DOE/NV/03624--1486-ATT A

September 2022

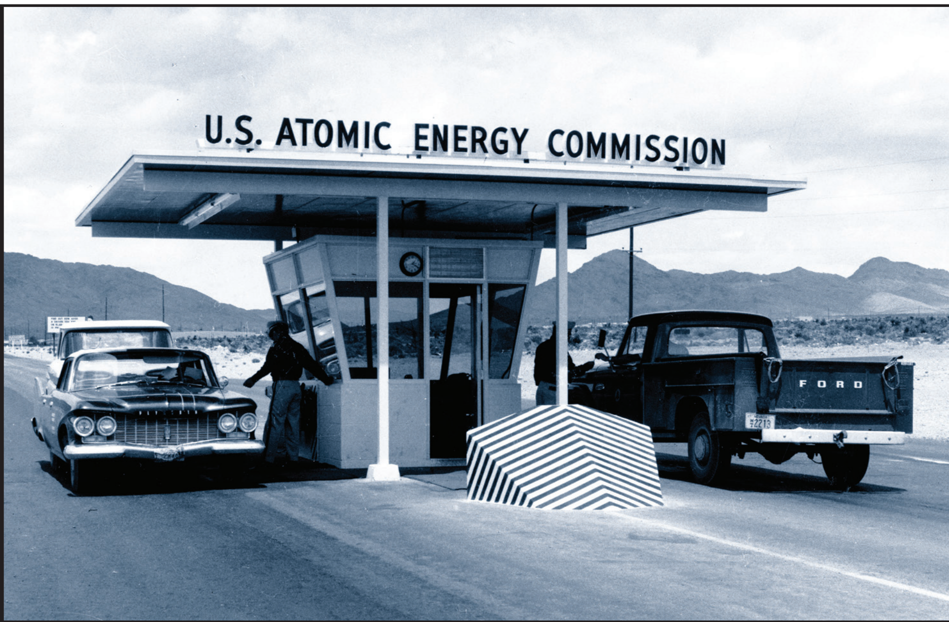
NNSA
National Nuclear Security Administration

