NTS has a large infrastructure. Hazardous and radioactive materials are used in some of the supporting operations, and facilities for the storage, treatment, and/or disposal of hazardous, non-hazardous, radioactive, and mixed wastes are an important part of the infrastructure. Most of these ancillary operations are located at or very near the land surface and at distances well away from past test locations. Although there is the potential of releases from these activities and operations to the groundwater regime, none have been documented. The great depth to water over most of the Test Site, the arid climate, and the use of engineered facilities for waste disposal lessen the potential for releases to the groundwater from the ancillary operations.

Remaining Radionuclide Inventory

The total quantity of radionuclides that have been released into the environment is not known. As part of the analyses performed for the preparation of the EIS, an assessment was made of the inventory of radionuclides that remains on the NTS (see Section 3..2.1.2, Effects on Geologic Resources). With respect to the current disposition of radioactivity at the NTS, it is important to note the difference between the total radionuclide source term and the hydrologic source term. The total radionuclide source term is considered as the total activity from all underground tests that were conducted beneath the water table or within 101 m (330 ft) of the top of the water table. Table and 18 and 19 summarize the isotopes and their remaining activities as of January 1, 1994. The total remaining inventory under, or within 100 m

Table 20. Materials used in underground nuclear testing

Fuels, Detectors, Tracers	Rack and Canister Materials	Organic Compounds	Drilling and Stemming Materials
Americium[a]	Aluminum	Alcohol	Bentonite
Curium[a]	Arsenic	Anionic Polyacrylamide	Cement
Neptunium	Barite	Coal-Tar Epoxy	Gel
Plutonium	Beryllium[a]	Complex Fluorescing	Gravel
Tritium	Boron	Compounds[b]	Modified Starch
Uranium	Cadmium	Galacto-Mannans $(C_6H_{10}O_5)_n$	Neoprene®
Lithium	Chrome	Laser Dyes[c]	Polyethylene

the rubble and begins to leach radionuclides from the now-solidified melt. During the second stage, some portion of the dissolved radionuclides are sorbed onto the surfaces of the rock or soil in another part of the chimney or onto the fractured rock adjacent to the cavity and chimney. The amount of radionuclides that can be mobilized in this manner is not well known and depends upon the solubility of the specific radionuclides, the rate of groundwater flow, and the physicochemical properties of the rock mass through which the groundwater flows.

There is considerable uncertainty concerning the actual quantity of this radioactivity that can enter the groundwater regime, that is, the hydrologic source term. Smith et al (1995) have summarized the uncertainties associated with the definition of a hydrologic source term for the NTS and concluded that the radionuclides most likely to become mobile and migrate via the groundwater regime are: 1) tritium; 2) a number of conservative anions and neutral species (such as Krypton-85, Technetium-99, Ruthenium-106, Chlorine-36, and Iodine-129); and 3) less conservative cationic species (including Strontium-90, Cesium-137, Antimony-125, Cobalt-60, Zirconium-95, Uranium-235, Plutonium-239, and others).

Environmental Fate of Radionuclide Inventory

The leaching of radionuclides from the rubble is probably an important pathway for tests that were conducted under the water table or in or under perched aquifers. Once detonation has occurred, the groundwater within the cavity area is vaporized and some portion of this vapor is forced by the shock wave out of the cavity and into the surrounding host rock. With time, groundwater gradually flows back into the cavity and chimney and comes into direct contact with the radionuclides that have condensed onto the chimney rubble. Depending on the solubility of the radionuclides, the groundwater dissolves the residues until chemical equilibrium has been achieved. Once dissolved, the radionuclides are available for migration through groundwater flow.

Leaching of radionuclides from the melt glass and cavity rubble probably has occurred to some degree. According to Borg et al (1976), past studies have asserted that (1) less than one percent of the radionuclides in the melt glass near the bottom of the chimney will be sorbed onto the chimney rubble and (2) most of the tritium will be mixed with the water in the chimney and cavity at times for about one year, and some tritium may be trapped in the melt glass. The leaching of radionuclides from the melt glass probably occurs over extended periods of time with the leachate available for transport through groundwater flow. The release of radionuclides through the leaching pathway continues to be an area of active research and, with time, a better understanding of the true hydrologic source term may be had.

As noted in the preceding discussion, tritium is one of the most mobile of the radionuclides present in the subsurface environment surrounding an underground nuclear test. It is also present at higher concentrations than other radionuclides for a period of 100 to 200 years following a test, and is generally believed to be present principally as part of a free water molecule rather than being bound in the puddle glass that contains the large majority of the radionuclides remaining after a test. Tritium is known to migrate when induced by nearby pumping, while many other radionuclides remain in or near the cavity (Bryant, 1992). Therefore, tritium represents the radionuclide of greatest concern to users of groundwater for at least the next 100 years because of its mobility and high concentration. It is for these reasons that tritium is the radionuclide used in the modeling processes in assessing the risks associated with the groundwater pathway. Other radionuclides either do not move as rapidly and are not of consequence in the assessments of risk for the period considered in the EIS, or are of much lower concentrations.

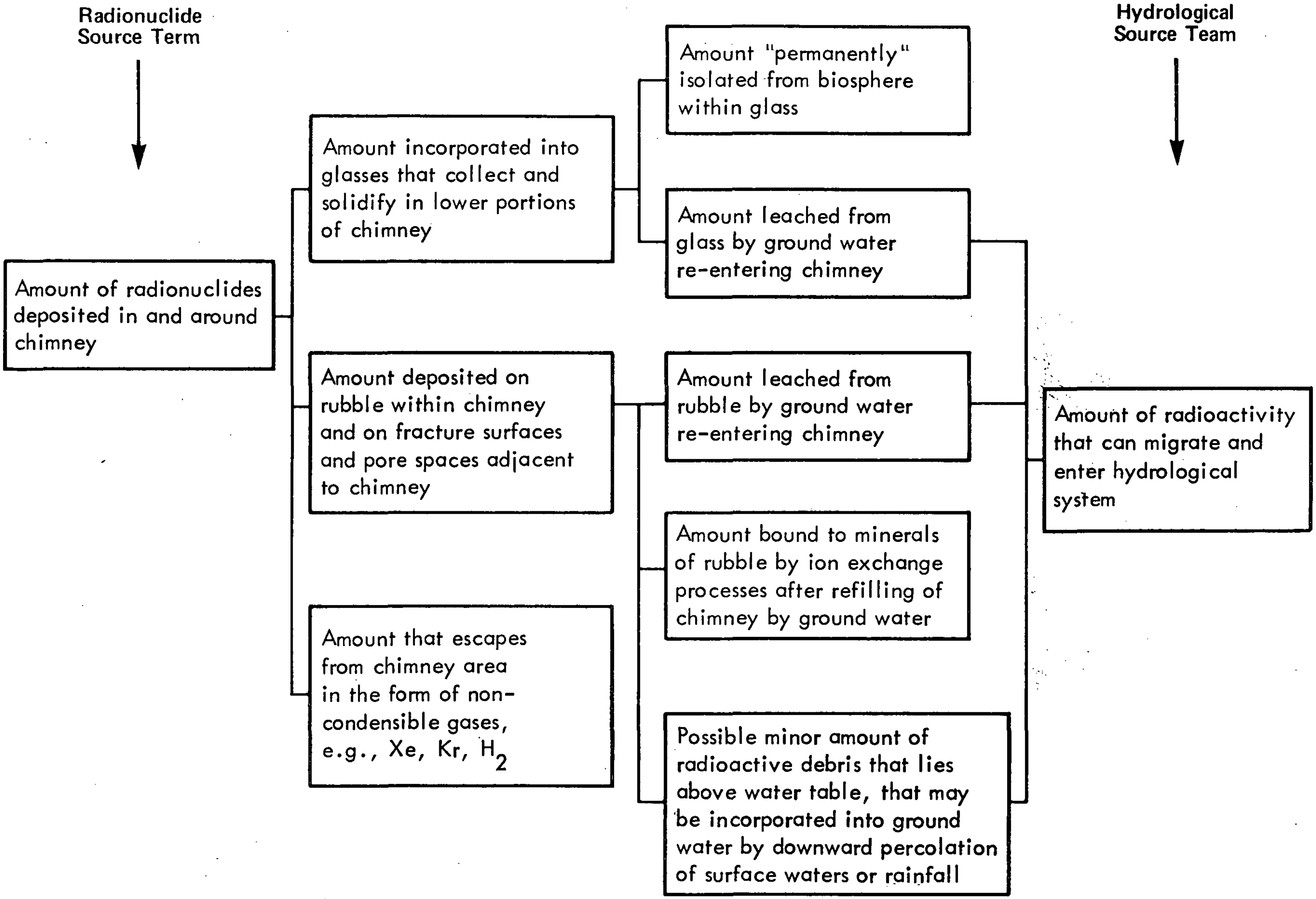


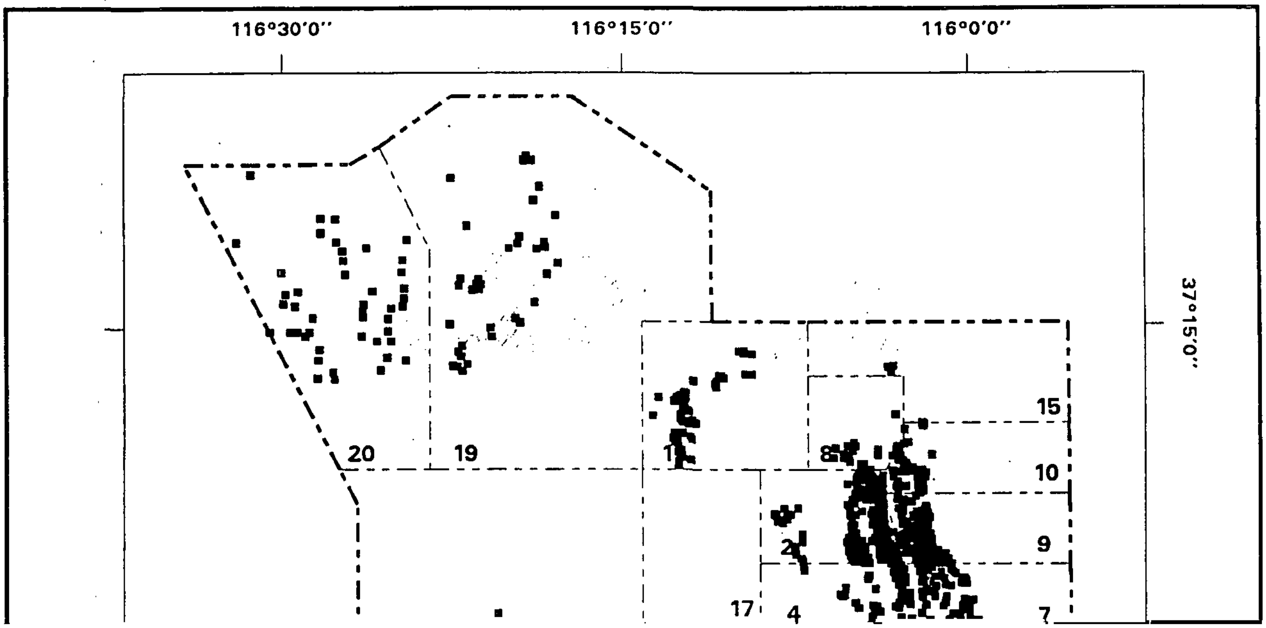
Fig. 26. Mode of distribution of radioactive nuclides to ground water at Nevada Test Site.

About a dozen instances of migration of radionuclides other than tritium have been documented (Nimz and Thompson, 1992). The largest distance of migration does not exceed 500 meters (1,640 ft). Migration of tritium is more difficult to interpret, but is thought to have migrated no more than several kilometers.

As noted by Borg et al (1976), the analysis of water samples for specific isotopes at random sites on the NTS is complicated and "it is possible that only relative or qualtitative conclusions could ever be made from such data. Such conclusions, nonetheless, may be important." In recent years, the drilling of new characterization wells and the retrofitting of existing boreholes and wells by the Environmental Restoration Program have provided valuable new data that are now being integrated into the overall database so that new evaluations can be made. These studies and planned future studies covered by the EIS will help to reduce the current levels of uncertainty concerning both the mechanisms and consequences of radionuclide transport via groundwater flow at the NTS. The other pathway by which radionuclides are known to have migrated from the cavity and chimney is the air pathway.

Smith et al (1995) note that once in solution, there are other factors which may remove the radionuclides from the groundwater as it flows through the subsurface. These authors reported that the transport and dispersal of radionuclides can be significantly retarded by sorption onto the rocks or soils, especially if the rock contains clay or zeolites which have high ion exchange capacities. Microscopic particles of clay (called colloids) are suspended in the groundwater and may also remove radionuclides from solution. These colloids may, in some instances, facilitate the migration of radionuclides through fractured rock. Research into the retardation of radionuclides and colloid transport continues to reduce the uncertainties concerning the fate of the radionuclides in the vicinity of past underground tests.

From a regional perspective, the distribution of the radionuclide source term can be determined by the location of underground tests. In other words, a traditional "plume map" can be approximated by the map of underground tests shown on Figure 27. Only one of those tests, Corduroy, in Yucca Flat, was conducted in the carbonate aquifer. The remainder were conducted in the alluvial or volcanic aquifers or aquitards. Within the areas of testing, significant quantities of clean water remain because of the limited migration of radionuclides in the groundwater.


116°30'0"
116°15'0"
116°0'0"
37°15'0"
20
19
15
8
10
2
9
17
4
7

3.3 Impact Analysis

This section provides the scientific and analytical basis for the comparison of the alternatives actions considered for the EIS. This comparison addresses the potential direct and indirect effects of each of the actions along with the unavoidable adverse effects, the relationship between short-term uses and long-term productivity, and the irreversible and irretrievable commitments of resources that would result from a given action.

The impact analysis is based on the best available data as presented in the preceding sections. The EIS is intended to serve as a baseline document for the preparation of subsequent, tiered National Environmental Policy Act documents that may be required prior to implementation of future specific projects. As such, it is also intended that this Technical Resource Report and the impact analyses presented in this section will provide a resource for the preparation of those lower-tiered documents.

3.3.1 Defense Program Actions

In this section, the actions specific to the Defense Program are evaluated. The potential actions covered under the four alternatives are quite different. As a consequence, the expected effects vary appreciably

3.3.1.1 Alternative 1

Under Alternative 1, two scenarios for stockpile stewardship are considered. In the first scenario, a state of readiness to conduct nuclear tests is maintained, but no tests are conducted. No impacts to geologic and soil media would result from readiness activities. Any on site maintenance actions that would impact the geologic and soils media are addressed in the section on. In the second scenario, which the DOE believes to be highly unlikely, the President directs that one or more nuclear tests be conducted. These stockpile tests would be conducted on Pahute Mesa and/or Yucca Flat. Because the type of tests that would be conducted cannot be identified, the impacts associated with testing in either area are addressed.

Soil and Drainage Disturbances

Approximately 12 acres of surface geologic media would be disturbed in Yucca Flat for each nuclear testing event. About 36 acres would be disturbed for each test on Pahute Mesa. The impacts of soils grading and excavation in support of testing under Alternative 1 are not considered significant. Given that one or more tests would be conducted under Alternative 1 and that an inventory of prepared sites exists, the associated soil disturbance either already exists or would be minor if a new location(s) is required. There is the potential for minor soil disturbances as a result of drill-back operations. In the event that a release occurs and results in soil contamination, corrective actions would be initiated, as required under the appropriate environmental regulations and DOE orders. The soil removed would be lost for the long term.

The consequences of altering the natural drainages and erosion rates are not considered significant. Short-term increases in sediment loss might occur; however, because of the overall slight precipitation over the NTS, the increase in soil erosion rates would be limited in both time and extent. Activities associated with conventional high-explosive testing, surface dynamic experiments, and hydrodynamic tests are not anticipated to significantly disturb the surficial geology. No significant changes in surface topography

Deep Underground Disturbances

Any test conducted at either Yucca Flat or Pahute Mesa would result in the formation of an underground cavity and rubble chimney. Underground testing at Yucca Flat would most likely also result in the creation of a subsidence crater. These subsurface disturbances represent an unavoidable and incremental impact on the geologic media in the vicinity of the planned tests. There are, however, already hundreds of such cavities, rubble chimneys, and craters on the NTS. The adverse impacts on geology and soils of one to a small number of nuclear tests are a small increment when viewed against existing baseline conditions. The analysis performed for this assessment is for the conduct of one nuclear test. The impacts to the environment from the conduct of multiple tests (a series) are assumed to be incremental. For example, the impacts of conducting two tests would be twice the impact of conducting a single test.

A deep subsurface cavity would be formed in the vicinity of any underground tests conducted under Alternative 1. According to information presented in Laczniak et al (1996), the radii of cavities at the NTS is variable, ranging from 15 m (50 ft) for a 20 kiloton event to about 61 m (200 ft) for a 150 kiloton event. Larger historic events resulted in cavities up to 107 m (350 ft). In the unlikely event that the President directs that a test be conducted, it is assumed that the test device will have a yield of less than 150 kilotons. Thus, a single test event at either Yucca Flat or Pahute Mesa would result in the creation of a subsurface cavity with a diameter of approximately 122 m (400 ft) or less in the deep subsurface.

A rubble chimney would be formed as a result of the spalling of rock from the walls of the cavity and the collapse of the roof. The rubble chimneys on the Test Site range up to 351 m (1,150 ft) high (Borg et al., 1976) and the chimney formed from a test in Yucca Flat would form a chimney that could extend to this height, or to ground surface, depending upon the depth of emplacement.

The natural soils and rock properties in the vicinity of the cavity would be altered. According to information presented in Laczniak et al (1996), a zone of intense crushing would extend outward about 1.3 cavity radii while pervasive fracturing of the rock would extend outward to about two radii on the average. A zone of moderately fractured rock would extend outward to about 2.5 to five cavity radii or, for the case of a 150 kiloton event, to a maximum of about 305 m (1000 ft) from the point of detonation. As the test would be conducted in an areas already used extensively for underground testing, the disturbances to the deep geologic media would be additive. Because the geologic media present are not used for any other purposes, the formation of the cavity, the alteration of soil and rock properties, and the formation of the rubble chimney are not considered significant impacts.

Underground subcritical experiments would produce some physical effects on the geologic media. Approximately 2,314 m^3 (81,700 cubic feet [ft^3]) would be disturbed each year in association with the conduct of up to four experiments. Irreversible effects would include the deposition of radiological material within the cavity mined in the subsurface. Approximately 20 acres of surface geologic media are currently disturbed in association with the Lyner Complex, where these experiments would be conducted.

In addition to the direct effect of detonating nuclear and other devices on geologic media and processes, preparation for such tests also disturbs geologic media. Disturbances include any associated infrastructure, excavated tunnels, and an existing inventory of deep boreholes up to 4 m (12 ft) in diameter for detonation of nuclear devices. Geologic media excavated in tunnels, boreholes, and borrow pits are considered to be permanently lost. Excavation of tunnels and testing conducted in those tunnels could potentially impact slope stability.

Release of Radionuclides

As an unavoidable consequence of underground nuclear testing, radioisotope contamination would extend up to five cavity radii from the point of each detonation under Alternative 1. The yields, locations, and proximity to the water table of tests to be conducted under Alternative 1 have not been defined. Therefore, it is not possible to estimate the total potential releases to the deep geologic media; however, significant releases of radionuclides and hazardous materials into the near test environment are to be expected. The estimated total release of fission and source-term radionuclides and activation products is 804,500 curies per kiloton of explosive yield. Thus, the potential releases to the deep geologic media from the testing of a single device far exceed releases from other actions to be included under Alternative 1.

Some quantity of radionuclides would be isolated in the melt that remains at the bottom of the cavity. These radionuclides are not mobile unless they come into contact with moisture moving through the unsaturated zone or if the cavity intercepts the water table. Even then, the leaching rates are believed to be slow and complete leaching could only be accomplished over geologic timeframes. Other radionuclides would be formed through neutron activation of naturally occurring elements in the geologic media. As these activation products are tightly bound in the rock structure, they will be generally immobile and will remain part of the rock mass.

Not all of the radionuclides that would be released will be immobile. Some unknown quantity of radionuclides will be forced into the disturbed rock surrounding the cavity and some quantity would rise upward through the chimney rubble. Some portion of these mobile radionuclides would be attenuated as they move through the fractures and rubble through sorption onto rock and soil particles. The remainder would remain mobile and continue seeping upward through the chimney rubble and laterally outward from the cavity through the fractured rock. Some portion of these radionuclides would be available for transport to the groundwater regime should the test be conducted within about five cavity radii of the water table.