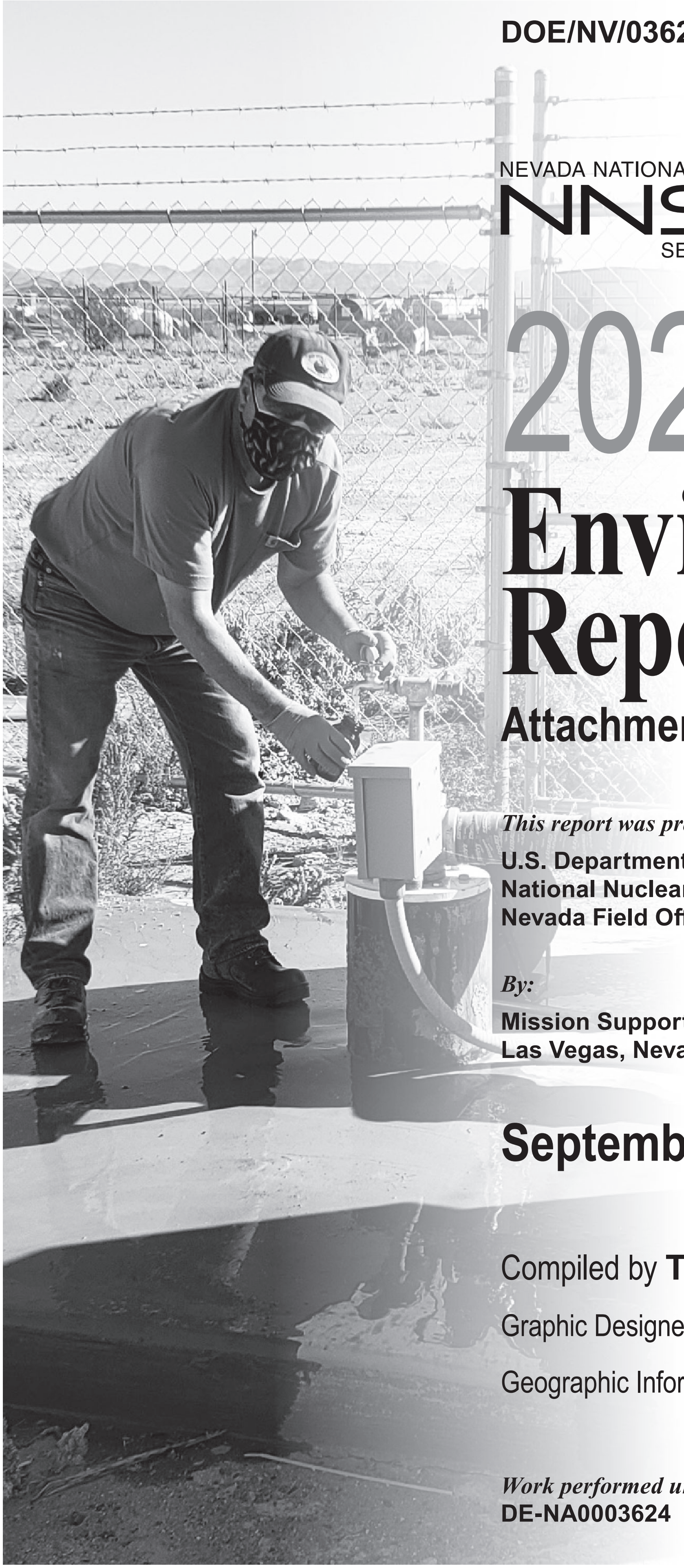
NEVADA NATIONAL
NNSS
SECURITY SITE

2021

Environmental Report

Attachment A: Site Description





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2021 Environmental Report

Attachment A: Site Description

This report was prepared for:

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Nevada Field Office

By:

Mission Support and Test Services LLC
Las Vegas, Nevada

September 2022

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Acronyms and Abbreviations

AA	alluvial aquifer
AEC	Atomic Energy Commission
a.k.a.	also known as
ARL/SORD	Air Resources Laboratory, Special Operations and Research Division
ATCU	argillic tuff confining unit
ATICU	Ammonia Tanks intrusive confining unit
BA	Benham aquifer
BFCU	Bullfrog confining unit
BLM	Bureau of Land Management
BMICU	Black Mountain intrusive confining unit
BN	Bechtel Nevada
BRA	Belted Range aquifer
BRCU	Belted Range confining unit
°C	degree Celsius
ca.	*circa,* meaning “approximately”
CA	carbonate aquifer
CAS	corrective action site
CAU	corrective action unit
CCICU	Claim Canyon intrusive confining unit
CCU	clastic confining unit
CFCM	Crater Flat composite unit
CFCU	Crater Flat confining unit
CG	cloud-to-ground
CHCU	Calico Hills confining unit
CHICU	Calico Hills intrusive confining unit
CHVCM	Calico Hills vitric composite unit
CHVTA	Calico Hills vitric-tuff aquifer
CHZCM	Calico Hills zeolitized composite unit
cm	centimeter(s)
CP	Control Point
DOE	U.S. Department of Energy
DOE/NV	U.S. Department of Energy, Nevada Operations Office
DRI	Desert Research Institute
dT/dz	change in temperature with height
DVCM	detached volcanics composite unit
ESA	Endangered Species Act
°F	degree Fahrenheit
FCCM	Fortymile Canyon composite unit
FCCU	Fluorspar Canyon confining unit
FFACO	Federal Facility Agreement and Consent Order
ft	foot or feet
GCU	granite confining unit

GPS	Global Positioning System
HGU	hydrogeologic unit
HSA	Hydrological Services America
HSU	hydrostratigraphic unit
IA	inlet aquifer
IICU	intracaldera intrusive confining unit
in.	inch(es)
IT	International Technology Corporation
KA	Kearsarge aquifer
km	kilometer(s)
kph	kilometer(s) per hour
kt	kiloton(s)
LCA	lower carbonate aquifer
LCA3	lower carbonate aquifer - upper thrust plate
LCCU	lower clastic confining unit
LCCU1	lower clastic confining unit - upper thrust plate
LFA	lava-flow aquifer
LPCU	lower Paintbrush confining unit
LTCU	lower tuff confining unit
LTCU1	lower tuff confining unit 1
LVTA	lower vitric-tuff aquifer
LVTA1	lower vitric-tuff aquifer 1
LVTA2	lower vitric-tuff aquifer 2
m	meter(s)
Ma	million years ago
mb	millibar(s)
MEDA	Meteorological Data Acquisition
MGCU	Mesozoic granite confining unit
mi	mile(s)
mph	mile(s) per hour
NASA	National Aeronautics and Space Administration
NDNH	Nevada Division of Natural Heritage
NNES	Navarro Nevada Environmental Services, LLC
NNSA/NFO	U.S. Department of Energy, National Nuclear Security Administration Nevada Field Office
NNSA/NSO	U.S. Department of Energy, National Nuclear Security Administration Nevada Site Office
NNSS	Nevada National Security Site
NOAA	National Oceanic and Atmospheric Administration
NRDS	Nuclear Rocket Development Station
NSTec	National Security Technologies, LLC
NTS	Nevada Test Site
NV	Nevada
OSBCU	Oak Spring Butte confining unit
PBRCM	Pre-Belted Range composite unit
PCM	Paintbrush composite unit
PCU	playa confining unit