There is the potential for minor soil contamination as a result of drill-back operations. In the event that such a release occurs and results in soil contamination, corrective actions would be initiated, as required under the appropriate environmental regulations and DOE orders. Any soil that would be removed as part of a corrective action would be lost for the long term.

Ground Motion

Ground-motion hazards can result from the underground nuclear explosion and secondary seismic effects. Because of the rather complete recording of ground motions related to past tests, the effects of future tests are predictable. Communities within 48 kilometers (km) (30 miles [mi]) of testing areas that could be most affected by ground motion from underground nuclear explosions are Beatty, Amargosa Valley, and Indian Springs. The closest potential testing area for these communities is 31 to 40 km (19 to 25 mi) away. Table 21 lists peak horizontal ground motions for 150-kt tests at 31 km (19 mi), using regressions developed by Long (1986). Peak ground acceleration, velocity, and displacement were computed at the 50th and 84th percentiles of the log-normal distributions given by Long (1986) for rock and alluvium recording geology at 31 km (19 mi) for a 150-kt test. Expected peak ground accelerations (g) are well below 0.05 g, which is the acceleration where slight damage might occur in typical buildings less than several stories in height.

Table 21. Predicted (50th and 84th percentiles) peak ground motions at localities 30 km (19 mi) from underground testing areas

Distance		Yield	Acceleration (g)*		Velocity				Displacement			
km	mi	kt	50%	84%	50%		84%		50%		84%	
					m/sec	ft/sec	m/sec	ft/sec	cm	in.	cm	in.
Rock												
31	19	150	0.012	0.029	0.009	0.03	0.020	0.07	0.23	0.09	0.51	0.20
Alluvium												
31	19	150	0.009	0.016	0.009	0.03	0.018	0.06	0.28	0.11	0.61	0.24

* Local acceleration due to gravity.

NOTE: All peak values reported are the largest of the radial and transverse components.

Several mining operations are located in the vicinity of the NTS, but all are at a distance greater than 40 km (25 mi) from the closest potential testing area. Because the distances from these mines to the testing areas are approximately the same as, or greater than, the distances to the communities, damage to structures in the mines is not expected. In investigations of earthquake effects on mines (Owen, 1981), there are very few reports of damage. Surveys of mines in the vicinity of the NTS by Owen and Scholl support these findings (ERDA, 1977).

In addition to direct ground motion effects of underground nuclear explosions, there is also potential hazard from secondary seismic effects. Secondary effects are associated with co-seismic strain release attributed to the release of tectonic strain, aftershocks that can be associated with tectonic strain release, and the collapse of cavities created by the underground nuclear explosions. Beyond 4.8 to 9.7 km (3 to 6 mi) of even the largest underground nuclear explosion (greater than 1 megaton), there would be no significant secondary seismic effects associated with the test. In no case has the magnitude of an aftershock been larger than the magnitude of the underground nuclear explosion (URS/John A. Blume and Associates, 1986).

Fault reactivation and associated seismicity could occur. Fault reactivation from testing of nuclear devices disturbs subsurface and surface geologic media, which may be significant depending upon the location and magnitude of the disturbances. The yield or size of underground nuclear explosions is controlled by the Threshold Test Ban Treaty to a maximum high-explosive equivalent of 150 kilotons (kt). For the purposes of this evaluation, any future weapons testing is assumed to occur under this limitation. Currently, underground nuclear testing can be conducted in the Pahute Mesa and Yucca Flat areas. Because geologic structure may differ considerably among the testing areas, predicting the effects of tests prior to characterizing the geologic environment in the unused areas is uncertain. Nevertheless, the geographic areas for testing and the yield limits can be used to estimate ground-motion effects from future weapons tests.

Mineral, Oil, Gas, and Geothermal Resource Availability

The continued withdrawal of the NTS would continue to exclude the facility from exploration or development of new mining operations or the reworking of former mining operations. The history of past mineral production indicates the potential for future production using modern techniques if the land were made accessible. Industrial minerals and materials are widespread throughout Nevada. The unavailability of these minerals and materials from the NTS has had little or no effect on Nevada's mining, manufacturing, and construction industries and would probably have little or no effect in the future. Aggregate resources have been used in the past as part of Defense Program actions, and aggregate mining would continue under Alternative 1. The impacts of this mining are not considered significant with respect to the resource availability as the aggregate resources of the region are immense, and the demand outside metropolitan Clark County is small. The NTS has low potential for geothermal, oil, and gas resources. No impact on these resources is anticipated as a result of Defense Program activities under

Alternative 1.

Effects on Surface Water Resources

Anticipated impacts on the surface water resources from Alternative 1 actions include the alteration of natural drainage paths, changes in erosion rates, deposition of sediments, ponding of water, or inundation of infrastructure. There is little surface water present on the NTS. Surface waters on the NTS consist of small areas of seepage associated with springs, small ponds associated with production wells, tritium-contaminated ponds created by tunnel drainage, and ephemeral waters caused by convective summer thunderstorms and runoff during wet winters. No surface waters are used for water supply. The ephemeral waters exist in normally dry washes for short periods of time and on the surfaces of playas for periods of days to weeks. Water quality of the ephemeral waters is poor because of naturally high sediment loads and dissolved solids. Surface disturbing actions would have minor effects on drainage patterns and discharge rates, existing surficial contamination, and infiltration rates. The changes to sediment loads and dissolved solids because of project activities would be minor compared to the natural conditions. No significant change in surface water quality or quantity is anticipated, and thus the impacts would be negligible.

Ground-surface disturbance and craters associated with underground nuclear tests have rerouted parts of natural drainage paths in areas of underground nuclear testing. Some craters have captured nearby drainage, and headward erosion of drainage channels is occurring. However, this is considered to be negligible. In some areas of the NTS, the natural drainage system has been all but obliterated by the craters. As noted in the *Final Environmental Impact Statement, Nevada Test Site, Nye County, Nevada* (ERDA, 1977), the development of surface craters is an unavoidable adverse impact of underground nuclear testing.

The alteration of the natural drainage system in testing areas is considered to be irrevocable. Whether water entering these craters and subsequently infiltrating into the ground has other than a negligible effect on the unsaturated zone, or potentially the saturated zone, is unknown. However, water entering the unsaturated zones or the saturated zone would account for a negligible source component when compared to the overall baseline condition. The erosion would continue, and over extended periods of time could result in some alteration of the natural drainage system. However, the principal areas where cratering has occurred are in Frenchman Flat and Yucca Flat, which are both topographically closed basins, and no effects on drainage would occur beyond the limits of these basins.

The potential impacts of detonating additional underground nuclear device(s) on flow rates of springs on the NTS are assumed to be negligible. Springs on the NTS are located outside the testing areas or are generally upgradient.

Effects on Groundwater Resources

The consequences of Alternative 1 activities on the water resources of the NTS and adjacent areas include two broad types of effects: reductions in water resource availability and impacts on water quality. The DOE routinely withdraws groundwater at the NTS and other DOE-administered lands in Nevada. These groundwater withdrawals could result in localized impacts, including a lowering of water levels, changes in groundwater flow directions, and a reduction in the quantity of water available to other users. If large-scale groundwater withdrawals occur, the impacts could increase to include reductions in spring off-site discharge rates, water quality impairment, and reduced underflow to downgradient areas.

The potential for increased percolation of water downward through the chimney and into the groundwater system is another potential impact. However, water entering the unsaturated zones or the saturated zone would account for a negligible source component when compared to the overall baseline conditions. The Desert Research Institute (Tyler et al., 1986) has investigated the effects of craters on infiltration and soil moisture movement, and research is continuing in this area. This study was inconclusive; additional studies are planned during 1997.

Two key areas of environmental concern are located beyond the NTS boundaries to the south: Devils Hole National Monument and Ash Meadows. Devils Hole is a small pool in the limestone in the Amargosa Desert that is the habitat for the desert pupfish. This fish feeds and spawns in the shallow water on limestone ledges in the pool. An adequate water level must be maintained in the pool to provide for the continued success of this endangered species. The Ash Meadows area is a point of regional discharge for the carbonate aquifer system. An estimated 2.09×10^7 m^3/yr (17,000 acre-feet/year) discharges to the surface, creating an extensive area of spring pools, streams, and wetlands. These wetlands form a valuable habitat for a great diversity of unique species. While the results of past investigations have not found any impacts resulting from DOE operations on these key environmentally sensitive areas, additional evaluation would be performed using sophisticated numerical simulation methods to ensure the continued existence of the pupfish and the important habitat at Ash Meadows.

Historically, the total annual demand for water at the NTS since the early 1960s has varied considerably, ranging from about 1.0×10^6 m^3/yr (850 acre-feet) in 1963 to a peak of 4.2×10^6 m^3/yr (3,430 acre-feet) in 1989. Long-term measurements of the water levels have demonstrated that historic water withdrawals have not resulted in significant impacts on water levels. It is considered unlikely that future Defense Program water withdrawals under Alternative 1 would result in significant impacts. Localized water-level declines and changes in flow direction would occur during periods of active pumping. These effects would be limited and are thus considered to be unavoidable, but not significant, impacts.

As an unavoidable consequence of underground nuclear testing, the quality of the groundwater under some portions of the NTS has been impaired. If an underground nuclear test is conducted under or near the water table, additional impairment of water quality and further losses of groundwater resources could be expected. NTS standard operating procedures are designed to protect groundwater from contamination by ensuring that no tests are conducted within two cavity radii (or a minimum of 100 m [328 ft]) of the groundwater table. The effects of underground testing have been well-documented in Borg et al. (1976), and the hazardous materials associated with testing have been detailed by Bryant and Fabryka-Martin

(1991). The yields, locations, and proximity to the water table of tests to be conducted under Alternative 1 have not been defined. Therefore, it is not possible to estimate the total potential releases to the groundwater. If tests are conducted in or near the water table, then significant releases of radionuclides and hazardous materials into the near-test environment are to be expected. As with the geologic media, the potential releases to the groundwater environment from testing of a single device far exceed releases from other actions to be included under Alternative 1. Tests conducted well above the water table would release significant quantities of radionuclides and hazardous materials into the unsaturated zone. Some downward migration of these contaminants may occur and would have the potential to contaminate the underlying groundwater.

The ancillary operations related to testing under Alternative 1 are primarily surface-based and have little potential for groundwater contamination. Minor quantities of drilling fluids or lost circulation materials might be introduced into the near-water-table environment during test hole drilling and post-shot drill-back operations. Any contamination that results from these activities would be considered inconsequential compared to the releases from the actual test.

The continuation of testing under Alternative 1 would have a significant impact on groundwater quality only if the testing is conducted in, or near, the water table. In this event, contamination of the near-test groundwater resources would occur. However, because of the conditions at the NTS (long travel paths, sorptive geologic media, slight hydraulic gradients, and the depths of the stockpiled holes), it is not considered likely that significant impacts would occur in areas downgradient of the underground testing locations. Underground conventional high-explosive tests, hydrodynamic tests, and dynamic experiments would not affect the groundwater because such tests and experiments would be conducted well above the water table.

Short-Term Uses Versus Long-Term Productivity

An underground nuclear test would result in the subsurface being unavailable for the long term. Following an underground nuclear test, the surface 40 acres could be available for limited uses unless cavity collapse has not occurred. Underground subcritical experiments would result in the mined cavity being unavailable for the long term. Following subcritical experiments, the land surface would be unaffected and unrestricted. Similarly, the Area 3 and Area 5 Waste Management Program sites would have an area of 34 acres of disturbed surface and an area of 821 acres of buffer zones. The disturbed areas would be restricted from subsurface access for the long term, and the surface would be restricted from most uses. Rehabilitation of the surface following closure would restore ecological productivity unless rock armor is used in closure. Rock armor would result in a sterile surface for the long term. The area in the buffer zones would have some restrictions on surface uses designed to prevent intrusion into the buried waste. Because it would likely remain undisturbed, its ecological productivity would remain unimpaired for the long term. Eighty acres would be disturbed for the long term in conjunction with weapons assembly/disassembly/interior storage.

Geologic resources and groundwater in the vicinity of the underground nuclear test would have long-term impairment of productivity. Disruption and contamination would mean the unavailability of the geologic resources in the vicinity of the shot cavity for the long term. While the effect on groundwater of underground tests detonated in or near the water table remains to be determined, any contamination in excess of regulatory levels would mean the long-term unavailability of the affected water. There also exists the possibility that collapse craters and their rubble chimney would provide preferential pathways from the surface to the vicinity of shot cavities, which could result in groundwater contamination.

Previous groundwater use in Yucca Flat has exceeded the perennial yield. However, during 1984 to 1994, water levels rose 26 m (85 ft), suggesting that reductions in the water table might not be long term. Activities within this alternative would disturb nearly 9,900 acres, most of which has been previously disturbed.

Irreversible and Irretrievable Commitments of Resources

Underground nuclear tests would represent, in large part, an irreversible and irretrievable commitment of the subsurface for any subsequent use. The surface above an underground nuclear test would be restricted from all access if cratering has not occurred. Where cratering has occurred, some limited surface use would be permissible. Underground subcritical experiments would result in an irreversible and irretrievable commitment of the mined cavity for subsequent use. Following subcritical experiments, the land surface would be unaffected and unrestricted.

The conduct of one or more underground nuclear tests would result in an undetermined impact on groundwater quality if it occurred in or near the water table. Any groundwater contamination in excess of EPA drinking water standards would constitute an irreversible and irretrievable commitment of a presently unquantifiable amount of water. Similarly, any contamination of groundwater above EPA drinking water standards at the existing underground test cavity locations would represent an irreversible and irretrievable commitment of the resource.

The subsurface area and geologic values at existing and future potential underground test cavity locations would represent an irreversible and irretrievable commitment of their associated natural resource services. A total of 2.1×10^6 m^3 per year (5.5×10^8 gal/yr) of water would be used to support all NTS programs under Alternative 1. This water would represent an irreversible and irretrievable commitment of this resource.

A total of about 59,000 acres has been disturbed to date, and an additional 9,900 acres would be disturbed over the next 10 years. With the exception of some of those areas that would be remediated under the Environmental Restoration Program, most of these acres would be irreversibly and irretrievably committed to their present uses. This would result in a minimal to total reduction of their associated natural resource services.

3.3.1.2 Alternative 2

No adverse impacts to geology, soils, or water resources would occur under Alternative 2 as all Defense Programs would be discontinued at the NTS. Stockpile stewardship would stop and no further underground testing would be conducted. Any areas of contaminated soils, geologic media, or water would not be restored, but would continue to be monitored. The remaining disturbed soils, geologic media, and contamination would represent the irreversible and irretrievable loss of the affected resources and would include large portions of Yucca Flat, Pahute Mesa, and Rainier Mesa, and lesser portions of Frenchman Flat and the other limited underground testing areas.

The short-term uses under Alternative 2 would be far more limited in scope and duration than those of Alternative 1. Consequently, the actions would pose less potential to impact the resources. The long-term productivity of some areas would be increased over Alternative 1 because the areas would not be disturbed. However, for areas with surficial contamination, the long-term productivity would be

3.3.1.3 Alternative 3

Under Alternative 3, the adverse impacts to the surface hydrologic environment discussed under the Defense Program in Alternative 1 apply. The additional facilities and activities included under actions taken under Alternative 3 would increase the adverse impacts on the environment. These increases would be additive to those that were presented under Alternative 1.

The proposed National Ignition Facility location at the North Las Vegas Facility is outside the 500-year floodplain of the local drainage. Construction of the National Ignition Facility at the North Las Vegas Facility would be expected to have minor to negligible effects on water quality with the implementation of a stormwater pollution and prevention plan to minimize soil erosion, sedimentation, and contamination of stormwater. Measures would be taken to comply with stormwater discharge regulations associated with construction activities.

Under Alternative 3, adverse impacts to geology and soils media are the same as those discussed under Alternative 1. The storage of weapons or components of weapons in the Device Assembly Facility and in the P-Tunnel has been proposed and, if implemented, would further disturb the geologic media. New stockpile management activities at the Device Assembly Facility would disturb approximately 29 acres of addtitional surface geologic media. Any additional excavation for this purpose would result in permanent loss of the excavated geologic media and could impact slope stability.

The construction and operation of the proposed National Ignition Facility at the North Las Vegas Facility would have no adverse impact on geological resources. The National Ignition Facility would require about 8 of vacant land. The soils at the North Las Vegas Facility are considered acceptable for standard construction techniques. Soil impacts during construction would be short-term and minor with appropriate standard construction erosion and sediment control measures. The site has been disturbed in the past; therefore, construction impacts would be minor. Net soil disturbance during operation would be less than for construction because areas temporarily used for laydown would be restored. Seismic risks would be taken into consideration during design, construction, and operation activities.

The relationship of short-term uses and long-term productivity under Alternative 3 would be as for Alternative 1 plus the additive impacts of some actions. A large area would be disturbed within the alternative energy sites. However, the energy produced would be clean and would prevent the occurrence elsewhere of the more significant impacts associated with other forms of energy production, such as fossil, fuels, hydropower, and nuclear. Thus, alternative energy production would create a substantial long-term benefit. The Big Explosives Experiment Facility would result in surface clearing on 30 acres, which could be remediated and made available for most uses upon cessation of operations. Its 7,000-acre buffer area would be unavailable for human use, but the ecological productivity should remain largely intact.

Additional underground nuclear tests conducted under Alternative 3 would result in the subsurface being unavailable for the long term. The surface above an underground test could be available for limited use unless cavity collapse has occurred at the underground test. Underground subcritical experiments would result in the mined cavity being unavailable for the long term. Following subcritical experiments, the land surface would be unaffected and unrestricted. Construction of a large, heavy-industrial facility, expansion of the Device Assembly Facility, facilities for the handling and storage of weapons-usable fissile materials, and advanced hydrodynamic testing would take land and habitat out of production for the long term. The area involved would be very small compared to the size of the NTS and would have limited effect.

Geologic resources and groundwater would have long-term impairment on productivity with an underground nuclear test as for Alternative 1. As for Alternative 1, underground nuclear testing and subcritical testing under Alternative 3 would represent an irreversible and irretrievable commitment of the subsurface for any subsequent use because of the formation of underground cavities surrounded by pockets of radioactive contamination.

Energy and materials utilized in the construction, operation and maintenance of the facilities would be irreversibly and irretrievably committed. Detonation of high or nuclear explosives would be an irreversible and irretrievable commitment of energy resources. Additional projects, including the alternative energy developments, would constitute a greater commitment of resources than would Alternative 1.

The conduct of one or more underground nuclear tests would result in an undetermined impact on ground water quality if it occurred in or near the water table. Any groundwater contamination in excess of EPA drinking water standards would constitute an irreversible and irretrievable commitment of a presently unquantifiable amount of water. Similarly, any contamination of groundwater above EPA drinking water standards at the existing underground test cavity locations would represent an irreversible and irretrievable commitment of the resource. A total of 1.1×10^7 m^3 per year (2.9×10^9 gal/yr) of water would be used to support all NTS programs under Alternative 3. This water would represent an irreversible and irretrievable commitment of this resource.

The subsurface area and geologic values at the existing and potential future underground test cavity locations would represent an irreversible and irretrievable commitment of their associated natural resource services. A total of about 59,000 acres has been disturbed to date, and approximately 15,600 more acres would be disturbed over the next 10 years. With the exception of some of those areas that would be remediated under the Environmental Restoration Program, most of these acres would be irreversibly and irretrievably committed to their present and proposed use. This would result in a minimal to total reduction of their associated natural resource services.

3.3.1.4 Alternative 4

Under Alternative 4, the impacts to geology, soils, and water resources would be the same as those described under Alternative 2 and the relationship between short-term uses and long-term productivity would be similar. Irreversible and irretrievable resource commitments under Alternative 4 also would be as those already described for Alternative 1.

3.3.2 Waste Management Program Actions

In this section, the actions specific to the Waste Mangement Program are evaluated. Unlike Defense Program actions, the potential actions covered under the four alternatives for the Waste Management Program differ mostly in terms of quantity of wastes to be stored, treated, or disposed, the number of disposal units that would be closed, and upgrades or expansions that would be included within a given alternative.

3.3.2.1 Alternative 1

Craters formed by past underground nuclear tests in Area 3 that meet certain criteria have been used to dispose of bulk low-level waste and will continue to be used under Alternative 1. In this process, the area between adjacent crater pairs is excavated, and the crater slopes are reshaped so waste containers can be stacked for disposal. The Area 3 Radioactive Waste Management Site covers approximately 128 acres. The craters that are, and would continue to be, used at the Area 3 Radioactive Waste Management Site represent the unavoidable adverse impacts that resulted from past underground nuclear tests. Use of the craters for waste disposal is a beneficial use of lands that have been significantly and unavoidably impacted by past DOE actions at the NTS.

Trenches, pits, and boreholes in Area 5 have been excavated to dispose of containerized low-level waste and mixed waste. The Area 5 Radioactive Waste Management Site covers approximately 732 acres surrounded by a fence. The waste disposal craters and excavations would be closed with an engineered cap.

Siting of waste management facilities is a critical issue in terms of protecting the facilities from floods. Also important, however, is the impact of such facilities on natural processes and media in areas of potential flood hazard. The Radioactive Waste Management Sites in Areas 3 and 5 and other waste disposal areas on the NTS alter natural drainage paths. The craters that are, and would continue to be used, in the Area 3 Radioactive Waste Management Site resulted from underground nuclear tests. The [illegible]

Emplacement of waste in the craters and subsequent engineered closure of the cells would return portions of the surface topography to a natural grade and help to restore drainage patterns. Similarly, engineered

Although technically reversible through excavation and clean closure, use of the radioactive waste management facilities for waste disposal would result in an irreversible and irretrievable commitment of the sites and surrounding buffer areas. Land uses would be severely restricted, as would access to the subsurface. Some surface areas would be rehabilitated upon closure and would provide natural habitat, but little other human use. Most closures would likely be designed using rock armor to inhibit vegetation or burrowing by animals. Sanitary and construction landfills would represent an irreversible and irretrievable commitment of the subsurface and some limitation of the surface uses.

3.3.2.2 Alternative 2

No adverse impacts on geology, soils, or water resources have been identified for Alternative 2 actions under the Waste Management Program. Under this alternative, waste disposal sites would be closed in place. Although less use of the radioactive waste management facilities for waste disposal would occur with this alternative than with Alternative 1, there would still be an irreversible and irretrievable commitment of the sites and surrounding buffer areas. Land use would be severely restricted as would access to the subsurface. Some surface areas would be rehabilitated upon closure and would provide natural habitat, but little other human use. Most closures would be designed using rock armor to inhibit vegetation or burrowing by animals.

Sanitary and construction landfills would represent an irreversible and irretrievable commitment of the subsurface and some limitation of the surface uses. Waste disposal would result in some minor amount of land being committed to long-term use as a disposal site. Alternative uses would be very limited because of the need to protect the subsurface from intrusion.

3.3.2.3 Alternative 3

Adverse impacts to geologic media discussed for the Waste Management Program under Alternative 1 also apply under Alternative 3. Under Alternative 3, the adverse impacts to the surface hydrologic environment discussed under the Waste Management Program in Alternative 1 apply. The additional facilities and activities included under Alternative 3 would increase the adverse impacts to the surface hydrologic environment that would occur under Alternative 1.

Under Alternative 3, additional waste disposal capacity would be developed, and minor added water demands would result. It is estimated that 9.251 m^3/yr (7.5 acre-feet per year) of groundwater will be needed for increased waste disposal. No significant adverse impacts are associated with this minor added demand for additional water. It is expected that the additional waste management activities would be similar to ongoing activities and that they would not have an additional impact on the groundwater. The craters that are, and would continue to be used, at the Area 3 Radioactive Waste Management Site represent the unavoidable adverse impacts that have resulted from past underground nuclear tests. The Waste Management Program sites would be restricted from subsurface access for the long term. Energy and materials utilized in the construction, operation, maintenance, decontamination, demolition, and closure of facilities would be irreversibly and irretrievably committed.

3.3.2.4 Alternative 4

Waste Management Program activities are anticipated to result in the same minor adverse impacts to geologic media, processes, or resources as described under the Waste Management Program under

Alternative 1. Waste Management Program activities are anticipated to result in the same adverse impacts to the surface hydrologic environment as described for Waste Management under Alternative 1.

Under Alternative 4, the water demand for Waste Management Program activities would be reduced from Alternative 1 levels. Because the demand for water would be insignificant (less than 1,233 m^3/yr [1 ac-ft/yr]), there would be no significant impacts associated with groundwater withdrawals for waste management. Energy and materials utilized in the construction, operation, maintenance, decontamination, demolition, and closure of facilities would be irreversibly and irretrievably committed.

3.3.3 Environmental Restoration Program Actions

In this section, the actions specific to the Environmental Restoration Program are evaluated. Unlike Defense Program actions, the potential actions covered under the four alternatives for the Environmental

3.3.3.1 Alternative 1

Actions taken as part of the Environmental Restoration Program under Alternative 1 will have minor impacts on geology resources but will significantly impact soil resources. Impacts on water sources are minimal under most anticipated future conditions.

Effects on Geology and Soils Resources

Environmental Restoration Program activities on the NTS under Alternative 1 are not anticipated to

Effects on Surface Water Resources

Water produced from characterization and monitoring wells drilled as part of the Environmental Restoration Program can only be discharged to the surface if it is in compliance with requirements of the Clean Water Act. Because monitoring of the water would be performed and erosion would be reduced through channel protection, drilling activities would have no significant impact to drainage channels or to downstream springs or surface impoundments. Any accidental discharge of produced water that is contaminated with radionuclides or hazardous substances has the potential to contaminate surface and near-surface geologic media. However, present practice is to contain all discharged water in lined sumps until the water quality is determined.

As with Defense Program activities, the Environmental Restoration Program soil-disturbing activities might result in slight increases in sediment yield and some inorganic compounds in surface water. The only planned Environmental Restoration Program action that could result in significant adverse impacts is the cleanup of large areas of plutonium-contaminated soils on the NTS. Appropriate dust and drainage controls would be implemented to ensure that unacceptable levels of plutonium would not become available for transport via surface water flows. Because such controls would be implemented, the impacts of soil restoration actions on surface water quality would not be considered significant.

Other Environmental Restoration Program activities would not have significant impacts to surface waters on the NTS; therefore, the impact of environmental restoration actions on the quantity of surface water resources is not expected to be significant.

Effects on Groundwater Resources

Groundwater use during environmental restoration activities would be minimal and would be limited to that used in pad and road construction, dust control, drilling and testing of characterization wells, decontamination of sampling materials, and purging of wells prior to sampling. Annual water requirements for characterization have not been well defined, but are expected to be minimal.

According to information from the Underground Test Area Corrective Action Unit project, the greatest demand for nonpotable water for drilling a characterization well was 7,400 m^3 (6 acre-feet). The total water demand for this program would probably be less than 74,0090 m^3/yr (60 acre-feet/year) between 1995 and 2005. Smaller quantities of water would be required to support decontamination and well sampling. The total demand for site characterization activities would probably be 123,400 m^3/yr (100 acre-feet/year), and no significant impact is expected from the withdrawal of such a small quantity of water.

Information concerning future remediation efforts is preliminary. Water demands projected for the decommissioning of some sites (e.g., the demolition of structures at Test Cell C) have been as high as 3,785 liters (L)/day (1,000 gallons [gal]/day) of potable water (or about 1,357 m^3/yr [1.1 acre-feet/year] over a two-year period). Long-term remediation requirements have not yet been determined. If it is assumed that remediation does not include any active groundwater controls, future requirements for monitoring and well-testing would be a few thousands of cubic meters per year (tens of acre-feet per year). If active groundwater controls were implemented (e.g., hydraulic barriers or extraction wells), future water demands could be several million cubic-meters per year (thousands of acre-feet per year).

Short-Term Uses Versus Long-Term Productivity

Most actions taken during the Environmental Restoration Program under Alternative 1 would increase the long-term productivity of the areas that would be remediated. The removal of contamination and the restoration of disturbed lands would return the lands for some types of use, and, in some cases, may return the land to unrestricted uses.

Irreversible and Irretrievable Commitments of Resources

Decontamination and decommissioning activities under Alternative 1 would produce mixed results depending on the remedy selected. Entombment would result in an irretrievable and irreversible commitment of the surface or associated subsurface for most land use. Most decontamination and decommissioning activities would result in either decontamination and consequent availability of the facility for other use or demolition of the facility and disposal. Reuse would entail the facility remaining in an industrial mode, which would represent a long-term commitment to that type of land use. Demolition of the facility would result in the land's availability for other development or for site rehabilitation and use as natural habitat.

Although technically reversible through excavation and clean closure, closure in place would result in an irreversible and irretrievable commitment for those Resource Conservation and Recovery Act industrial [illegible]

sites that are so treated. Land use on these sites and in a surrounding buffer zone would be severely constrained. Rehabilitation by revegetation would permit their functioning as natural habitat, but closure would likely be designed using rock armor to inhibit vegetation or burrowing by animals.

Energy and materials utilized in the decontamination, demolition, and closure of facilities would be irreversibly and irretrievably committed. Removal of soils for environmental restoration projects would result in their irreversible and irretrievable loss since they would be landfilled and any associated natural resource services that they provide would be lost as well. Environmental restoration would involve up to about 9,800 acres, most of which have been previously disturbed. The amount that would be disturbed during remediation depends, first, upon the levels of contamination that would be determined during characterization and, second, upon the agreements reached with the state of Nevada regarding cleanup levels.

3.3.3.2 Alternative 2

Under Alternative 2, no actions would be taken under the Environmental Restoration Program. Areas of remaining soil contamination would represent an irretrievable commitment of soil resources. The migration of uncontained contaminants over the long term could cause restrictions on land and

3.3.3.3 Alternative 3

Under Alternative 3, the adverse impacts to geologic media discussed under the Environmental Restoration Program for Alternative 1 would occur. The impacts would occur on a slightly accelerated schedule. Additional restoration actions would be taken, and characterization wells would be drilled at a faster rate.

Acceleration of the Environmental Restoration Program schedule could result in a doubling of characterization water demands to about 246,700 m^3/yr (200 acre-feet per year). The impacts of this increase would not be significant, as the increase represents only a small portion of the available water in all but Yucca Flat.

Because no significant impacts on the water resources were identified and because of constraints on the length of time that would be required for remediation, no significant added impacts are anticipated as a result of accelerated remedial actions under Alternative 3. Small quantities of water would be needed for remedial actions unless active groundwater controls were implemented. In the unlikely event that such controls would be necessary, large-scale groundwater withdrawals (millions of cubic-meter per year [thousands of acre-feet per year]) could be required.

3.3.3.4 Alternative 4

Environmental Restoration Program activities are anticipated to result in adverse impacts to geologic media, processes, or resources as described under the Environmental Restoration Program under Alternative 1. The demand for water resources for Environmental Restoration Program activities would accelerate under Alternative 4 if specific actions are accelerated; however, the total demand for water for environmental actions would still be quite small, less than 2.5×10^5 m^3 (200 ac-ft/yr). No significant impacts on water resources are anticipated because of an acceleration of Environmental Restoration Program activities under Alternative 4.

3.3.4 Nondefense Research and Development Program Actions

In this section, the effects of the actions under the Nondefense Research and Development Program are evaluated. In general, the impacts from the proposed actions are not considered significant except for the construction of a Solar Enterprise Zone in Alternatives 3 and 4.

3.3.4.1 Alternative 1

Projects conducted within the NTS Environmental Research Park are not anticipated to result in significant adverse impacts to geologic media. Tests conducted at the Spill Test Facility on Frenchman Playa in Area 5 do not pose a risk of significant adverse impact to geologic media at or near the facility (DOE/OFE, 1994).

The facilities for the Nondefense Research and Development Program have already been constructed, and no new soil-disturbing actions that might impact the surface water regime are included as part of Alternative 1. Tests conducted at the Spill Test Facility on Frenchman Playa in Area 5 do not pose a significant adverse impact to any surface water at or near the facility (DOE/OFE, 1994).

The current water demand for the Spill Test Facility has not been determined, but is expected to be slight for fire control, safety, experiments, and potable and nonpotable water. Similarly, the Environmental

Management and Technology Development Program has unquantified, but minimal, water demands. Some field measurements and testing might be included in the feasibility study of a Solar Enterprise Zone facility; however, any requirements would be negligible. In total, the water demands for the Nondefense Research and Development Program activities would probably be no more than 12,335 m^3/yr (10 acre-feet/year), and no significant impact would be related to this water use. Water consumed for these uses would not be available for other purposes.

3.3.4.2 Alternative 2

Under Alternative 2, there would be no activity associated with the Nondefense Research and Development Program. Because of the discontinuation of all activities, there would be no adverse impacts on the geology, soils, or water resources.

3.3.4.3 Alternative 3

Under Alternative 3, the adverse impacts to geologic media discussed under the Nondefense Research and Development Program in Section Alternative 1 apply. Other facilities that could adversely impact geologic media are the Treatability Test Facility and the Area 6 decontamination pad.

Under Alternative 3, the adverse impacts to the surface hydrologic environment discussed under the Nondefense Research and Development Program in Alternative 1 apply. Specific other facilities that could adversely impact the surface hydrologic environment are the Treatability Test Facility and the Area 6 decontamination pad.

The water demand for the Nondefense Research and Development Program is likely to be large and would have a significant impact on the availability of the groundwater in the basins in which actions are taken. There are two candidate sites at the NTS for the Solar Enterprise Zone facility, Fortymile Canyon in Area 25 and Mercury Valley in Area 22. Peak historic demand has not exceeded perennial yield at either location. However, a Solar Enterprise Zone facility would require a substantial increase in groundwater use. Total groundwater withdrawal would increase above the natural recharge of the affected aquifer. This would require the use of some underflow and could result in long-term effects on groundwater resources.

The peak demand for a Solar Enterprise Zone facility has been estimated at between 4.0×10^6 m^3 and 6.8×10^6 m^3 (3,250 and 5,550 acre-ft/yr), depending on the final array of power-generating options that would be constructed. The alternate fuel vehicle and other demonstration projects would not have appreciable water demands unless large-volume aquifer testing were conducted. Any such occurrences would be evaluated on a case-by-case basis, and National Environmental Policy Act requirements would be met, as needed. Use of water for a Solar Enterprise Zone facility would more than triple the annual water use at the NTS. The impacts of a Solar Enterprise Zone facility on the water resources of the NTS would depend on the location, aquifer, perennial yield, and other water uses in the area. The two candidate sites for the facility are in Area 25 in Fortymile Canyon and Area 22 in Mercury Valley. The perennial yield of Fortymile Canyon is 9.4×10^6 m^3 (7,600 acre-feet per year). The peak historic demand was only 419,384 m^3 (340 acre-ft), leaving as much as 8.9×10^6 m^3 (7,260 acre-ft) of water available. Mercury Valley has a perennial yield of 9.9×10^6 m^3/yr (8,000 acre-ft/yr) and a peak historic demand of only 527,930 m^3 (428 acre-ft), leaving as much as 9.3×10^6 m^3 (7,570 acre-ft) of unappropriated water available.

The perennial yields of the two areas are based on the limited recharge from precipitation and the appreciable underflow from upgradient basins. In Fortymile Canyon, the naturally occurring recharge has been estimated by Scott et al. (1971) to be about 2.8 x 10^6 m^3/yr (2,300 acre-feet per year), with underflow estimated at 7.2 x 10^6 m^3/yr (5,800 acre-feet per year). The location of a Solar Enterprise Zone facility in Fortymile Canyon would increase total groundwater withdrawals from 1.2 x 10^6 to 3.7 x 10^6 m^3 (1,000 to 3,100 acre-ft) above the recharge from precipitation and would thus capture some of the underflow out of the basin. There may not be a one-to-one correspondence between the quantity of water withdrawn in excess of the perennial yield and the reduction in underflow to downgradient basins. The results of preliminary modeling of the groundwater withdrawals indicates that the groundwater level impacts will be localized within the vicinity of the well and most impacts will be upgradient. It is likely that some groundwater will be removed from storage, a process referred to as groundwater mining, and there will be a corresponding decrease in the impact on downgradient discharge rates. The results presented herein are preliminary and are adequate for the purposes of the sitewide EIS. More detailed evaluations will be performed as more detailed information on water use by the facility becomes available and will be presented in lower-tiered National Environmental Policy Act documents prior to the development of the water.

The recharge from precipitation over Mercury Valley is slight, estimated at only 3.1 x 10^5 m^3/yr (250 acre-ft/yr) by Scott et al. (1971). Existing historic demands for water have exceeded this amount; thus, the development of water supplies for a Solar Enterprise Zone facility in Mercury Valley would likely capture some portion of the underflow out of the basin into Amargosa Desert (an estimated 2.09 x 10^7 m^3/yr [17,000 acre-ft/yr]).

Sensitive environmental areas downgradient of the NTS include Ash Meadows, Devils Hole, and Death Valley. A recent evaluation of water-level declines in Devils Hole was performed by the Las Vegas Valley Water District (Avon and Durbin, 1994). A statistical analysis of precipitation, water withdrawals in Pahrump Valley, water withdrawals on the NTS, and water levels in Devils Hole was performed as part of this evaluation. The results indicated that there was no relationship between water withdrawals on the NTS to lowering of water levels at Devils Hole. It is considered very unlikely that the withdrawal of the groundwater from the NTS for a Solar Enterprise Zone facility would have any significant adverse impact on downgradient water levels or spring discharge rates.

3.3.4.4 Alternative 4

Nondefense Research and Development Program activities are anticipated to result in the same adverse impacts to geologic, soils, and water resources as described under Alternatives 1 and 3. The major demand for water would be for the Solar Enterprise Zone. The impacts would be as described under Alternative 3, except that any reductions in underflow to downgradient basins would be reduced.

3.5.5 Work for Others Program Actions

3.3.5.1 Alternative 1

Activities under the Work for Others Program, such as defense-related research, development projects, and military training exercises, could have an adverse impact on geologic media of the NTS. One potential impact would be soil contamination resulting from weapons firing tests on the NTS. Another would be alteration of natural drainage paths, resulting in potential preferential erosion of natural or fill deposits or deposition of sediments. Weapons-firing tests conducted on the NTS, primarily in Area 25, have contaminated relatively small areas of surface and near-surface geologic media. Lead and depleted uranium are the primary contaminants. Continued tests are assumed to have similar impacts as those in the past. Assuming that contaminants are long-lived, these media would be considered permanently lost either through closure in place or removal to a disposal facility. Removal of the contaminated media would make that surface temporarily vulnerable to erosion by water or wind processes.

Surface-based testing under the Work for Others Program might have negligible impacts on the surface water regime. Slight alterations in runoff and minor contributions of inorganic compounds and increased sediment yield might occur. Any such impacts would likely be very short-term and small-scale. Because of the very limited surface water flows and the limited extent of disturbances, significant impacts on the surface-water regime are not anticipated.

Other activities of the Work for Others Program could have a significant impact on surface waters of the NTS. Whether these activities have a significant impact is dependent on the sizes and locations of the activities, which are yet to be determined.

One potential impact would be contamination of surface waters resulting from weapons-firing tests on the NTS. Weapons-firing tests conducted on the NTS, primarily in Area 25, have contaminated relatively small areas of surface and near-surface geologic media. Lead and depleted uranium are the primary contaminants. Continued tests and military training activities are assumed to have similar impacts as in the past.

The water demand for the Work for Others Program has not been defined, but is expected to be minimal. The defense-related research and development activities would include the development of nonintrusive detection and imaging capabilities and surface-based testing. Small quantities of water (probably less than 1,233 m^3/r [1 acre-feet/year]) may be required to support personnel. The withdrawal of this quantity of water is not significant.

3.3.5.2 Alternative 2

Under Alternative 2 there would be no adverse impacts to the geologic media under the Work for Others Program.

3.3.5.3 Alternative 3

Under Alternative 3, the adverse impacts to geologic media discussed under the Work for Others Program in Alternative 1 would occur. Other specific actions that could adversely impact geologic media are associated with the demilitarization of conventional weapons.

3.3.5.4 Alternative 4

Work for Others Program activities are not anticipated to result in any adverse impacts to geologic media, processes, or resources beyond those from past activities as described in the Work for Others Program under Alternative 1. The water demand for the Work for Others Program under Alternative 4 would be reduced from Alternative 1. Because the demand for water would be insignificant, there are no significant impacts associated with groundwater withdrawals for the Work for Others Program.

3.3.6 Site-Support Actions

3.3.6.1 Alternative 1

Infrastructure and grading associated with disposal of bulk waste in Area 3 and containerized waste in Area 5 have further disturbed nearby surface and near-surface unconsolidated deposits, including soils. Continued aggregate use on the NTS for road and facility construction would result under Alternative 1. Aggregate excavated for site-support activities is considered to be permanently lost. Other geologic resources are not anticipated to be significantly impacted by site-support activities. Site-support structures (i.e., roads and buildings) could be removed, and the disturbed geologic media could be restored.