PDT	Pacific Daylight Time
PLFA	Paintbrush lava-flow aquifer
PM-OV	Pahute Mesa–Oasis Valley
PST	Pacific Standard Time
PVTA	Paintbrush vitric-tuff aquifer
RMBCU	Rainier Mesa breccia confining unit
RMICU	Rainier Mesa intrusive confining unit
RM-SM	Rainier Mesa–Shoshone Mountain
RVA	Redrock Valley Aquifer
RVBCU	Redrock Valley Breccia Confining Unit
RVICU	Redrock Valley intrusive confining unit
SCCC	Silent Canyon caldera complex
SCICU	Silent Canyon intrusive confining unit
SCVCU	subcaldera volcanic confining unit
SNJV	Stoller-Navarro Joint Venture
SWA	Stockade Wash aquifer
SWL	static water level
SWNVF	Southwestern Nevada Volcanic Field
TCA	Tiva Canyon Aquifer
TCU	tuff confining unit
TCVA	Thirsty Canyon volcanic aquifer
THCM	Tannenbaum Hill composite unit
THLFA	Tannenbaum Hill lava-flow aquifer
TMA	Timber Mountain aquifer
TMCC	Timber Mountain caldera complex
TMCM	Timber Mountain composite unit
TMLVTA	Timber Mountain lower vitric-tuff aquifer
TMUVTA	Timber Mountain upper vitric-tuff aquifer
TMWTA	Timber Mountain welded-tuff aquifer
TPA	Twin Peaks aquifer
TSA	Topopah Spring aquifer
TUBA	Tub Spring aquifer
UCA	upper carbonate aquifer
UCCU	upper clastic confining unit
UGTA	Underground Test Area
UPCU	upper Paintbrush confining unit
USFS	U.S. Forestry Service
UTCU	upper tuff confining unit
UTCU1	upper tuff confining unit 1
UTCU2	upper tuff confining unit 2
VCU	volcaniclastic confining unit
VTA	vitric-tuff aquifer
WCU	Wahmonie confining unit
WTA	welded-tuff aquifer
WWA	Windy Wash aquifer

YMCFCM	Yucca Mountain Crater Flat composite unit
YMCHLFA	Yucca Mountain Calico Hills lava-flow aquifer
YVCM	younger volcanic composite unit

Attachment A: Nevada National Security Site Description

This attachment expands on the general description of the Nevada National Security Site (NNSS) presented in the Chapter 1 Introduction to the *Nevada National Security Site Environmental Report 2021*. Included are subsections that summarize the site's geological, hydrological, climatological, and ecological settings and the cultural resources of the NNSS. The subsections are meant to aid the reader in understanding the complex physical and biological environment of the NNSS. An adequate knowledge of the site's environment is necessary to assess the environmental impacts of new projects, design and implement environmental monitoring activities for current site operations, and assess the impacts of site operations on the public residing in the vicinity of the NNSS. The NNSS environment contributes to several key features of the site that afford protection to the inhabitants of adjacent areas from potential exposure to radioactivity or other contaminants resulting from NNSS operations. These key features include the general remote location of the NNSS, restricted access, extended wind transport times, the great depths to slow-moving groundwater, little or no surface water, and low population density. This attachment complements the annual summary of monitoring program activities and dose assessments presented in the main body of this report.

A summary of information about historic NNSS underground nuclear explosive tests, including their locations and geologic setting, is provided in Table A-1.

A.1 Geology

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A.1.1 Physiographic/Geologic Setting

The NNSS is located in the southern part of the Great Basin, the northern-most subprovince of the Basin and Range Physiographic Province (Figure A-1). The NNSS terrain is typical of much of the Basin and Range Physiographic Province, characterized by mostly tilted, fault-bounded blocks that are as much as 80 kilometers (km) (50 miles [mi]) long and 24 km (15 mi) wide. These features are modified locally by the Las Vegas Shear Zone (a component of the Walker Lane regional structural belt) in the southern part of the NNSS, and by resurgent calderas of the Southwestern Nevada Volcanic Field (SWNVF). The land forms and topography of the NNSS area reflect the complex geology and its location in the arid Mojave Desert.