Surface water impacts from the siting of support infrastructure in certain areas would include the alteration of natural drainage paths, resulting in potential preferential erosion of natural or fill deposits, deposition of sediments, ponding of water, or inundation of infrastructure. Construction activities could result in some temporary impacts on surface water quality. Anticipated impacts include increases in sediment yield and perhaps in the loading of naturally occurring inorganic compounds (salts). Because of the very infrequent surface water flows, these impacts would likely be negligible and are not considered significant. Road building associated with well drilling and soil remediation might disturb significant areas of soils. However, because of the very limited nature of surface water resources on the NTS and other DOE-administered lands in Nevada, the impact on surface water flows is expected to be minimal.

The DOE monitored water withdrawals at the NTS for the periods between 1951 through 1990 (see Chapter 4). These records serve as the basis for predicting the demand for water for the period 1996 through 2005. Under Alternative 1, water use is expected to remain relatively stable because the activities included within the alternative are the same as those that have been conducted previously at the NTS. For the purpose of evaluating the environmental consequences of testing, the water-use rate for 1989 was assumed to be representative for active testing conditions. Water use for 1993 was assumed to be representative of the water demand to support nuclear testing readiness.

Because the water required to support the NTS is derived exclusively from groundwater, there would be some level of impacts on groundwater resources. Because the effects of groundwater withdrawals vary depending on the location, geologic conditions, and withdrawal rates, a more detailed evaluation is required.

The localized water-level declines in areas adjacent to operating water supply wells is not considered a significant impact. The impacts of water-level declines would not be considered significant unless water levels decline in areas off-site from the NTS or if the quantity of groundwater discharging from the NTS to downgradient areas would be diminished. The U.S. Geological Survey maintains a water-level monitoring network downgradient of the NTS. The water level in the Devils Hole well rose more than 1 m (3 ft) between the lowest recorded measurement in 1972 and the highest recorded measurement in 1993. Similarly, in the Point of Rocks south well, static water levels rose more than 22 m (72 ft) between the lowest recorded measurements in 1970 and 1994. These data and records for other monitoring wells in the region do not show any effects that might be attributed to water withdrawals on the NTS.

3.3.6.2 Alternative 2

Under Alternative 2, the demand for water resources would be significantly decreased to levels required for environmental monitoring and potable water supplies for a caretaker workforce. Water quality might be adversely impacted because of the cessation of waste management and restoration activities that protect the groundwater quality. This, in turn, might limit the availability of water for other uses.

3.3.6.3 Alternative 3

The impacts associated with site-support activities under Alternative 3 would be the same as those discussed under Alternative 1. Construction of new facilities could adversely impact the geologic media. Impact to geologic media is primarily from clearing of the site, construction of infrastructure, and excavation of aggregate.

The demand for water resources under Alternative 3 would increase for all programs on the NTS. The major demands would be the Defense Program and a Solar Enterprise Zone facility under the Nondefense Research and Development Program. As a result of the increased demand for water, the impacts for Alternative 3 would be the same as Alternative 1, plus the added effects of the new actions that would be included under Alternative 3. The additional demand for water under Alternative 3 includes 3.8×10^4 m^3/yr (31 acre-ft/yr) of potable water and 6.5×10^5 m^3/yr (525 acre-ft/yr) of nonpotable water. In total, the increase of 6.9×10^5 m^3/yr (556 acre-ft) is not a large quantity of water, and added impacts are not considered unless a large portion of that total is withdrawn from Yucca Flat. For Yucca Flat, any increases in groundwater withdrawals would add to the overdraft of groundwater (withdrawals in excess of the perennial yield) of that basin. In Yucca Flat, the total quantity of water needed would be quite small, a few thousands of cubic-meter (tens of acre-feet) at most.

3.3.6.4 Alternative 4

The impacts associated with site-support activities under Alternative 4 would be the same as those discussed under Alternative 3. The reduction in site support activities and personnel would result in an overall decrease in water demand. However, support activities for environmental restoration actions might offset this water demand reduction.

REFERENCES CITED

REGULATION, ORDER, LAW

10 CFR Part 1022 U.S. Department of Energy (DOE), "Energy: Compliance with Floodplain/ Wetlands Environmental Review Requirements," *Code of Federal Regulations*, Office of the Federal Register, National Archives and Records Administration, U.S. Government Printing Office, Washington, DC, 1995.

29 CFR Part 1910 U.S. Department of Labor, "Labor: Occupational Safety and Health Standards," *Code of Federal Regulations*, Office of the Federal Register, National Archives and Records Administration, U.S. Government Printing Office, Washington, DC, 1995.
29 CFR Part 1926

U.S. Department of Labor, "Labor: Occupational Safety and Health Administration," *Code of Federal Regulations*, Office of the Federal Register, National Archives and Records Administration, U.S. Government Printing Office, Washington, DC, 1993.

40 CFR Part 52 EPA, "Protection of the Environment: Approval and Promulgation of Implementation plans," *Code of Federal Regulations*, Office of the Federal Register, national Archives and Records Administration, U.S. Government Printing Office, Washington, DC, 1993.
40 CFR Part 81.329

Environmental Protection Agency (EPA), "Protection of the Environment: Attainment Status Designation for Nevada," *Code of Federal Regulations*, Office of the Federal Register, National Archives and Records Administration, U.S. Government Printing Office, Washington, DC, 1995.
40 CFR Part 264

EPA, "Protection of the Environment: Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities," *Code of Federal Regulations*, Office of the Federal Register, National Archives and Records Administration, U.S. Government Printing Office, Washington, DC, 1993.

40 CFR Part 264.18 EPA, "Protection of the Environment: Containment and Detection of Release," *Code of Federal Regulations*, Office of the Federal Register, National Archives and Records Administration, U.S. Government Printing Office, Washington, DC, 1995.

40 CFR Part 264.193 EPA, "Protection of the Environment: Location Standards," *Code of Federal Regulations*, Office of the Federal Register, National Archives and Records Administration, U.S. Government Printing Office, Washington, DC, 1995.

40 CFR Part 270.14 EPA, "Protection of the Environment: Contents of Part B: General Requirements," C...

44 CFR Part 9 Federal Emergency Management Agency (FEMA), Emergencies Management and Assistance: Floodplain Management and Protection of Wetlands," *Code of Federal Regulations*, Office of the Federal Register, National Archives and Records Administration, U.S. Government Printing Office, Washington, DC, 1995.

44 CFR Part 65 FEMA, "Emergencies Management and Assistance: Identification and Mapping of Special Hazard Areas," *Code of Federal Regulations*, Office of the Federal Register, National Archives and Records Administration, U.S. Government Printing Office, Washington, DC, 1994.
50 CFR Parts 17.11 & 17.12

DOE Order 5400.1 DOE, "General Environmental Protection," Washington, DC, 1988.

DOE Order 5400.5 DOE, "Radiation Protection of the Public and Environment," Washington, DC, 1993.

DOE Order 5480.1B DOE, "Environmental Safety and Health Program for Department of Energy Operations," Washington DC, 1986.

DOE, "Nuclear Safety Analysis Reports," Washington, DC, 1992.

DOE Order 5480.28 DOE, "Natural Phenomena Hazards Mitigation," Washington, DC, 1993.

DOE (U.S. Department of Energy), "Radiological Protection for DOE Activities," Washington, DC, 1995.

Executive Order, *Floodplain Management*, Office of the President, Washington, DC, 1977.
EO 11990

Executive Order, *Protection of Wetlands*, Office of the President, Washington, DC, 1977.
EO 12898

DOE, "DOE Standard National Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities," Washington, DC, 1994.

GENERAL

Anderson, J.G., J.N. Brune, D. dePolo, J. Gomberg, S.C. Harmsen, M.K. Savage, A.F. Sheehan, and K.D. Smith, "Preliminary Report: The Little Skull Mountain Earthquake, June 29, 1992," in *Proceedings of Symposium on Dynamic Analysis and Design Considerations for High-Level Nuclear Waste Repositories*, American Society of Civil Engineers, pp. 162-175, 1993.

Armstrong, R. L., "Sevier Orogenic Belt in Nevada and Utah," *Geological Society of America Bulletin*, Vol. 79, No. 4, pp. 429-458, 1968.

Avon, L., and T.J. Durbin, *Hydrologic Evaluation of Recent Water - Level Decline at Devils Hole*, Report No. 2, Las Vegas Valley Water District, Las Vegas, NV, 1994.

BLM, 1979 Bureau of Land Management, *Final Environmental Impact Statement: Proposed Public Land Withdrawal: Nellis Air Force Bombing Range: Nye, Clark and Lincoln Counties, NV*, U.S. Department of Interior, Washington, DC, 1979.

BLM, 1992 Bureau of Land Management, *Draft Stateline Resource Management Plan and Environmental Impact Statement*, U.S. Department of Interior, Las Vegas, NV, 1992.

BLM 1993, Bureau of Land Management, *Draft Tonopah Resource Management Plan and Environmental Impact Statement*, U.S. Department of Interior, Las Vegas, NV, 1993.

| Bates, R.L., and J.A. Jackson, (eds.), *Glossary of Geology*, 3rd Edition, American Geological Institute, Alexandria, VA, 1987.

Benjamin, T.M., 1995, Memorandum from T.M. Benjamin to M. Pankratz, "Selected NTS Underground Inventory Data," June 23, 1995.

| Borg, I.Y., R. Stone, H.B. Levy, and L.D. Ramspott, *Information Pertinent to the Migration of Radionuclides in Ground Water at the Nevada Test Site, Part 1: Review and Analysis of Existing Information*, UCRL-52078 Pt. 1, Lawrence Livermore National Laboratory, Livermore, CA, 1976.

Bradshaw, T.K., and I.I. Smith, *Polygenetic Quaternary volcanism in Crater Flat, Nevada, Journal of Volcanology and Geothermal Research*, v. 63, p. 165-182, 1994.

Bryant, E.A., *The Cambric Migration Experiment, A Summary Report, LA-12335-MS*, Los Alamos National Laboratory, Los Alamos, NM 1992.

Bryant, E. A., and J. Fabryka-Martin, *Survey of Hazardous Material Used in Nuclear Testing*, LA-12014-MS, Los Alamos National Laboratory, Los Alamos, NM, 1991.

Byers Jr., F.M., W.J. Carr, P.P. Orkild, W.D. Quinlivan, and K.A. Sargent, *Volcanic Suites and Related Cauldrons of the Timber Mountain-Oasis Valley Caldera Complex, Southern Nevada*, Professional Paper 919, U.S. Geological Survey, Washington, DC, 1976.

Byers Jr., F.M.,, W.J. Carr, and P.P. Orkild, "Volcanic Centers of Southwestern Nevada: Evolution of Understanding, 1960-1988," *Journal of Geophysical Research*, Vol. 94, No. B5, pp. 5908-5924, 1989.

Carr, W.J., *Summary of Tectonic and Structural Evidence for Stress Orientation at the Nevada Test Site*, USGS-OFR-74-176, Open-File Report, U.S. Geological Survey, Denver, CO, 1974.

Chapman, J.B., and B.F. Lyles, *Groundwater Chemistry at the Nevada Test Site: Data and Preliminary Interpretations*, DOE/NV/10845-16, Desert Research Institute, Water Resources Center, Las Vegas, NV, 1993.

Chapman, J.B., *Classification of Groundwater at the Nevada Test Site*, DOE/NV/10384-28, Water Resources Center,
| Desert Research Institute, Las Vegas, NV, 1994.

Christiansen, R.L., and P.W. Lipman,"Cenozoic Volcanism and Plate-Tectonics Evolution of the Western United States; Part II, Late Cenozoic," *Philosophical Transactions of the Royal Society of London*, Ser. A, Vol. 271, pp. 249-284, 1972.

Clary, S.L., D.R. McClary, R. Whitney, and D.D. Reeves, *Water Resources Data Nevada, Water Year 1994*, U.S. Geological Survey Water-Data Report NV-94-1, 1995.

Cole, J.C., R.R. Wahl, and M.R. Hudson,"Structural Relations Within the Paleozoic Basement of the Mine Mountain Block; Implications for Interpretation of Gravity Data in Yucca Flat, Nevada Test Site," in *Proceedings from the Fifth Symposium on Containment of Underground Nuclear Explosions, held on September 19-21, 1989 at Santa Barbara, CA*, CONF-8909163, Vol. 2., pp. 431-456, 1989.

Cole, J.C., A.G. Harris, M.R. Lanphere, C.E. Barker, and R.G. Warren, "The Case for Pre-middle Cretaceous Extensional Faulting in Northern Yucca Flat, Southwestern Nevada," *Geological Society of America Abstracts with Programs*, Vol. 25, No. 5, p. 22, 1993.

Connor, C.B., and B.E. Hill, *Estimating the probability of volcanic disruption of the candidate Yucca Mountain Repository using spatially and temporally nonhomogeneous Poisson models: American Nuclear Society Focus '93*, 1994.

Crowe, B.M., *Study Plan for Characterization of Volcanic Features*, LA-SP-8.3.1.8.5.1, Los Alamos National Laboratory, Los Alamos, NM, 1993.

Crowe, B.M., K.H. Wohletz, D.T. Vaniman, E. Gladney, and N. Bower, *Status of Volcanic Hazard Studies for the Nevada Nuclear Waste Storage Investigations*, LA-9325-MS, Vol. II, Los Alamos National Laboratory, Los Alamos, NM, 1986.

D'Agnese, F.A. *Using Geoscientific Information Systems for Three-Dimensional Modeling of Regional Ground-Water Flow Systems, Death Valley Region, Nevada and California.* Unpublished PhD. Dissertation, Colorado School of Mines, 1994.

Davisson, M.L., J.M. Kenneally, D.K. Smith, G.B. Hudson, G.J. Nimz, and J.H. Rego, *Preliminary Report on the Isotope Hydrology Investigations at the Nevada Test Site: Hydrologic Resources Management Program, FY 1992-1993*, Lawrence Livermore National Laboratory, January, 1994.

DOE, *Environmental Assessment, Yucca Mountain Site, Nevada Research and Development Area, Nevada*, Volumes 1, 2, and 3, DOE/RW-0073, Office of Civilian Radioactive Waste Management, Washington, DC, 1986.

DOE, *Site Characterization Plan, Yucca Mountain Site, Nevada Research and Development Area, Nevada*, Volumes 1 and 2. DOE/RW-0199, Office of Civilian Radioactive Waste Management, Washington, DC, 1988.

DOE, *Environmental Restoration Sites Inventory, 1994 Annual Status Report, Draft*, DOE/NV-UC700, Vols, I, II, III, and IV, Las Vegas, NV, 1994.

DOE, *Environmental Assessment for Solid Waste Disposal,* Pre-Approval Draft, U.S. Department of Energy, Nevada Operations Office, Las Vegas, NV, 1995.

U.S. Department of Energy, Nevada Operations Office (DOE/NV), *Annual Site Environmental Report, 1990*, Vols. I and II, DOE/NV/10630-2, Reynolds Electrical & Engineering Co., Inc., Las Vegas, NV, 1991.

DOE/NV, *Environmental Assessment for the Groundwater Characterization Project, Nevada Test Site, Nye County, Nevada,* Las Vegas, NV, 1992.

DOE/NV, 1992b, *Annual Site Environmental Report , 1991,* Vols. I and II, DOE/NV/10630-33, Reynolds Electrical & Engineering Co., Inc., Las Vegas, NV, 1992.

DOE/NV, 1993, *Annual Site Environmental Report - 1992, Vols. I and II,* DOE/NV/10630-66, Las Vegas, NV, 1993.

DOE/NV, 1994a *Annual Site Environmental Report*, 1993 DOE/NV/11432-123, Vols. I and II, Las Vegas, NV, 1994.

DOE/NV, 1994b, *Nevada Solar Enterprise Zone Development Study*, prepared by Nevada Solar Enterprise Zone Task Force Work Group and DynCorp-Meridan, U.S. Department of Energy, Nevada Operations Office, Las Vegas, NV, 1994.

DOE/NV, 1995a, U.S. Department of Energy, Nevada Operations Office, *Underground Test Area Operable Unit Work Plan, Nevada Test Site, Nevada,* DOE/NV--389 UC-700, Las Vegas, NV, February 1995.

DOE/NV, 1995b Annual Site Environmental Report , 1994, Vols. I and II, DOE/NV/11432-175, Reynolds Electrical & Engineering Co., Inc., Las Vegas, NV, 1995.

Desert Research Institute (DRI), *CERCLA Preliminary Assessment of DOE's Nevada Operations Office Nuclear Weapons Testing Areas,* Volumes 1 and 2, Water Resources Center, Desert Research Institute, Las Vegas, NV, 1988.

D'Azevedo, W.L., (eds), *Great Basin*, Volume II, Smithsonian Institution, Washington, DC, 1986.

Dudley, W.W., Jr., and J.D. Larson, *Effect of Irrigation Pumping on Desert Pupfish Habitats in Ash Meadows, Nye County, Nevada,* U.S. Geological Survey Professional Paper 927, U.S. Government Printing Office, Washington, DC, 1976.

Dunaway, P.B., and M.G. White (Eds), *The Dynamics of Plutonium in Desert Environments,* NVO-142, U.S. Energy Research and Development Administration, Nevada Operations Office, Las Vegas, NV, 1974.

ERDA, 1977 U.S. Energy Research and Development Administration (ERDA), *Final Environmental Impact Statement, Nevada Test Site, Nye County, Nevada,* ERDA-1551, Las Vegas, NV, 1977.

Essington, E.H., 1987, "Soil Radionuclide Distribution Studies for the Nevada Applied Ecology Group--1981," in: W.A. Howard and R.G. Fuller, Eds., U.S. Department of Energy, *The Dynamics of Transuranics and Other Radionuclides in natural Environments,* NVO-272, Las Vegas, NV, pp. 123-195, 1987.

Faults, J.E., J.W. Bell, D.L. Feuerbach, and A. R. Ramelli, *Geologic map of the Crater Flats area, Nevada: Nevada Bureau of Mines and Geology Map 101*, 1994.

Faunt, C.C., *Characterization of the Three-Dimensional Hydrogeologic Framework of the Death Valley Region, Nevada and California,* unpublished PhD. Dissertation, Colorado School of Mines, 1994.

Ferguson, J.F., A.H. Cogbill, and R.G. Warren, "A Geophysical-Geological Transect of the Silent Canyon Caldera Complex, Pahute Mesa, Nevada," *Journal of Geophysical Research*, Vol. 99, No. B3, pp. 4323-4339, 1994.
Fiero, B., *Geology of the Great Basin, Reno*, University of Nevada Press, Reno, NV, 1986.

Francis, C.W., "Plutonium Mobility in Soil and Uptake in Plants: A Review," *Journal of Environmental Quality*, pp. 67-70, 1973.

French, R.H., A. Elzeftawy, J. Bird, and B. Elliot, *Hydrology and Water Resources Overview for the Nevada Nuclear Waste Storage Investigations, Nevada Test Site, Nye County, Nevada,* NVO-284, Desert Research Institute, Las Vegas, NV, 1984.

Frizzell, Jr., V.A., and J. Schulters, *Geologic Map of the Nevada Test Site, Southern Nevada,* Miscellaneous Investigations Series Map I-2046, Scale 1:100,000, U.S. Geological Survey, Denver, CO, 1990.

Garside, L.J., R.H. Hess, K.L. Fleming, and B.S. Weimer, *Oil and Gas Developments in Nevada,* Nevada Bureau of Mines and Geology Bulletin 104, University of Nevada, Reno, NV, 1988.

Giampaoli, M.E., *Trip Report: Hydrologic Field Reconnaissance Led by Robert Coache, Water Resources Division*, April 24, 1986, M86-GEO-MEG-054, Science Applications International Corporation, Las Vegas, NV, 1986.

Gilbert, R.O., J.H. Shinn, E.H. Essington, T. Tamura, E.M. Romney, K.S. Moor, and T.P. O'Farrell, "Radionuclide Transport from Soil to Air, Native Vegetation, Kangaroo Rats and Grazing Cattle on the Nevada Test Site," *Health Physics*, Vol. 55:869-887, 1988.

Glasstone, S. (ed.), *The Effects of Nuclear Weapons*, Revised Edition, U.S. Department of Defense, U.S. Atomic Energy Commission, Washington, DC, 1962.

Glasstone, S., and P.J. Dolan, *The Effects of Nuclear* Weapons, Third Edition, U.S. Department of Defense and U.S. Department of Energy, Washington, DC, 1977.

Goishi, W., B.K. Esser, J. W. Meadows, N. Naboodiri, D. K. Smith, J.F. Wild, S.M. Bowen, P.L. Baca, L.F. Olivas, C.G. Geoffrion, J. L. Thompson, C.M. Miller, *Total Radionuclide Inventory Associated with Underground Nuclear Tests Conducted at the Nevada Test Site, 1955-1992 (U)*, LA-CP-94-0222, Los Alamos National Laboratory, 1995.