The NNSS area is geologically complex, with at least seven Tertiary-age calderas nearby, many relatively young basin-and-range-style normal faults (due to extensional forces), Mesozoic-age thrust faults (due to compressional forces), and igneous intrusive bodies, all superimposed on a basement complex of highly deformed Proterozoic- and Paleozoic-age sedimentary and metasedimentary rocks. Geologic units exposed at the surface in the NNSS area can be categorized as approximately 40% alluvium-filled basins and 20% Paleozoic and uppermost Precambrian sedimentary rocks, the remainder being Tertiary-age volcanic rocks with a few intrusive masses (Orkild 1983; Slate et al. 1999). A generalized geologic map of the NNSS area is given in Figure A-2.

The NNSS area is dominated by Tertiary-age volcanic rocks formed from materials that were erupted from various vents in the SWNVF, located on and adjacent to the northwestern part of the NNSS (Figure A-2). At least seven major calderas have been identified in this multi-caldera silicic volcanic field (Byers et al. 1976; National Security Technologies, LLC [NSTec] 2007). The calderas were formed by the voluminous eruption of zoned ash-flow tuffs between 16 and 7.5 million years ago (Ma) (Sawyer et al. 1994). From oldest to youngest, the calderas are Redrock Valley, Grouse Canyon, Area 20, Claim Canyon, Rainier Mesa, Ammonia Tanks, and Black Mountain calderas. A comprehensive review of past studies and the evolution of concepts on calderas of the SWNVF during the period from 1960 to 1988 is presented in Byers et al. (1989).

The volcanic rocks are covered in many areas by a variety of late Tertiary and Quaternary surficial deposits. These younger deposits consist of alluvium, colluvium, eolian (wind-blown sand) deposits, spring deposits, basalt lavas, lacustrine (fresh-water lake) deposits, and playa deposits.

Table A-1. Information summary of NNSS underground nuclear tests

Physiographic Area NNSS Area(s)	Total Underground(a)		Test Dates(a)	Depth of Burial Range	Overburden Media	Comments
	Tests	Detonations				
Yucca Flat 1, 2, 3, 4, 6, 7, 8, 9, 10	659	747	1951–1992	27–1,219 m (89–3,999 ft)	Alluvium/playa, Volcanic tuff	Various test types and yields; almost all were vertical emplacements above and below static water level; includes four high-yield(b) detonations.
Pahute Mesa 19, 20	85	85	1965–1992	31–1,452 m (100–4,765 ft)	Alluvium (thin), volcanic tuffs and lavas	Almost all were large-diameter vertical emplacements above and below static water level; includes 18 high-yield detonations.
Rainier/Aqueduct Mesa 12	61	62	1957–1992	61–640 m (200–2,100 ft)	Tuffs with welded tuff caprock (little or no alluvium)	Two vertical emplacements; all others were horizontal tunnel emplacements above static water level; mostly low-yield(c) U.S. Department of Defense weapons effects tests.
Frenchman Flat 5, 11	10	10	1965–1971	179–296 m (587–971 ft)	Mostly alluvium, minor volcanic tuff	Various emplacement configurations, both above and below static water level.
Shoshone Mountain 16	6	6	1962–1971	244–640 m (800–2,100 ft)	Bedded tuff, ash-flow tuff	Tunnel-based low-yield weapons effects and Vela Uniform(d) tests.
Oak Spring Butte (Climax Area) 15	3	3	1962–1966	229–351 m (750–1,150 ft)	Granite	Three tests above static water level. (Hard Hat, Tiny Tot, and Pile Driver).
Buckboard Mesa 18	3	3	1962–1964	≤ 27 m (90 ft)	Basaltic lavas	Shallow, low-yield experiments (Sulky, Johnnie Boy(e), and Danny Boy); all were above static water level.
Dome Mountain 30	1	5	03/12/1968	50 m (165 ft)	Mafic lava	Buggy (A, B, C, D, and E); Plowshare cratering test using a 5-detonation, horizontal salvo; all above static water level.

Source: Allen et al. (1997)

(a) Source: U.S. Department of Energy, National Nuclear Security Administration Nevada Field Office (NNSA/NFO) (2015).

(b) High-yield detonations – detonations more than 200 kt.

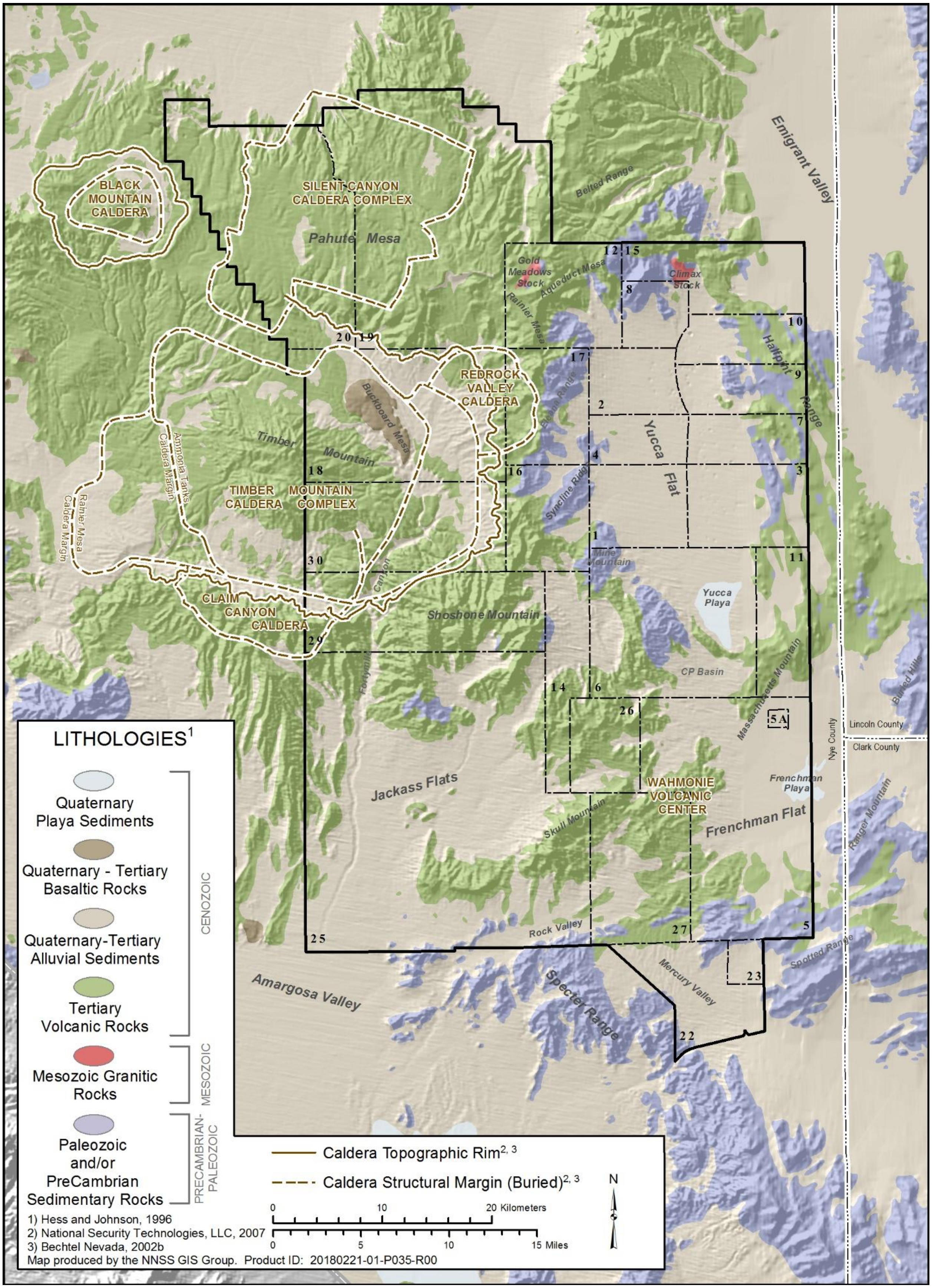
(c) Low-yield detonations – detonations less than 20 kt.

(d) Vela Uniform was a Department of Defense program designed to improve the capability to detect, identify, and locate underground nuclear explosions (according to NNSA/NFO 2015).

(e) Johnnie Boy was detonated at a depth of 23 ft (NNSA/NFO 2015; essentially a surface burst) approximately 1 mi east of Buckboard Mesa.

Note: ft = foot/feet; kt = kiloton(s); m = meter(s).

Figure A-1. Basin and Range Province and Great Basin Province (Fiero 1986)



1) Hess and Johnson, 1996
2) National Security Technologies, LLC, 2007
3) Bechtel Nevada, 2002b
Map produced by the NNSS GIS Group. Product ID: 20180221-01-P035-R00

Figure A-2. Generalized geologic map of the NNSS and vicinity

The area includes more than 300 described Tertiary-age volcanic units (Warren et al. 2000a, 2003). As a matter of practicality, some units are grouped together, especially those of limited areal extent or thickness. Table A-2 presents most of the Tertiary volcanic units useful in characterizing the subsurface at the NNSS.