Grayson, D.K., *The Desert's Pas, A Natural Prehistory of the Great Basin*, Smithsonian Institution Press, Washington, DC, 1993

Grow, J.S., C.A. Barker, and A.G. Harris, "Oil and Gas Exploration near Yucca Mountain, Southern Nevada, High-Level Radioactive Waste Management," in *Proceedings of the Fifth International Conference, Las Vegas, NV, May 11-16, 1994*, pp. 1298-1315, 1994.

Guth, P.L., "Tertiary Extension North of the Las Vegas Valley Shear Zone, Sheep and Desert Ranges, Clark County, Nevada," *Geological Society of America Bulletin*, Part I, Vol. 92, No. 10, pp. 763-771, 1981.

Hamilton, W.B., *Detachment Faulting in the Death Valley Region, California and Nevada, Geologic and Hydrologic Investigations of a Potential Nuclear Waste Disposal Site at Yucca Mountain, Southern Nevada*, M.D. Carr, and J.C. Yount (eds.), U.S. Geological Survey Bulletin 1790, U.S. Government Printing Office, Washington, DC, 1988.

Harrill, J.R., J.S. Gates, and J.M. Thomas, *Major Ground-Water Flow Systems in the Great Basin Region of Nevada, Utah and Adjacent States*, Hydrological Investigations Atlas HA-694-C Scale 1:1,000,000, U.S. Geological Survey, Denver, CO, 1988.

Harry Reid Center for Environmental Studies and Professional Analysis, Inc., *Preliminary Assessment of Geothermal Potential, Nevada Test Site, Nye County, Nevada*, Prepared for: U.S. Department of Energy, Las Vegas, NV, December 1994.

Harris, A.G., B.R. Wardlaw, C.C. Rust, and G.K. Merril, *Maps for Assessing Thermal Maturity Conodont Color Alteration Index Maps, in Ordovician through Triassic Rocks in Nevada, Utah and Adjacent parts of Idaho and California*, Miscellaneous Investigations Series Map I-1249, U.S. Geological Survey, Denver, CO., 1980.

Hawkins and Kunkle, 1996a, Personal communication from W.L. Hawkins and T.D. Kunkle to R. Papazian dated January 19, 1996, the subject of cavity collapse and the subsequent overburden subsidence, Los Alamos, NM, 1996.

Hawkins and Kunkle, 1996b, Memorandum from Hawkins, W.L. and T.D. Kunkle to R. Papazian on Cavity Collapse and Overburden Subsidence, January 12, 1996.

Hess, R., and D. Davis, *Oil and Gas Wells Drilled in Nevada Since 1986*, Nevada Bureau of Mines, Reno, NV, 1995.

Ho, C.H., E.I. Smith, D.L. Feuerbach, and T.R. Naumann, *Eruptive probability calculation for the Yucca Mountain site, USA, Statistical estimation of recurrence rates, Bulletin of Volcanology*, v.54, pp. 50-56, 1991.

Ho, D.M., R.L. Sayre, C.L. Wu, *Suitability of Natural Soils for Foundations for Surface Facilities at the Prospective Yucca Mountain Nuclear Waste Repository*, Bechtel National, Inc., SAND 85-7107, San Francisco, CA, for Sandia Laboratories, Albuquerque, NM, 1986.

Hodges, K.V., and J.D. Walker, "Extension of the Cretaceous Sevier Orogeny, North America Cordillera," *Geological Society of America*, Vol. 104, pp. 560-569, 1992.

Houser, F.N., "Application of Geology to Underground Nuclear Testing, Nevada Test Site," Memoir 110, *The Geological Society of America, Inc.*, Boulder, CO, pp. 21-34, 1968.

Howard, W.A., and R.G. Fuller (eds), *The Dynamics of Transuranics and Other Radionuclides in Natural Environments*, NVO-272, U.S. Department of Energy, Nevada Operations Office, Las Vegas, NV, 1987.

Humphrey, F.L., "Geology of the Groom District, Lincoln County, Nevada," *University of Nevada Bulletin 42*, Nevada State Bureau of Mines, Reno, NV, 1945.

Hunt, C.B., *Natural Regions of the United States and Canada*, W. H. Freeman & Co., San Francisco, CA, 1974.

King, J.M., Computing Drawdown Distributions Using Microcomputers, Ground Water, Vol. 22, No. 6., pp.780-784, 1984.

Kleinhampl, F.J., and J.I. Ziony, *Mineral Resources of Northern Nye County, Nevada*, Nevada Bureau of Mines and Geology Bulletin 99B, University of Nevada, Reno, NV, 1984.

Laczniak, R.L., J.C. Cole, D.A. Sawyer, and D.A. Trudeau, *Hydrogeologic Controls on the Movement of Ground Water at the Nevada Test site, Nye County, Nevada -- A Summary Description for Environmental Restoration*, Draft [illegible]

Minor, S.A., D.A. Sawyer, R.R. Wahl, V.A. Frizzell, Jr., S.P. Schilling, R.G. Warren, P.P. Orkild, J.A. Coe, M.R. Hudson, R.J. Fleck, M.A. Lamphere, W. C. Swadley, and J.C. Cole, *Preliminary Geological Map of the Pahute Mesa 30' x 60' Quadrangle, Nevada*, OFR-93-299, Open File Report, U.S. Geological Survey, Denver, CO, 1993.

Moore, J.E., *Records of Wells, Test Holes, and Springs in the Nevada Test Site and Surrounding Area*, USGS-TEI-781, Trace Elements Investigations Report, U.S. Geological Survey, 1961.

Nevada Administrative Code (NAC), "Sanitation: Facilities for the Management of Hazardous Waste," Section 444.8456, Bureau of National Affairs, Washington, DC, 1992.

Nimz, G.J. and J.L. Thompson, *Underground Radionuclide Migration at the Nevada Test Site*, DOE/NV-346, Reynolds Electrical & Engineering Co., Inc., Las Vegas, NV, 1992.

Office of Technology Assessment (OTA), *The Containment of Underground Nuclear Explosions*, OTA-ISC-414, U.S. Congress, Washington, DC, 1989.

PAL Consultants, Inc., A Conceptual Model of the Death Valley Ground-Water Flow System, Nevada and California: Prepared for U.S. Department of Interior, National Park Service, 1995.

Pearl, R., Personal communication dated October 21, 1994, from R. Pearl, U.S. Department of Energy, Las Vegas, NV, to Beth Moore, GeoTrans, Inc., Las Vegas, NV, regarding summary water well information and water chemistry data for 1993, for Nevada Test Site wells, 1994.

Poole, F.G., and C.A. Sandberg, "Mississippian Paleography and Conodont Biostratigraphy of the Western United States," in *Paleozoic, Paleogeography of the Western United States-II: Pacific Section, Society of Economic Paleontologists and Mineralogists*, J.D. Cooper, and C.H. Stephens, (eds.), Vol. 67, pp. 107-136, 1991.

Price, K.R. "A Review of Transuranic Elements in Soils, Plants and Animals," *Journal of Environmental Quality*, pp. 62-66, 1973.

Quade, J., and J.V. Tingley, *A Mineral Inventory of the Nevada Test Site, and Portions of Nellis Bombing and Gunnery Range, Southern Nye County, Nevada*, DOE/NV/10295-1, U.S. Department of Energy, Nevada Operations Office, Las Vegas, NV, 1983.

Quiring, R.F., *Climatological Data, Nevada Test Site and Nuclear Rocket Development Station*, ESSA Technical Memorandum ARL-7, Environmental Sciences Service Administration, U.S. Department of Commerce, Las Vegas, NV, 1968.

Reynolds Electrical & Engineering Co., Inc. (REECo), *Environmental Monitoring Plan Nevada Test Site and Support Facilities, Volumes I and II*, DOE/NV/10630-28, Reynolds Electrical & Engineering Co., Inc., Las Vegas, NV, 1991.

REECo, *Contaminated Areas Report*, Reynolds Electrical & Engineering, Co.,Inc., Las Vegas, NV, 1992.

Rogers, A.M., S.C. Harmsen, and M.E. Meremonte, *Evaluation of the Seismicity of the Southern Great Basin and Its Relationship to the Tectonic Framework of the Region*, USGS-OFR-87-408, draft, Open-File Report, U.S. Geological Survey, Denver, CO, 1987.

Rogers, A.R., C. Harmsen, E.J. Corbett, K. Priestly, and D. de Polo, *The Seismicity of Nevada and Some Adjacent Parts of the Great Basin*, Geological Society of America, 1991.

Romney, E.M., V.Q. Vale, A. Wallace, O.R. Lunt, J.D. Childress, H. Kaaz, and G.V. Alexander, *Some* [illegible]

Romney, W.M., A. Wallace, R.O. Gilbert, and J.E. Kinnear, "239-240 Pu and 241 Am Contamination of Vegetation in Aged Plutonium Fallout Areas," in *The Radioecology of Plutonium and Other Transuranics in Desert Environments,* NVO-153: 43-88, U.S. Department of Energy, Las Vegas, NV, 1975.

Romney, E.M., "Plutonium Contamination of Vegetation in Dusty Field Environments," in *Transuranics in Natural Environments*, M.G. White and P.B. Dunaway, (eds), U.S. Atomic Energy Commission, NVO-178:287-302, Washington, DC, 1977.

Raytheon Services Nevada (RSN), *FY 1994, Nevada Test Site Technical Site Information, Vol I and II*, prepared by Raytheon Services Nevada, U.S. Department of Energy, Nevada Operations Office, Las Vegas, NV, 1994.

Rush, F.E., *Regional Ground-Water Systems in the Nevada Test Site area, Nye, Lincoln, and Clark Counties, Nevada*, Water Resources - Reconnaissance Series, Report No. 54, State of Nevada, Department of Conservation and Natural Resources, Carson City, NV, 1970.

Russell, G., Letter dated January 26, 1994 from G. Russell, U.S. Geological Survey, Las Vegas, NV, to Douglas Duncan, U.S. Department of Energy, Las Vegas, NV, regarding hydrologic data collection program, 1994.

Science Applications International Corporation/Desert Research Institute (SAIC/DRI), *Special Nevada Report*, U.S. Air Force, Tactical Weapons Center, Office of Public Affairs, Nellis Air Force Base, Las Vegas, NV, 1991.

Sawyer, D.A., R.J. Fleck, M.A. Lanphere, R.G. Warren, and D.A. Broxton, "Episodic Volcanism in the Southwest Nevada Volcanic Field: New $^{40}Ar/^{39}Ar$ Geochronologic Results," *EOS Transactions, AGU*, Vol. 71, No. 43, pp. 1290 and 1296, 1990.

Schaller, F.W. and P. Sutton, *Reclamation of Drastically Disturbed Lands*. American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Madison, WI, 1978.

Schmeltzer et al., 1993a, Schmeltzer, J.S., J.J. Miller, and D.L. Gustafson, "Flood Assessment at Low-level

Thordarson, W., *Geohydrologic Data and Test Results from Well J-13, Nevada Test Site, Nye County, Nevada: U.S. Geological Survey Water-Resources Investigations Report 83-4171*, p. 57, 1983.

Tyler, S.W., W.A. McKay, J.W. Hess, R.L. Jacobson, and K. Taylor, *Effects of Surface Collapse Structures on Infiltration and Moisture Redistribution*, Desert Research Center, Water Resources Center, DOE/NV/10384-04.

Vortman, L.J., *Prediction of Ground Motion from Nuclear Weapons Tests at NTS*, SAND79-1002, Sandia National Laboratories, Albuquerque, NM, 1979.

Vortman, L.J., *An Evaluation of the Seismicity of the Nevada Test Site and Vicinity*, SAND86-7006, Sandia National Laboratories, Albuquerque, NM, 1991.

Vortman, L.J. and J.W. Long, *Effects of Repository Depth on Ground Motion—The Pahute Mesa Data*, SAND82-0174, Sandia National Laboratories, Albuquerque, NM, 1982.

Vortman, LJ. and J. W. Long, 1982b. *Effects of Ground Motion on Repository Depth, The Yucca Flat Data*, SAND82-1647, Sandia National Laboratories, Albuquerque, NM., 1982.

Waddell, R.K., *Two-Dimensional, Steady-State Model of Ground-Water Flow, Nevada Test Site and Vicinity, Nevada-California*, USGS-WRI-82-4085, Water-Resources Investigations Report, U.S. Geological Survey, 1982.

Waddell, R.K., J.H. Robinson, and R.K. Blankennagel, *Hydrology of Yucca Mountain and Vicinity, Nevada - California - Investigative Results Through Mid-1983*, USGS-WRI-84-4267, Water-Resources Investigations Report, U.S. Geological Survey, Denver, CO, 1984.

Warren, R.G., D.A. Sawyer, and H.R. Covington, "Revised Volcanic Stratigraphy of the Southwestern Nevada Volcanic Field," in *Proceedings from the Fifth Symposium on Containment of Underground Nuclear Explosives, held on September 19-21, 1989 in Santa Barbara, California*, CONF-8909163, Vol. 2, p. 387, Lawrence Livermore National Laboratory, Livermore, CA, 1989.

Webb, R.H. and H.G. Wilshire, "Recovery of Soils and Vegetation in a Mojave Desert Ghost Town, Nevada, U.S.A," *Journal of Arid Environments*, 3:291-303, 1980.

Wells, S.G., L.D. McFadden, C.E. Renault, and B.M. Crowe, v. 18, p. 549-553.

Wernicke, B., G.J. Aden, and J.K. Snow, "Basin and Range Extensional Tectonics at the Latitude of Las Vegas," *Geologic Society of America Bulletin*, Vol. 100, pp. 1738-1757, 1988.

White, M.G., and P.B. Dunaway (eds), *The Radioecology of Plutonium and Other Transuranics in Desert Environments*, NVO-153, U.S. Energy Research and Development Administration, Nevada Operations Office, Las Vegas, NV, 1975.

White, M.G., and P.B. Dunaway (eds), *Studies of Environmental Plutonium and Other Transuranics in Desert Ecosystems*, NVO-159, U.S. Energy Research and Development Administration, Nevada Operations Office, Las Vegas, NV, 1976.

White, M.G., and P.B. Dunaway (eds), *Transuranics in Natural Environments*, NVO-178, U.S. Energy Research and Development Administration, Nevada Applied Ecology Group, Las Vegas, NV, 1977.

White, M.G., P.B. Dunaway, and D.L. Wireman (eds), *Transuranics in Desert Ecosystems*, NVO-181, U.S. Department of Energy, Nevada Operations Office, Las Vegas, NV, 1977.

White, M.G., P.B. Dunaway, and W.A. Howard (eds), *Environmental Plutonium on the Nevada Test Site Environs*. NVO-171, U.S. Energy Research and Development Administration, Nevada Applied Ecology Group, Las Vegas, NV, 1977.

Winograd, I.J., and W. Thordarson, *Hydrogeologic and Hydrochemical Framework, South-Central Great Basin, Nevada-California, with Special Reference to the Nevada Test Site*, Professional Paper 712-C, U.S. Geological Survey, Washington, DC, 1975.

Wood, D.B., Letter dated June 8, 1994 from David B. Wood, U.S. Department of the Interior, U.S. Geological Survey to John Eberlin, IT Corp., regarding groundwater withdrawal data, Las Vegas, NV, 1994.

Young, R.A., *Water Supply for Nuclear Rocket Development Station at the U.S. Atomic Energy Commission's Nevada Test Site*, U.S. Geological Survey Water-Supply Paper 1938, 1972.

505

APPENDIX

ASSESSMENT OF GROUNDWATER RESOURCES IN SUPPORT OF THE ENVIRONMENTAL IMPACT STATEMENT

Prepared by

Chuck Russell

July 14, 1995

CONTENTS

FIGURES

TABLES

INTRODUCTION

Groundwater beneath the Nevada Test Site (NTS) represents a vast and relatively under utilized resource. Future activities to be conducted on the NTS may require large quantities of ground water. The quantity of water available in the basins beneath the NTS has been determined by the State of Nevada's Division of Water Resources' State Engineers' Office. Utilization of this resource will require the identification of aquifers capable of sustaining discharge at a rate less than or equal to the perennial yield of the basin. Perennial yield is defined as the amount of groundwater which can be removed from a basin each year without depleting the groundwater reservoir.

This report documents efforts to evaluate the most productive aquifer in each hydrographic basin on the NTS in terms of that aquifers capability to sustain yields of groundwater in quantities equal to the perennial yield of the basin. In addition, a limited effort is made to determine if well fields pumping this groundwater are at risk from contaminant migration from nearby facilities associated with underground nuclear testing.

ANALYTICAL SOLUTION

The groundwater resources for a given hydrographic basin were assessed through the use of analytical solutions solving for the drawdown of hypothetical well fields. Strack's (1989) two–dimensional analytical solutions for steady state flow were used to calculate discharge potential. The discharge potential (Φ) for horizontal confined conditions is defined as

$$\Phi = KH\mathit{\Phi} + C_c \quad (1)$$

and for unconfined flow is defined as

$$\Phi = 1/2\, K\mathit{\Phi}^2 + C_u \quad (2)$$

where

K = hydraulic conductivity
H = thickness of the confined aquifer
$\mathit{\Phi}$ = piezometric head
C_c = arbitrary constant for a confined aquifer
C_u = arbitrary constant for an unconfined aquifer

Discharge potentials were computed using Strack's (1989) analytical solutions as they are incorporated into the groundwater flow model Quickflow (Geraghty and Miller, Inc., 1991). Quickflow utilizes several of Strack's (1989) solutions to calculate the discharge potential at any given point. Two of these solutions were used in this modeling effort; the first equation modeled discharge potential created as a function of the regional gradient

$$\Phi(x,y) = -Q_o(x\cos a_u + y\sin a_u) + C \qquad (3)$$

where

Q_o = uniform two dimensional regional flow
x = x coordinate of calculation point
y = y coordinate of calculation point
α_u = angle between uniform flow and x axis
C = constant

and the second equation modeled discharge potential as a function of stress created by one or more pumped wells

$$\sum^{n}_{j=1} Q_j/4\pi(\ln[r^2_j(x,y)] \qquad (4)$$

where

Q_j = discharge of well j
r_j = discharge of well j
x = x coordinate of calculation point
y = y coordinate of calculation point.

The solutions of the two equations were summed at any given point and then converted to head.

ASSUMPTIONS AND LIMITATIONS

Several assumptions are inherent in Strack's solutions: aquifers have infinite extent, are homogeneous, isotropic, have a constant thickness with the underlying impermeable basement completely horizontal, uniform regional hydraulic gradient, horizontal laminar flow, and are fully penetrated by wells. All of the results for this modeling effort must be qualified by these assumption. During modeling, these assumptions were translated into the following boundary conditions: regional flow is uniform and unhampered by boundary conditions between and within each basin, recharge from precipitation does not occur, vertical flow does not occur, and leakage between aquifers and aquitards does not occur. The intent of this model is to determine if an idealized version of the most productive formation in each hydrographic basin is capable of sustaining groundwater production under steady–state conditions at rates specified by the State of Nevada's Division of Water Resources State Engineers' Office. It is not to determine the overall groundwater budget for any given basin. Any such attempt will require additional data collection and a much more intensive modeling effort using finite–difference or finite–element models.

APPLICATION OF MODEL TO HYDROGRAPHIC BASINS

The major hydrographic basins that underlie the Nevada Test Site consist of Frenchman Flat, Yucca Flat, Mercury Valley, Rock Valley, Jackass Flat, Buckboard Mesa, Oasis Valley, and Gold

Flat. Of these basins, the portions of Yucca Flat, Oasis Valley, and Gold Flat that are beneath the NTS have been the locations of a significant number of underground nuclear tests. For this reason, these hydrographic basin were excluded during this investigation. In addition, Mercury Valley is the most developed and one of the smallest, in areal extent, of the remaining basins. Additional development is unlikely, thus Mercury Valley was removed from further consideration. The remaining basins, Frenchman Flat, Rock Valley, Jackass Flat, and Buckboard Mesa were evaluated. The process of evaluation consisted of the compilation of existing geologic and hydrologic information. The information needed to conduct the analysis consisted of aquifer type, depth to aquifer top and bottom, effective porosity, regional flow direction, regional gradient, hydraulic conductivity, and static water level elevation. The information was gleaned from a variety of sources for each of the modeled basins. The next step was to determine the perennial yield of the valley and to design a hypothetical well field that could sustain this level of groundwater production without substantially dewatering the aquifer.