Table A-2. Quaternary and Tertiary stratigraphic units of the NNSS and vicinity

Stratigraphic Assemblages and Major Units(a, b)	**Volcanic Sources(c)**
Quaternary and Tertiary Sediments	Not applicable
Young alluvium (Qay)	
Playa (Qp)	
Quaternary - Tertiary colluvium (QTc)	
Middle alluvium (Qam)	
Eolian sand (QTe)	
Quaternary-Tertiary alluvium (QTa)	
Quaternary Basalts (Qby)	Several discrete sources
Pliocene Basalts (Typ)	Several discrete sources
Tertiary alluvium (Tgy)	Not applicable
Miocene Basalt and Rhyolite	Several discrete sources
Thirsty Canyon and Younger Basalts (Tyb)	
Rhyolite of Obsidian Butte (Tyr)	
Tertiary Sediments	Not applicable
Late synvolcanic sedimentary rocks (Tgm)	
Caldera moat-filling sedimentary deposits (Tgc)	
Younger landslide and sedimentary breccia (Tgyx)	
Thirsty Canyon Group (Tt)	Black Mountain Caldera (9.1–9.4 Ma)
Gold Flat Tuff (Ttg)	
Trachyte of Hidden Cliff (Tth)	
Trachytic rocks of Pillar Spring and Yellow Cleft (Tts)	
Trail Ridge Tuff (Ttt)	
Pahute Mesa and Rocket Wash Tuffs (Ttp)	
Comendite of Ribbon Cliff (Ttc)	
Volcanics of Fortymile Canyon (Tf)	Several discrete vent areas in and around the Timber Mountain Caldera Complex
Rhyolite of Boundary Butte (Tfu)	
Post-Timber Mountain Basaltic Rocks (Tft)	
Trachyte of Donovan Mountain (Tfn)	
Rhyolite of Shoshone Mountain (Tfs)	
Lavas of Dome Mountain (Tfd)	
Younger intrusive rocks (Tiy)	
Rhyolite of Rainbow Mountain (Tfr)	
Beatty Wash Formation (Tfb)	
Tuff of Leadfield Road (Tfl)	
Rhyolite of Fleur-de-lis Ranch (Tff)	
Timber Mountain Group (Tm)	**Timber Mountain Caldera Complex:**
Trachyte of East Cat Canyon (Tmay)	
Tuff of Buttonhook Wash (Tmaw)	
Ammonia Tanks Tuff (Tma)	Ammonia Tanks Caldera (11.45 Ma)
Bedded Ammonia Tanks Tuff (Tmab)	
Timber Mountain landslide breccia (Tmx)	
Rhyolite of Tannenbaum Hill (Tmat)	
Basalt of Tierra (Tmt)	
Rainier Mesa Tuff (Tmr)	Rainier Mesa Caldera (11.6 Ma)
Rhyolite of Fluorspar Canyon (Tmrf)	
Tuff of Holmes Road (Tmrh)	
Landslide or eruptive breccia (Tmrx)	
Rhyolite of Windy Wash (Tmw)	
Transitional Timber Mountain rhyolites (Tmn)	
Paintbrush Group (Tp)	
Rhyolite of Benham (Tpb)	
Post-Tiva Canyon rhyolites (Tpu)	
Rhyolite of Scrugham Peak (Tps)	
Paintbrush caldera-collapse breccias (Tpx)	