BUCKBOARD MESA

The State Engineers' Office has determined that there is 4,000 acre–feet of groundwater available for withdrawal on an annual basis from the Buckboard Mesa hydrographic basin. The Buckboard Mesa hydrographic basin is bounded on the east by Rainier Mesa and the Eleana Range, to the west by Timber Mountain, to the north by Pahute Mesa and to the south by Forty Mile Canyon. The majority of the basin is underlain by the Timber Mountain/Silent Canyon Caldera Complex. Formations that have been shown to be fairly good aquifers within the calderas are the rhyolitic lavas and welded tuffs (Blankennagel and Wier, 1973) and the intercaldera nonwelded deposits (unpublished data of groundwater production during drilling at well ER–30–1). The saturated intracaldera fill deposits in the Timber Mountain Moat were chosen due to their large areal extent (Byers, *et al.*, 1976) and lack of underground testing that has been conducted in or near the areas where this aquifer is saturated.

The data type, values, and sources of the data used in the model are listed in Table 1. Base maps of the area were digitized and transferred into Quickflow. The base maps were used to locate all wells. Aquifer data, regional flow gradients and directions, and pump rates were manually entered into Quickflow and a solution was determined. The results are presented in Figures 1 and 2. Figure 1 presents the NTS administrative boundaries, roads, the well 8, the five wells that compose the hypothetical well–field for Buckboard Mesa, and the idealized regional gradient of the area. Well 8, 20, and u19c are located in the Timber Mountain hydrographic basin and have been pumped historically at a rate of 1100 gpm (Witherill, 1986), accounting for 1774 acre–ft per year of the basins total allotment of 4000 acre–ft per year. It is assumed that these wells will be used in any future groundwater development schemes. These three wells produce water from the welded tuff/lava flow aquifers, but for the purpose of this study are assumed to produce water from the intracaldera fill deposits. Wells U19c and Well 20, although in the hydrographic basin, are so distant as to include in model results and are not shown for that reason.

Table 1. Data used to Model Hypothetical Well Field in Buckboard Mesa Hydrographic Basin

Data Type	Value	Source
Basins perennial yield	4000 acre–ft/yr	State of Nevada, 1971
Regional flow direction	South by southwest	Wadell, Robison, and Blankennagel, 1984
Regional flow gradient	3.6×10^{-3}	Calculated from Static water level at UE–18t (Byers and Hawkins, 1981) and ER–30–1 (IT Corp, 1995)
Aquifer	tuffaceous gravelly sand and bedded tuff	IT Corp, unpulished logs of ER–30–1
Aquifer thickness	240'	IT Corp, unpublished logs of ER–30–1
Hydraulic conductivity	4.1 gpd/ft^2 (0.62 ft/d)	Winograd and Thordarson, 1975, pg C–36
Effective porosity	30%	Assumed based upon Winograd and Thordarson, 1975, pg C–36
Well field assumptions	5 wells each pumping 500 gpm full–time year around	Assumption
Well field locations	Well Name / Coordinates / Pump Rate W1 865050 603300 276 gpm W2 857500 610000 276 gpm W3 849100 609100 276 gpm W4 840000 610000 276 gpm W5 830900 607500 276 gpm	Assumption
Aquifer condition	Unconfined and in equilibrium with stresses	Assumption
Pumping rates of pre–existent wells	Well 8 – 400 gpm Well 20 – 340 gpm Well U19c 360 gpm	Witherill, 1986 Witherill, 1986 Witherill, 1986

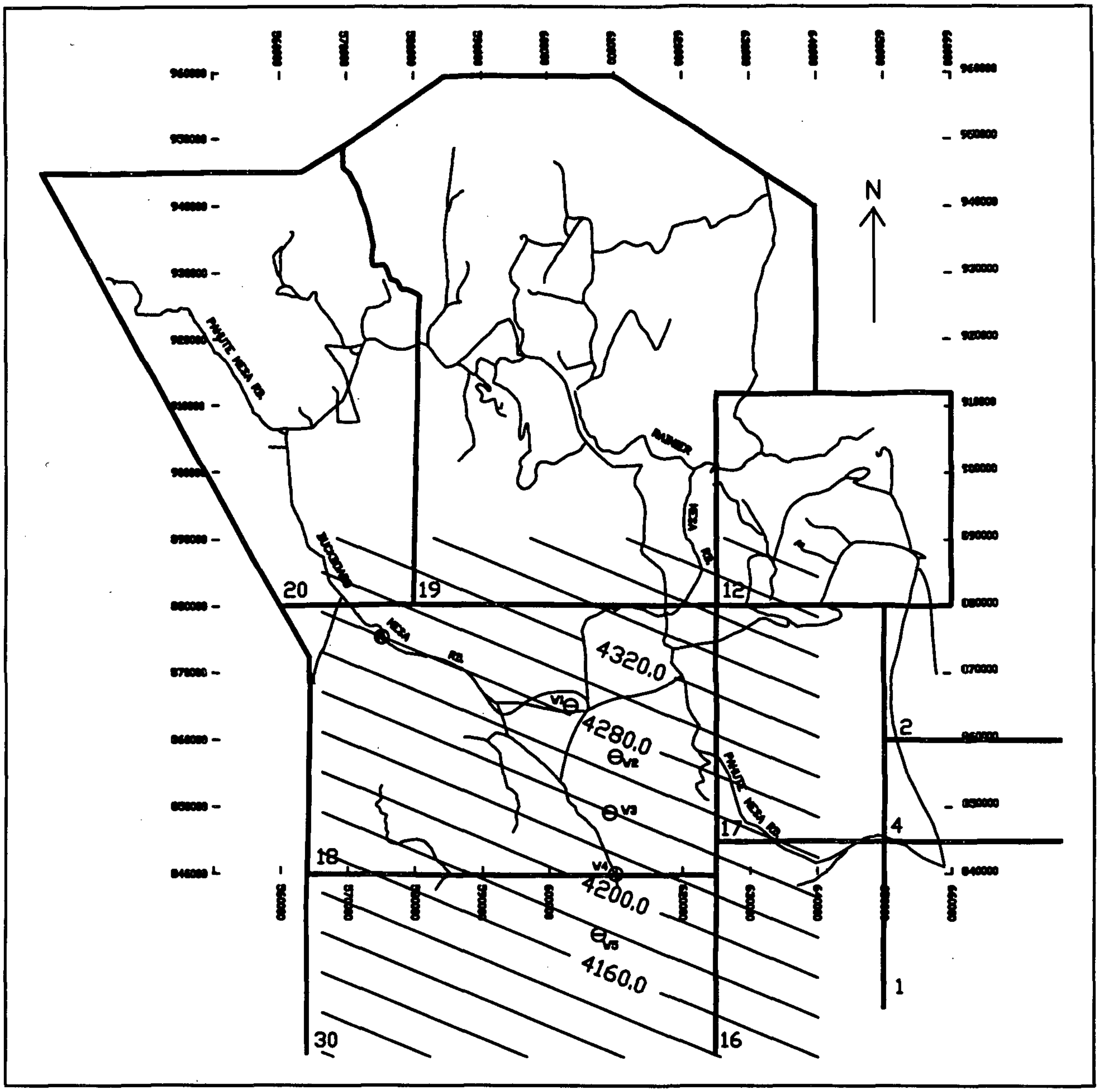


Figure 1. Idealized regional flow field through the hypothetical Buckboard Mesa well field.

Figure 2 contains the identical features contained in Figure 1, with the exception that all wells are being stressed. Wells W1 through W5 are being stressed at 276 gpm and Wells 8 is being stressed at 400 gpm. The equilibrium drawdown created by the hypothetical well field ranges from 85 ft to 60 ft at each of the stressed wells. The greatest drawdown occurred at well W1 with 85 ft of drawdown. A graph of drawdown versus distance from well w1 is given in Figure 3. Drawdown may be more or less due to mitigating factors. Drawdown may be greater as Quickflow is not able

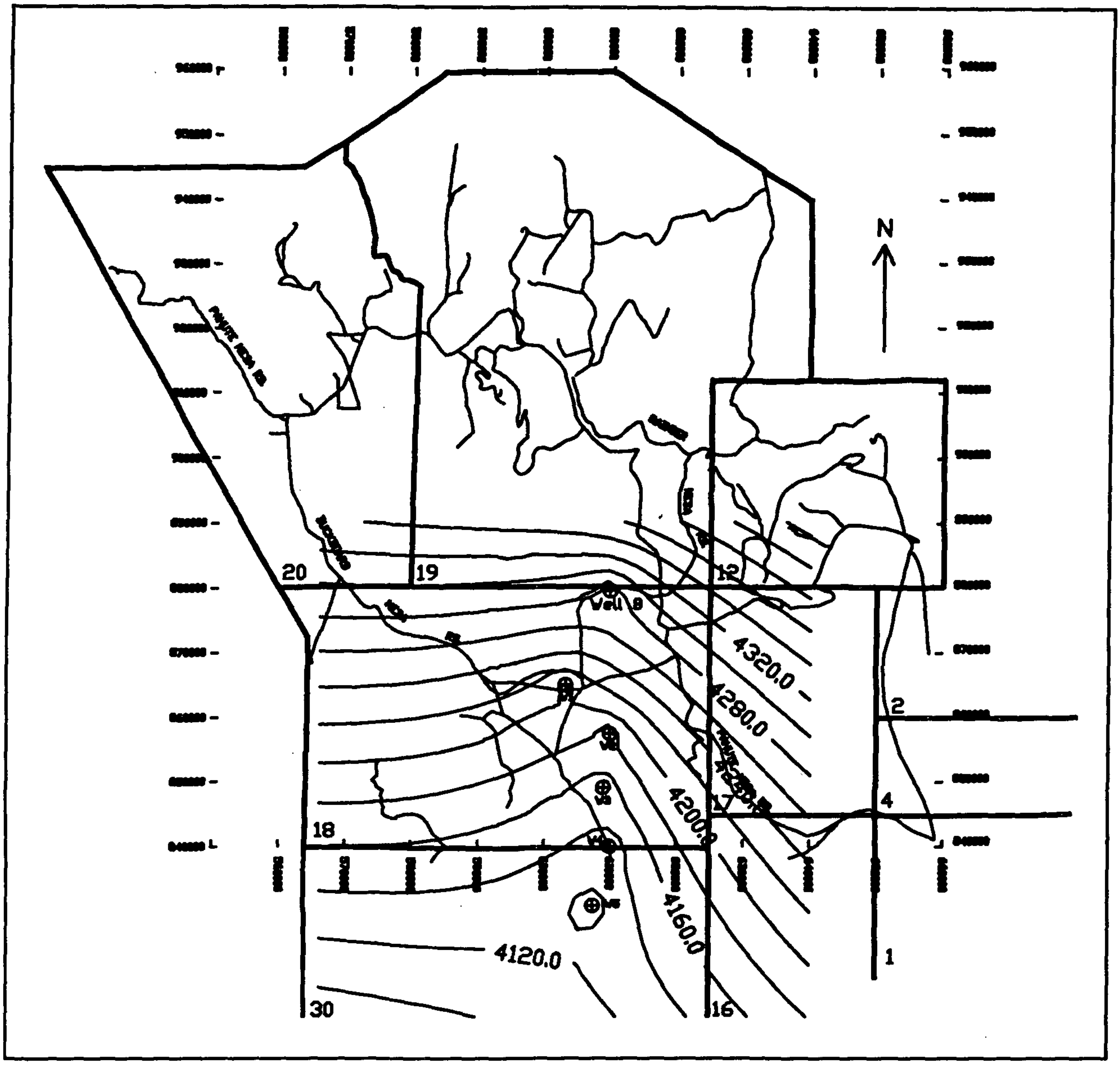


Figure 2. Drawdown of idealized regional flow field created by pumping the hypothetical Buckboard Mesa well field at 3354 acre–ft/yr.

to account for additional well turbulence created by steep drawdown cones and lost well efficiency as the upper screens are dewatered or as the drawdown cone intersects less permeable units or from heterogeneities in hydraulic properties. On the other hand, Quickflow does not account for leakage from overlying units that may impart less drawdown. Drawdown versus distance from well W2 is shown in Figure 3. Based upon the results, it appears that the idealized model of the saturated intracaldera fill deposits in the Timber Mountain Moat is significantly dewatered while transmitting,

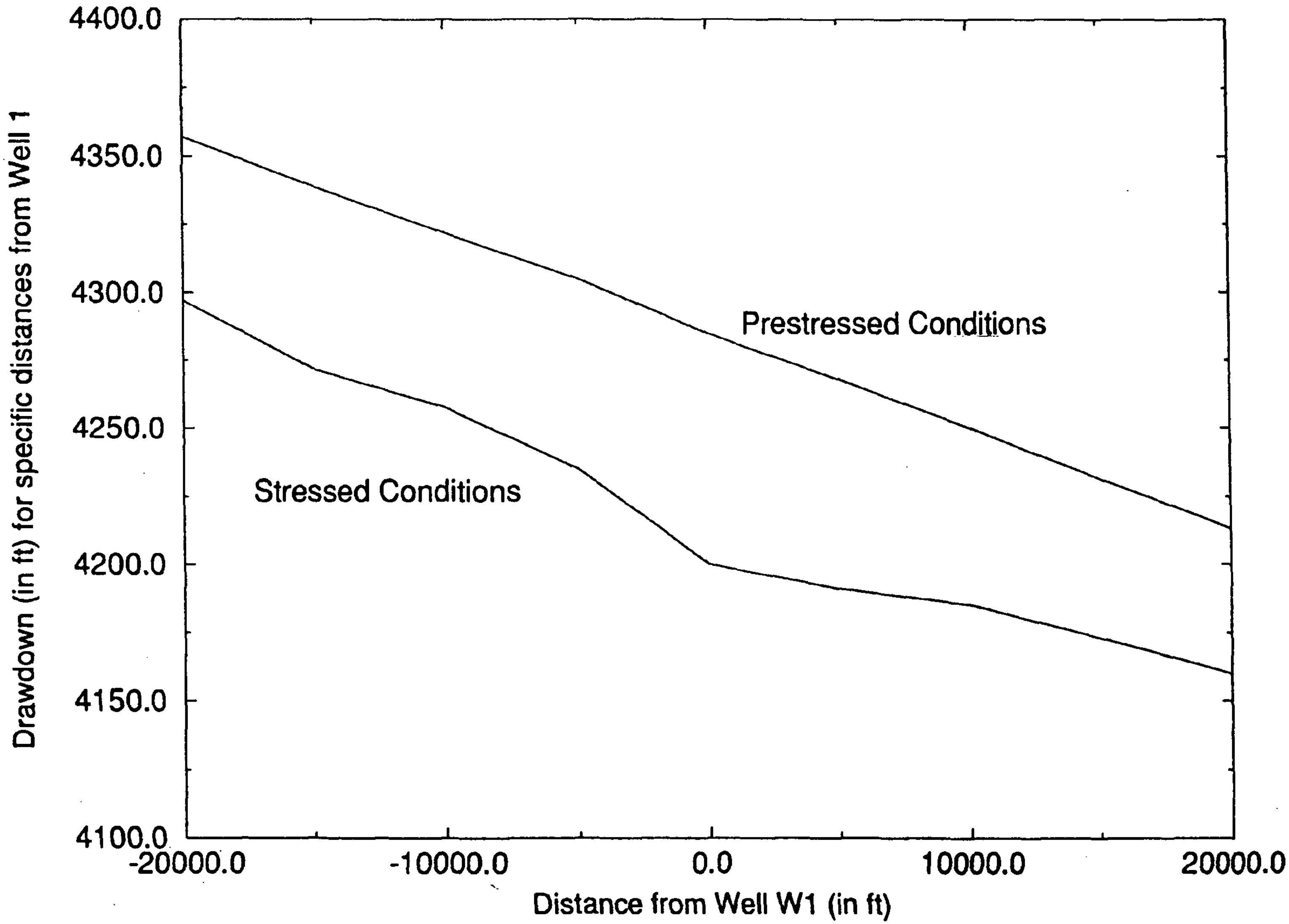


Figure 3. Well W1 Drawdown Curve for Buckboard Mesa.

producing, and sustaining groundwater in the quantities identified by the state engineer for the Buckboard Mesa Hydrographic Basin.

Particle tracking was not conducted on the Timber Mountain Caldera due to lack of contaminated sites that may impact the saturated zone.

JACKASS FLAT

The State Engineers' Office has determined that there is 4,000 acre–feet of groundwater available for withdrawal on an annual basis from the Jackass Flat hydrographic basin. Jackass Flat is bounded to the north by the Timber Mountain Caldera Complex, to the east by Rock Valley, to the west by Crater Flat and to the south by the Amargosa Desert. The basin is underlain, at great depth, by paleozoic carbonate and clastic formations. Overlying the Paleozoic formations are a thick (> 6000 ft) sequence of ash–flow and ash–fall tuffs and alluvial material. The most productive aquifer within Jackass Flat is the Topopah Spring Tuff (Winograd and Thordarson, 1975). Underground nuclear testing has not been conducted in Jackass Flat, however, the basin was the location of a nuclear rocket development center and has several locations that have shallow soil contamination generated by these tests. A second possible future source of contamination may be nuclear waste stored in the potential waste repository currently being evaluated at Yucca Mountain. The data type, values, and sources of the data used in the model are listed in Table 2. Results of the model are presented in Figures 4 and 5. Figure 4 presents the NTS administrative boundaries, roads, pre–existent wells UE–25c#1, UE–25c#3, J–12, and J–13, the five wells that compose the hypothetical well–field for Jackass Flat, and the idealized regional gradient of the area. Permits have been applied for wells UE–25c#1, UE–25c#3, J–12, and J–13 that total 430.19 acre–ft per year of the 4000 acre–ft per year allotment from the Jackass Flat hydrographic basin. It is assumed that these wells will be used in any future groundwater development schemes. Figure 5 contains the identical features contained in Figure 1, with the exception that, all wells are being stressed. Wells W1 through W5 are being stressed at 442 gpm and Wells UE–25c#1, UE–25c#3, J–12, and J–13 are being stressed at the previously stated rates. The equilibrium drawdown created by the hypothetical well field ranges less than 30 ft at each of the stressed well. The greatest drawdown occurred at well W2 with 27 ft of drawdown. Drawdown versus distance from well W2 is shown in Figure 6. Based upon the results, it appears that the idealized model of the saturated Topopah Spring Tuff, as it occurs in Jackass Flat, is capable of transmitting, producing, and sustaining groundwater in the quantities identified by the state engineer.

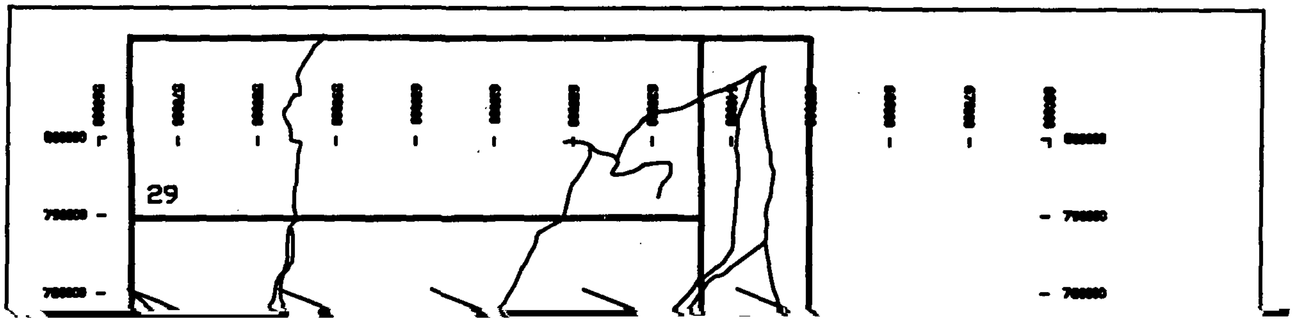
Particle tracing of groundwater flow in Jackass Flat indicates that groundwater beneath the Yucca Mountain Repository would not impact a potential well Field in Jackass Flat. The particle tracking is an extremely idealized version of reality. Additional modeling and field sampling are required to verify or refute these predictions.

ROCK VALLEY

The State Engineers' Office has determined that there is 8,000 acre–feet of groundwater available for withdrawal on an annual basis from the Rock Valley hydrographic basin. Rock Valley

Table 2. Data used to Model Hypothetical Well Field in Jackass Flat Hydrographic Basin.