Table A-2. Quaternary and Tertiary stratigraphic units of the NNSS and vicinity

Stratigraphic Assemblages and Major Units$^{(a, b)}$	Volcanic Sources$^{(c)}$
Tiva Canyon Tuff (Tpc)	Claim Canyon Caldera (12.65 Ma)
Yucca Mountain Tuff (Tpy)	
Rhyolite of Delirium Canyon (Tpd)	
Rhyolite of Echo Peak (Tpe)	
Middle Paintbrush Group rhyolites (Tpm)	
Pah Canyon Tuff (Tpp)	
Rhyolite of Silent Canyon (Tpr)	
Topopah Spring Tuff (Tpt)	
Calico Hills Formation (Th; formerly Tac)	Unknown (12.8 Ma)
Wahmonie Formation (Tw)	Wahmonie Volcanic Center (13.0 Ma)
Crater Flat Group (Tc)	**Silent Canyon Caldera Complex:**
Rhyolite of Inlet (Tci)	
Prow Pass Tuff (Tcp)	
Rhyolite of Kearsarage (Tcpk)	
Andesite of Grimy Gulch (Tcg)	
Bullfrog Tuff (Tcb)	Area 20 Caldera (13.1 Ma)
Rhyolites in the Crater Flat Group (Tcr)	
Tram Tuff (Tct)	
Belted Range Group (Tb)	
Deadhorse Flat Formation (Tbd)	
Grouse Canyon Tuff (Tbg)	Grouse Canyon Caldera (13.6 Ma)
Comendite of Split Range (Tbgs)	
Comendite of Quartet Dome (Tbq)	
Tram Ridge Group (Tr)	Uncertain
Lithic Ridge Tuff (Trl)	
Dikes of Tram Ridge (Trd)	
Rhyolite of Picture Rock (Trr)	
Tunnel Formation (Tn)	Uncertain
Tunnel 4 Member (Tn4)	
Tunnel 3 Member (Tn3)	
Volcanics of Quartz Mountain (Tq)	Uncertain
Tuff of Sleeping Butte (Tqs)	
Hornblende-bearing rhyolite of Quartz Mountain(Tqh)	
Tuff of Tolicha Peak (Tqt)	
Early rhyolite of Quartz Mountain (Tqe)	
Dacite of Mount Helen (Tqm)	
Volcanics of Big Dome (Tu)	Unknown (14.9 Ma)
Comendite of Ochre Ridge (Tuo)	
Tub Spring Tuff (Tub)	
Comendite of Emigrant Valley (Tue)	
Volcanics of Oak Spring Butte (To)	
Tunnel bed 2 (Ton2)	
Yucca Flat Tuff (Toy)	Unknown (15.1 Ma)
Tunnel bed 1 (Ton1)	
Redrock Valley Tuff (Tor)	Redrock Valley Caldera (15.4 Ma)
Tuff of Twin Peaks (Tot)	Unknown (15.5 Ma)
Older Volcanics (Tqo)	Unknown
Paleocolluvium (Tl)	Not applicable

(a) Compiled from Slate et al. (1999) and Ferguson et al. (1994).
(b) Letters in parentheses are stratigraphic unit map symbols.
(c) Sources and ages, where known, from Sawyer et al. (1994). Sources for Redrock Valley caldera from NSTec (2007).
Refer to Table A-3 for lists of Mesozoic, Paleozoic, and Precambrian sedimentary rock formations.

Underlying the Tertiary volcanic rocks are Paleozoic and Proterozoic sedimentary rocks including dolomite, limestone, quartzite, and argillite, some of which form the primary regional aquifer and the regional hydrologic "basement" (Table A-3). In Precambrian and Paleozoic time, as much as 10,000 m (32,800 ft) of marine sediments were deposited in the NNSS region (Cole 1997). The only surface exposure of Mesozoic-age rocks in the NNSS area are granitic intrusive masses, the Gold Meadows Stock north of Rainier Mesa (Gibbons et al.

1963; Snyder 1977), and the Climax Stock located at the extreme north end of Yucca Flat (Barnes et al. 1963; Maldonado 1977) (Figure A-2).

Table A-3. Pre-Tertiary stratigraphic units of the NNSS and vicinity

Map Unit	Stratigraphic Unit Map Symbol	Stratigraphic Thickness		Dominant Lithology
		Feet	Meters	
Gold Meadows Stock Climax Stock	Kgg Kgc	N/A	N/A	Quartz monzonite Granodiorite
Tippipah Limestone (correlative with the Bird Spring Formation)	PPt	3,500	1,070	Limestone
Chainman Shale and Eleana Formation	Mc MDe	4,000	1,220	Shale, argillite, and quartzite
Guilmette Formation	Dg	1,400	430	Limestone
Simonson Dolomite	Ds	1,100	330	Dolomite
Sevy Dolomite	DSs	690	210	Dolomite
Laketown Dolomite	Sl	650	200	Dolomite
Ely Spring Dolomite	Oes	340	105	Dolomite
Eureka Quartzite	Oe	400	125	Quartzite
Antelope Valley Limestone	Oa	1,530	466	Limestone
Ninemile Formation	On	335	102	Limestone
Goodwin Limestone	Og	685	209	Limestone
Nopah Formation	Cn	2,050	620	Limestone
Bonanza King Formation	Cb	4,350	1,330	Limestone/dolomite
Carrara Formation (upper)	Cc	925	280	Limestone
Carrara Formation (lower)	Cc	925	280	Shale/Siltstone
Zabriskie Quartzite	Cz	200	60	Quartzite
Wood Canyon Formation	CZw	2,300	700	Micaceous quartzite
Stirling Quartzite	Zs	2,900	890	Quartzite
Johnnie Formation	Zj	3,000	914	Quartzite/siltstone/limestone

(Stratigraphic units and lithologies adapted from Cole [1992])