Data Type	Value	Source
Basins perrennial yield	4000 acre–ft	State of Nevada, 1971
Regional flow direction	South–southwest	Winograd and Thordarson, 1975
Regional flow gradient	1.37×10^{-3}	Winograd and Thordarson, 1975
Aquifer	Topopah spring tuff	Winograd, 1983
Aquifer thickness	1000 ft	McKay and Williams, 1964
Hydraulic conductivity	25 gal/day/ft^2 (3.28 ft/day)	Winograd, 1983
Effective porosity	5.4%	Winograd, 1983
Well field assumptions	5 wells each pumping (442 gpm) year round. Wells UE–25c #1, UE–25c #3, J–12, J–13 are pumping 66 gpm year round.	Assumption
Well field locations	Well Name / Coordinates / Pump Rate W1 735000 615000 442 gpm W2 735000 625000 442 gpm W3 740000 620000 442 gpm W4 745000 615000 442 gpm W5 745000 625000 442 gpm	Assumption
Aquifer condition	Unconfined and in equilibrium with all stresses	Assumption
Pumping rates of pre–existant wells	UE–25c #1 66 gpm UE–25c #3 66 gpm J–12 66 gpm J–13 66 gpm	Calculated from a total permited withdrawal of 430.19 acre ft/yr applied for by the Yucca Mtn. Project Personal communication Greg Fasana (SAIC 6/1/95)


29

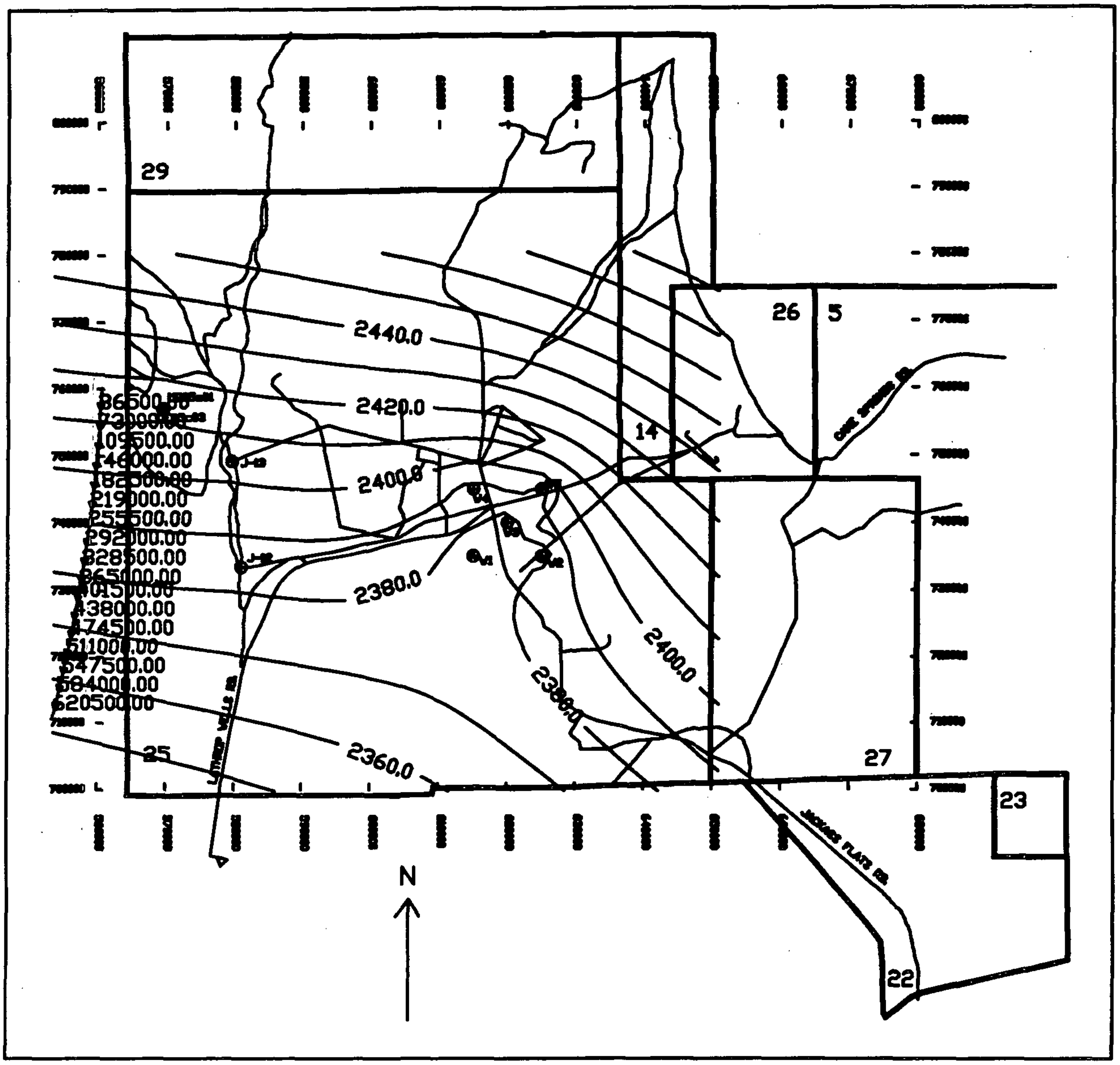


Figure 5. Drawdown of idealized regional flow field created by pumping the hypothetical Jackass Flat well field at 3570 acre ft/yr.

was the location of a facility associated with the assembly of nuclear weapons. A well near this facility (well F) was chosen as a hypothetical site that may negatively affect a future well field. The data type, values, and sources of the data used in the model are listed in Table 3. The results of the model are presented in Figures 7 and 8. Figure 7 presents the NTS administrative boundaries, the ten wells that compose the hypothetical well–field for Rock Valley, and the idealized regional gradient of the area. Figure 8 contains the identical features contained in Figure 7, with the exception

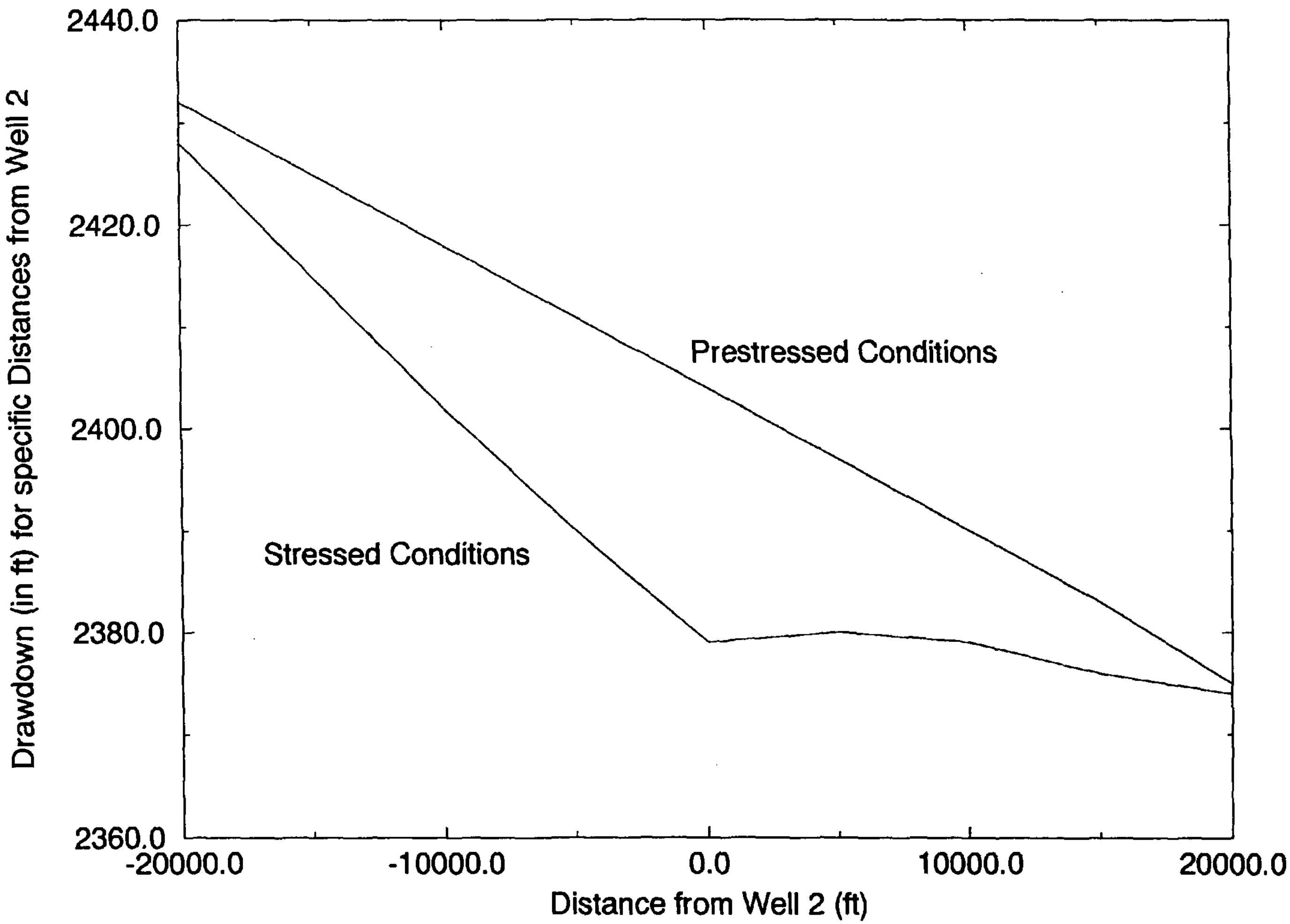


Figure 6. Well 2 drawdown curve for Jackass Flat.

Table 3. Data used to Model Hypothetical Well Field in Rock Valley Hydrographic Basin.

Data Type	Value				Source
Basins perennial yield	8000 acre–ft/yr				State of Nevada, 1971
Regional flow direction	South–southeast				Winograd and Thordarson, 1975
Regional flow gradient	4.4×10^{-4}				Winograd and Thordarson, 1975
Aquifer	Lower carbonate aquifer				Sargent and Stewart, 1976
Aquifer thickness	> 2400 ft				Sargent and Stewart, 1976
Hydraulic conductivity	10.7 ft/day				Winograd and Thordarson, 1975
Effective porosity	2.3%				Winograd and Thordarson, 1975
Well field assumptions	10 wells each pumping 496 gpm year round				Assumption
Well field locations	Well Name	Coordinates		Pump Rate	Assumption
	W1	704800	636850	496 qpm	
	W2	707125	635325	496 gpm	
	W3	709700	633750	496 gpm	
	W4	707750	639650	496 gpm	
	W5	710150	638175	496 gpm	
	W6	712575	636650	496 gpm	
	W7	710650	642500	496 gpm	
	W8	712900	641050	496 gpm	
	W9	715250	639650	496 gpm	
	W10	715650	644100	496 gpm	
Aquifer conditions	Uncontained and in equilibrium with all stresses				


29
25
26
5
14
27
2396.0
2392.0
2388.0
2384.0

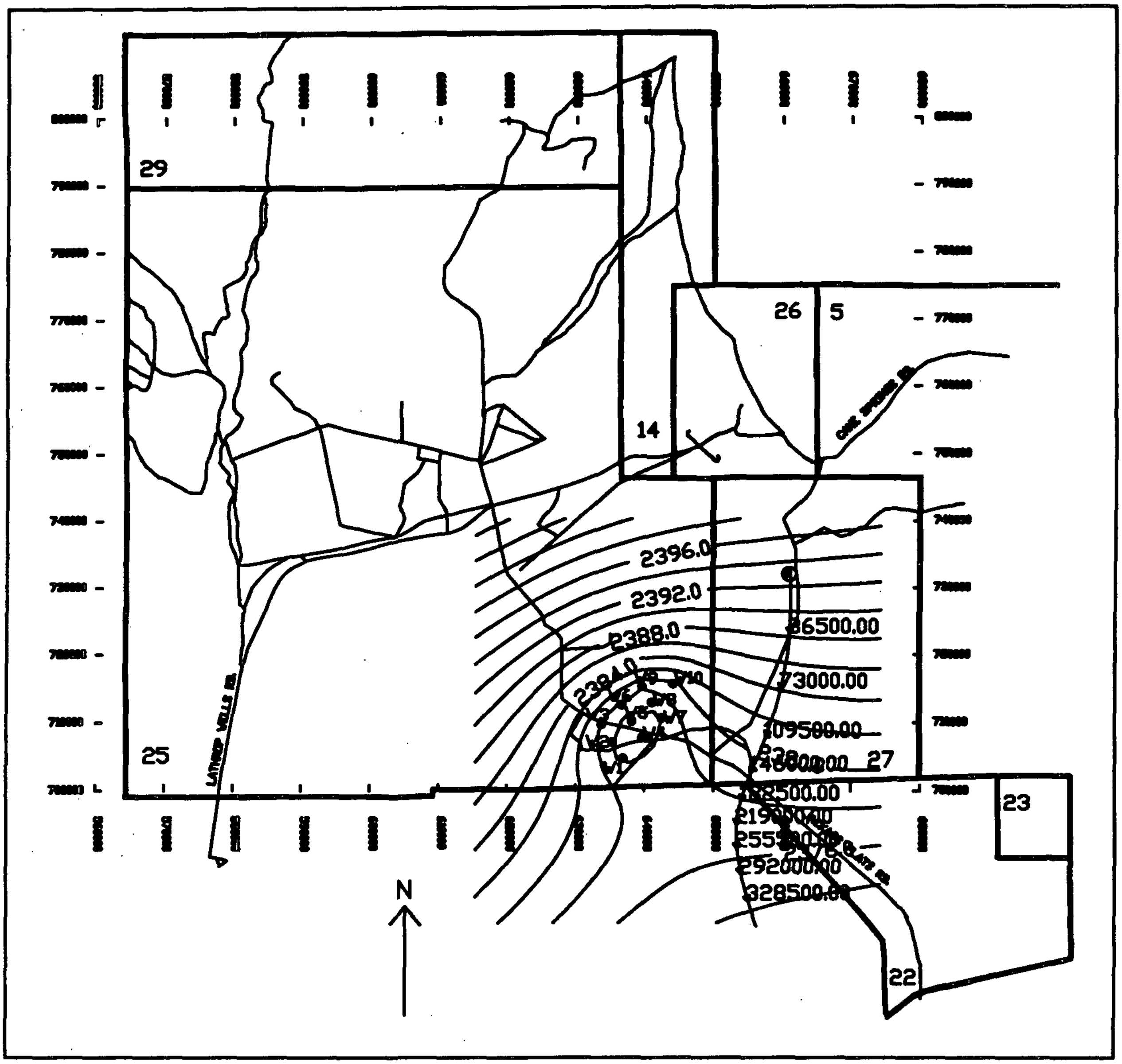


Figure 8. Drawdown of idealized regional flow field created by pumping the hypothetical Rock Valley well field at 8000 acre ft/yr.

Particle tracing of groundwater flow in Jackass Flat indicates that groundwater beneath the Device Assembly Facility would impact a potential well Field in Rock Valley in approximately 215 years assuming complete miscibility of the contaminant with water and no adsorption.

FRENCHMAN FLAT

The State Engineers' Office has determined that there is 16,000 acre–feet of groundwater available for withdrawal on an annual basis from the Frenchman Flat hydrographic basin.

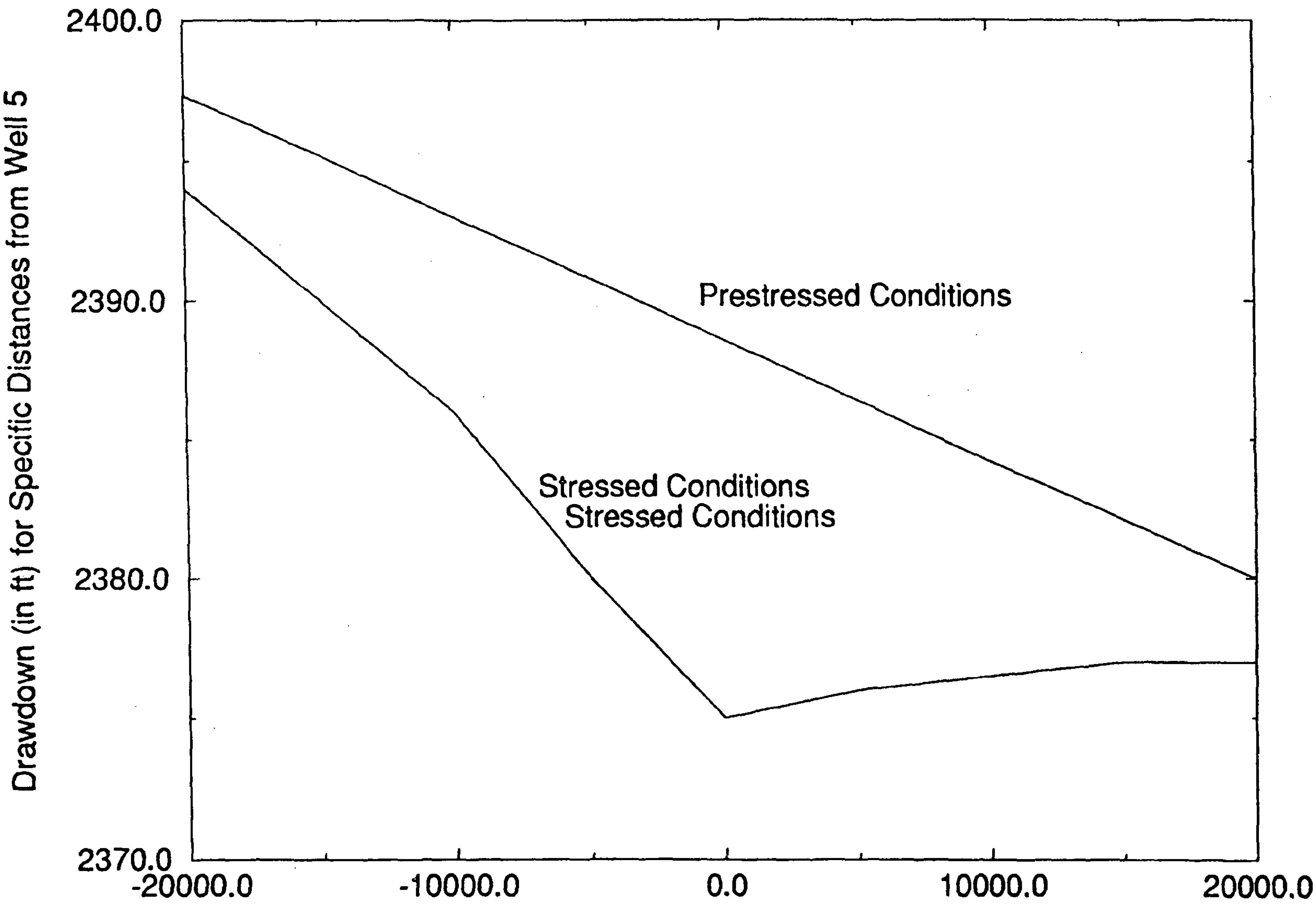


Figure 9. Well 5 drawdown curve for Rock Valley.

Frenchman Flat is bounded to the north by Yucca Flat, to the South by Mercury Valley, to the east by Indian Spring Valley and to the west by Jackass Flat. The basin is underlain by Paleozoic carbonate and possible some paleozoic clastic formations. The paleozoic formations have undergone basin and range faulting, resulting in a deep basin that has been filled with Tertiary volcanics and alluvial fill. Most of the existing wells in Frenchman Flat utilize the alluvial fill as the primary aquifer (Russell, 1989), making this aquifer the logical choice to evaluate in terms of its production capabilities. Underground nuclear testing has been conducted to a limited extent in Frenchman Flat. The closest underground nuclear test to the hypothetical well field was the cambric test. The working point for this detonation was in the alluvium. The data type, values, and sources of the data used in the model are listed in Table 4. Two values for hydraulic conductivity are given for the alluvial aquifer, with the two values representing an order of magnitude difference. Prestressed conditions are presented in Figure 10. Two model runs were made, one utilizing a value of 6.78 ft/d for hydraulic conductivity and a total pump rate of 16,000 acre–ft/yr (Figure 11) and the other utilizing a value of 0.735 ft/d and a total pump rate of 4,000 acre–ft/yr (Figure 12). Figure 10 presents the NTS administrative boundaries, the twenty wells that compose the hypothetical well–field for Frenchman Flat, and the idealized regional gradient of the area. Individual wells in both Figures 11 and 12 were stressed at a rate of 496 gpm. The equilibrium drawdown created by the hypothetical well field in Figure 11 is less than 116 ft at each of the stressed wells and is less than 350 ft in Figure 12. Drawdown versus distance from well determined from Figures 11 and 12 are shown in Figure 13. Based upon the results, it appears that the ability of the idealized model of the saturated alluvial aquifer to produce and sustain quantities of groundwater equal to the perennial yield is extremely dependent upon the hydraulic conductivity of the alluvial aquifer. The two values used in the different models are both representative of silty loess alluvial deposits (Freeze and Cherry, 1979). It is very likely that the two hydraulic conductivity values may alternatively exceed or underestimate the actual hydraulic conductivity of Frenchman Flat. It is likely, due to the variability of hydraulic conductivity, that the alluvial aquifer will not support the production of 16,000 acre–ft per year and alternate well sites in the carbonate aquifer in southwestern Frenchman Flat will need to be evaluated.

Particle tracing of groundwater flow in Jackass Flat indicates that groundwater emanating from the cambric test would require 50 to 60 years, assuming no dilution or adsorption, to reach any of the wells in the hypothetical well field.

Table 4. Data used to Model Hypothetical Well Field in Frenchman Flat Hydrographic Basin.

Data Type	Value				Source
Basins perennial yield	16,000 acre–ft/yr				State of Nevada, 1971
Regional flow direction	South–south west				Winograd and Thordarson, 1975
Regional flow gradient	0.00303				Winograd and Thordarson, 1975
Aquifer	Alluvium				Winograd and Thordarson, 1975
Aquifer thickness	~600 ft				Russell, 1989
Hydraulic Conductivity	6.78 ft /d				Winograd and Thordarson, 1975 from well 74–70a
	0.735 ft/d				Winograd and Thordarson, 1975 from well 74–70b
Effective porosity	31%				Winograd and Thordarson, 1975
Well field assumptions	20 wells each pumping 496 gpm year round				Assumption
Well field location	Well Name	Coordinates		Pump Rate	Assumption
	W1	740450	705650	496 gpm	
	W2	740500	703200	496 gpm	
	W3	740500	700050	496 gpm	
	W4	744050	704400	496 gpm	
	W5	744300	701400	496 gpm	
	W6	747300	705500	496 gpm	
	W7	747650	702850	496 gpm	
	W8	748100	700550	496 gpm	
	W9	750000	706550	496 gpm	
	W10	750150	703550	496 gpm	
	W11	750900	700600	496 gpm	
	W12	751950	708200	496 gpm	
	W13	753050	705300	496 gpm	
	W14	753775	702500	496 gpm	
	W15	753825	709300	496 gpm	
	W16	754950	707050	496 gpm	
	W17	755850	704250	496 gpm	
	W18	756325	710000	496 gpm	
	W19	756900	708600	496 gpm	
	W20	757950	706250	496 gpm	
Aquifer status	Unconfined and in equilibrium with all stresses				Assumption

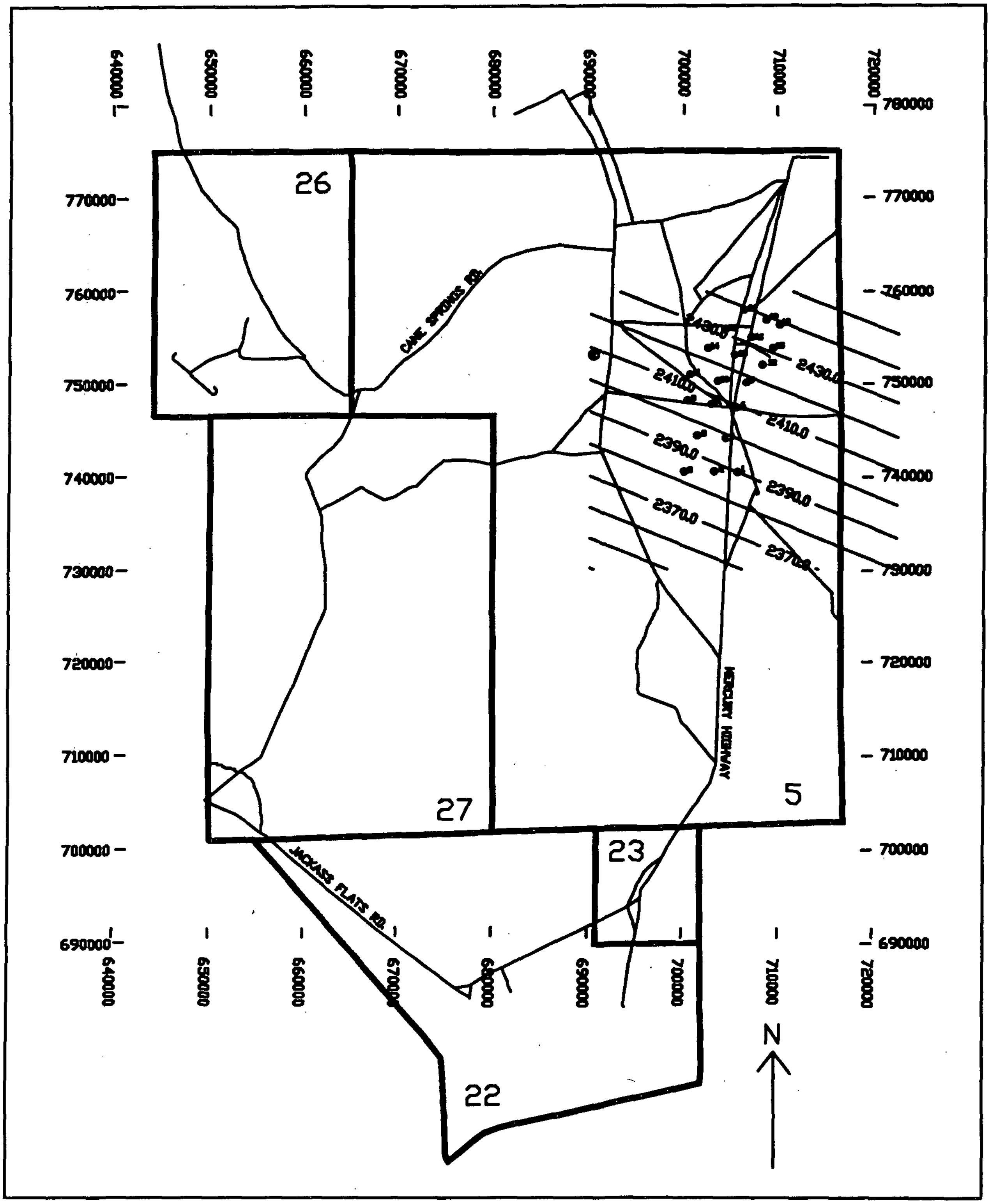


Figure 10. Idealized regional flow field through the hypothetical Frenchman Flat well field.

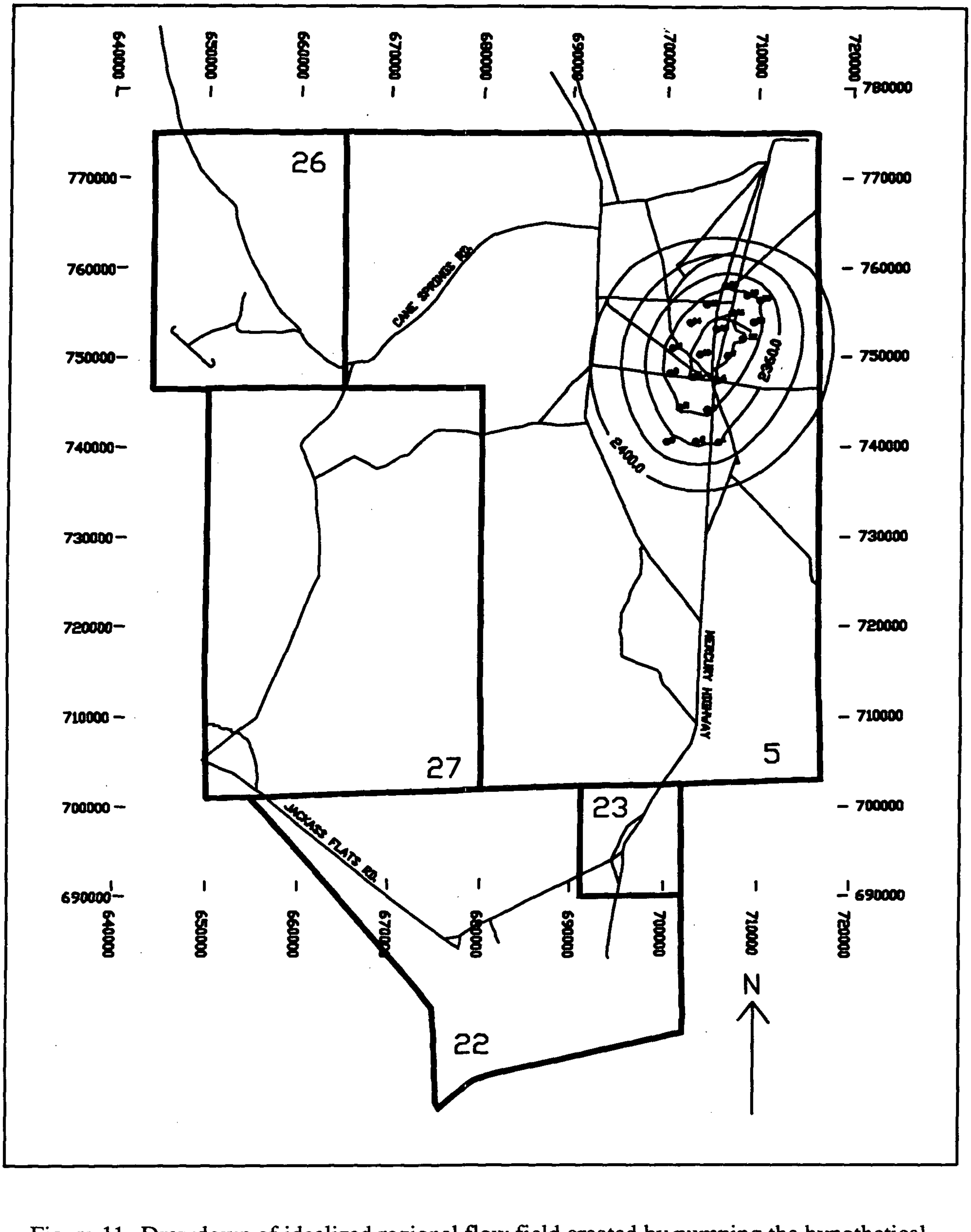


Figure 11. Drawdown of idealized regional flow field created by pumping the hypothetical Frenchman Flat well field at 16,000 acre–ft/yr with a hydraulic conductivity of 6.78 ft/day.

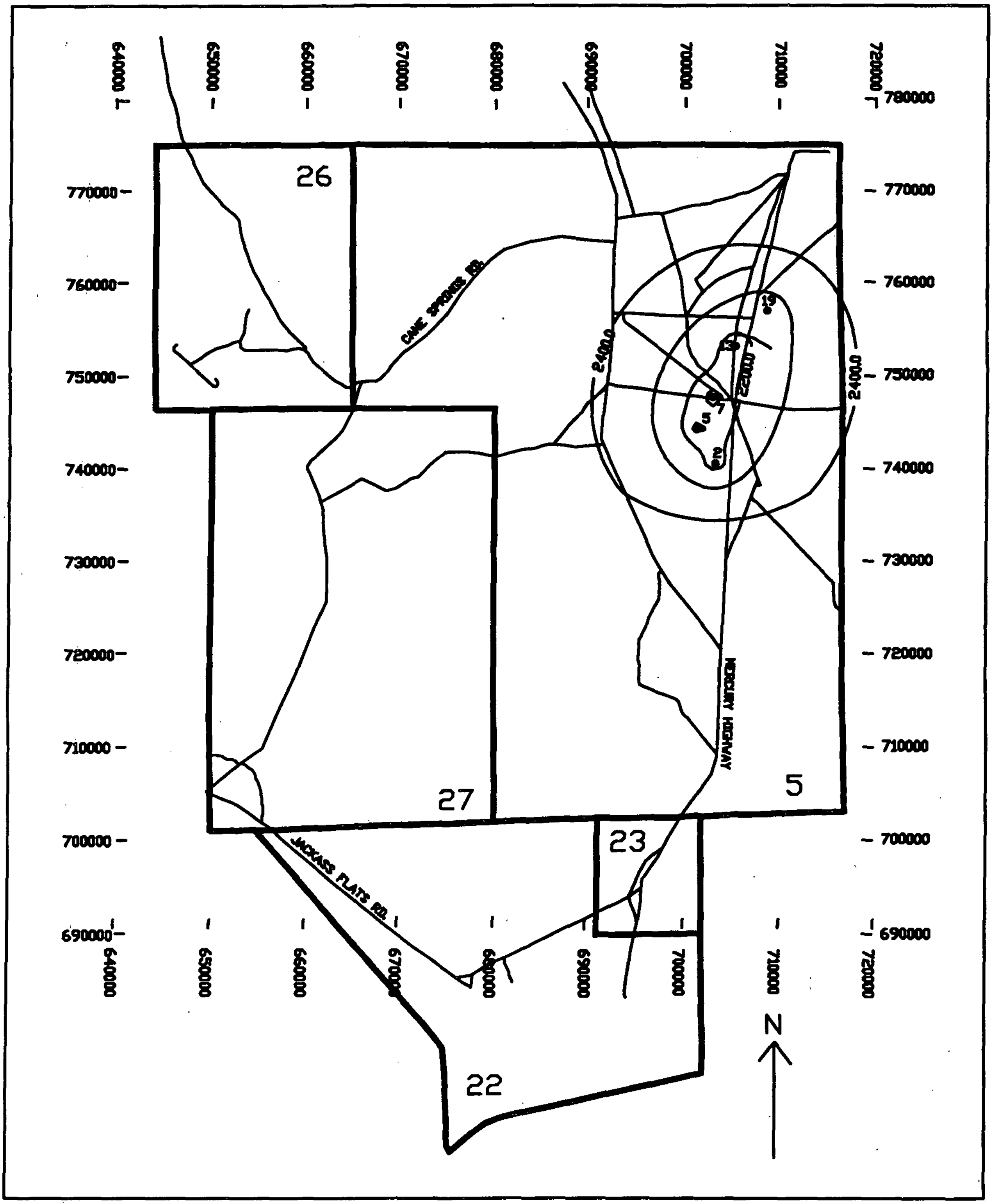


Figure 12. Drawdown of Idealized regional flow field created by pumping the hypothetical Frenchman Flat well field at 4000 acre–ft/yr with a hydraulic conductivity value of 0.735 ft/day.

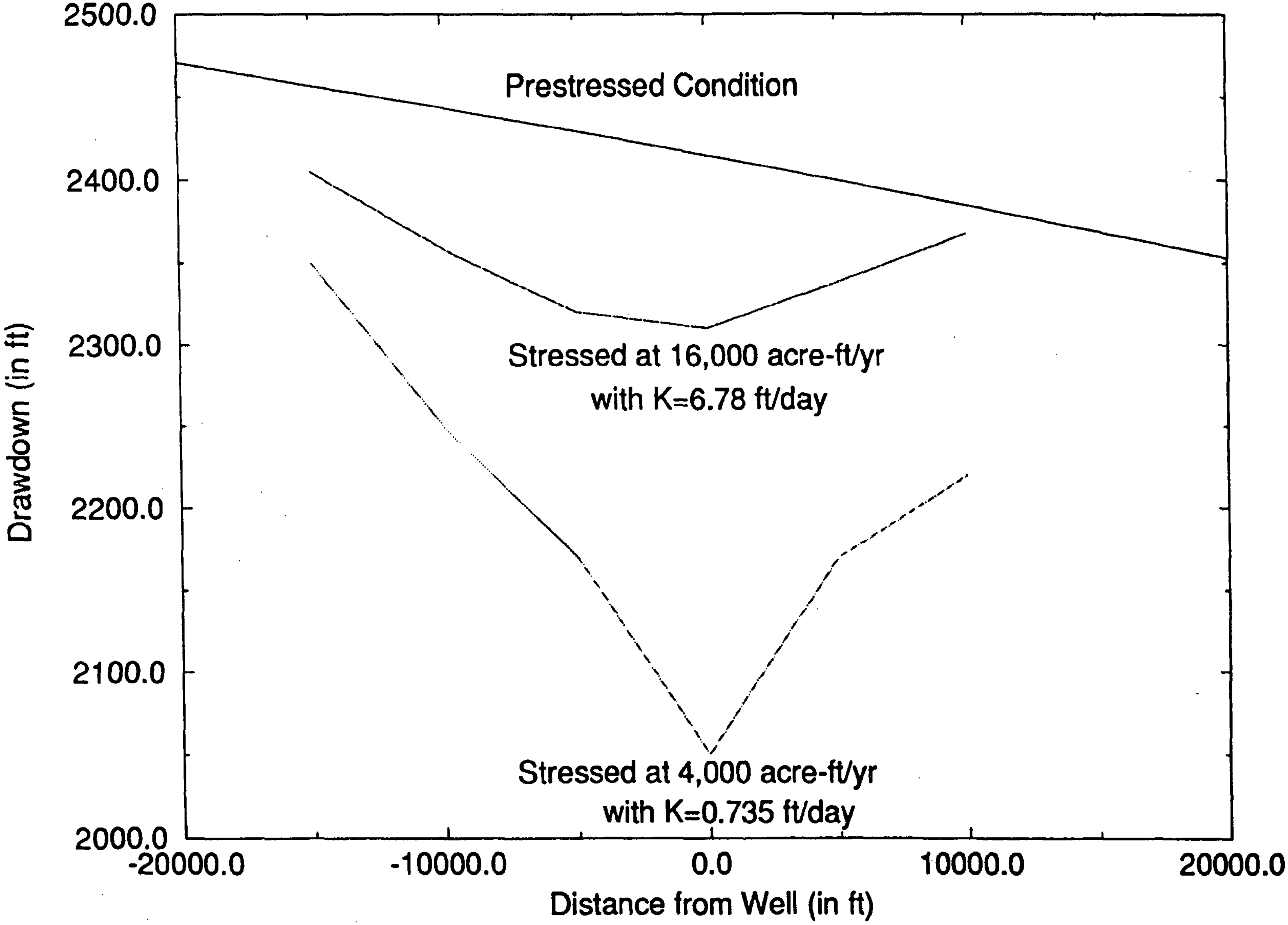


Figure 13. Idealized drawdown curve for Frenchman Flat caldera.

REFERENCES

Blankennagel, R.K. and J.E. Weir Jr. 1973. Geohydrology of the Eastern Part of Pahute Mesa, Nevada Test Site, Nye County, Nevada. U.S. Geological Survey Professional Paper 712–B 34 p.

Byers, F.M. Jr., W.J. Carr, R.L. Christiansen, P.W. Lipman, P. P. Orkild, and W.D. Quinlivan, Geologic Map of the Timber Mountain Caldera Area, Nye County, Nevada, U.S. Geologic Survey Miscellaneous Investigations Series Map I–891.

Byers, F.M., and Hawkins, W.L., 1981, Geology of Drill Hole UE–18t and Area 18, Timber Mountain Caldera Moat, Nevada Test Site, U.S. Geological Survey Specials Studies USGS–474–312, 67 p.

Freeze, R.A., and J.A. Cherry, 1979, Groundwater, Prentice–Hall Inc., Englewood Cliffs, New Jersey, p 29.

Geraghty and Miller, 1991, Quickflow, Geraghty and Miller, Inc., Reston, VI.

International Technologies Corporation, 1995, Geologic Data Analysis Quality Assurance Documentation, International Technologies Corp., Las Vegas, NV.

International Technologies Corporation, 1995, Potentiometric Data Task Documentation Package, International Technologies Corp., Las Vegas, NV.

McKay, E.J., and Williams, W.P., 1964, Geology of the Jackass Flats Quadrangle, Nye County, Nevada, U.S. Geological Survey 1:24,000 Map GQ–368.

Russell, C.E., 1989, Assessment of the Nevada Test Site Monitoring Well System., Desert Research Institute Report 45072, Las Vegas, NV, 42 p.

Sargent, K.A., and Stewart, J.H., 1971, Geologic Map of the Specter Range Northwest Quadrangle, Nye County, Nevada, U.S. Geological Survey 1:24,000 Map GQ–884.

State of Nevada, 1971, State of Nevada Water Resources and Water–Basin Flows, State of Nevada's Division of Water Resources State Engineers Office, Carson, NV.

Strack, O. D. L., 1989, Groundwater Mechanics, Prentice Hall, Englewood Cliffs, New Jersey, 676 p.

Waddell, R.K., 1984, Hydrology of Yucca Mountain and Vicinity, Nevada–California–Investigative Results through mid–1983: U.S. Geological Survey Water–Resources Investigations report 84–4267, 40 p.

Winograd I.J. and W. Thordarson, 1975. Hydrogeologic and Hydrochemical Framework, South–Central Great Basin, Nevada–California, with Special Reference to the Nevada Test Site. U.S. Geological Survey Professional Paper 712–C. p. 92.

Winograd, I.J., 1983, Geohydrologic Data and Test Results from Well J–13, Nevada Test Site, Nye County Nevada, U.S. Geological Survey Water Resources Investigation Report 83–4171, 55 p.

Witherill, V.F., 1986, Personal Letter, dated June 4, 1986, to Michael Tuebner (SAIC) describing the NTS water supply as of May, 1986, Vern F. Witherhill, Former NTS Office Director.