A.1.2 Stratigraphy

In order to confidently characterize the geology at the NNSS, geoscientists must start from a well-understood stratigraphic system. Refinement of the stratigraphy of the area was a continuous process during the decades in which geoscientists associated with the Weapons Testing Program worked to understand the complex volcanic setting (documented by Byers et al. 1989). The need to develop detailed geologic models in support of the Underground Test Area (UGTA) activity (Chapter 11 of the main report) intensified this process, and the recognition of smaller and smaller distinct volcanic units permitted a greater understanding of the three-dimensional configuration of the various types of rocks, which has been incorporated into the geologic framework. Efforts to understand the structure and stratigraphy of the non-volcanic rocks (pre-Tertiary) have also continued to a lesser degree (Cashman and Trexler 1991; Cole 1997; Cole and Cashman 1999; Trexler et al. 2003). The most widespread and significant Quaternary and Tertiary (mainly volcanic) units of the NNSS area are listed in Table A-2. Refer to Table A-3 for a list of Mesozoic (granitic), Paleozoic (sedimentary), and Precambrian (sedimentary and metamorphic) stratigraphic units.

A.1.3 Structural Controls

Geologic structures define the geometric configuration of the area, including the distribution, thickness, and orientation of units. Synvolcanic structures, including caldera faults and some normal faults, had a strong influence on depositional patterns of many of the units. Geologic structures are an important component of the hydrogeology of the area. The juxtaposition of units with different hydrologic properties across faults may have significant hydrogeologic consequences. Also, faults may act as either conduits or barriers to groundwater flow, depending on the difference in permeability between a fault zone and the surrounding rocks and the fault orientation within the present stress field. This is partially determined by whether the fault zone is characterized by open fractures, or if it is associated with fine-grained gouge or increased alteration, which can reduce permeability.

Five main types of structural features exist in the area:

- Thrust faults (e.g., Belted Range and Control Point [CP] thrusts)
- Normal faults (e.g., Yucca and West Greeley faults)
- Transverse faults and structural zones (e.g., Rock Valley and Cane Spring faults)
- Calderas (e.g., Timber Mountain and Silent Canyon caldera complexes)
- Detachment faults (e.g., Fluorspar Canyon–Bullfrog Hills detachment fault)

The Belted Range thrust fault is the principal pre-Tertiary structure in the NNSS region and, thus, controls the distribution of pre-Tertiary rocks in the area. The fault can be traced or inferred from Bare Mountain, just south of the southwest corner of the NNSS area, to the northern Belted Range, just north of the NNSS, a distance of more than 130 km (81 mi). It is an eastward-directed thrust fault that generally places late Proterozoic to early Cambrian rocks over rocks as young as Mississippian. Several imbricate thrust faults have been identified east of the main thrust fault. Deformation related to the Belted Range thrust fault occurred sometime between 100 and 250 Ma. Lesser thrusts of similar age are also mapped in the area (e.g., the CP and Spotted Range thrusts).

Normal faults in the area are related mainly to basin-and-range extension (e.g., Yucca fault in Yucca Flat and West Greeley fault on Pahute Mesa). Most of these faults likely developed during and after the main phase of volcanic activity of the SWNVF (Sawyer et al. 1994). The majority of these faults are northwest- to northeast-striking, high-angle faults. However, the exact locations, amount of offset along the faults, and character of the faults become increasingly uncertain with depth.

Calderas are probably the most hydrogeologically important features in the NNSS area. Volcano-tectonic and geomorphic processes related to caldera development resulted in abrupt and dramatic lithologic and thickness changes across caldera margins. Consequently, caldera margins (i.e., faults) separate regions with considerably different hydrogeologic character.

A.2 Hydrology

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The hydrologic character of the NNSS and vicinity reflects the region's arid climatic conditions and complex geology (D'Agnese et al. 1997). The hydrology of the NNSS has been extensively studied for over 60 years (U.S. Department of Energy, Nevada Operations Office [DOE/NV] 1996); numerous scientific reports and large databases are available (refer to cited references for more detailed information). The following subsections present an overview of the hydrologic setting of the NNSS and vicinity, including summary descriptions of surface water and groundwater, hydrogeologic framework, and brief descriptions of the hydrogeology for each of the idle underground test areas on the NNSS. The reader is directed to Chapter 11 of the main report for a discussion of the hydrogeologic modeling efforts conducted through the UGTA activity.

A.2.1 Surface Water

The NNSS is located within the Great Basin, a closed hydrographic province that comprises numerous closed (no outlet for surface water) hydrographic subbasins (Figure A-3). The closed hydrographic basins of the NNSS (most notably Yucca and Frenchman Flats) are subbasins of the Great Basin. Streams in the region are ephemeral, flowing only in response to precipitation events or snowmelt. Runoff is conveyed through normally dry washes toward the lowest areas of the closed hydrographic subbasins, and collects on playas. There are two playas (seasonally dry lakes) on the NNSS: Frenchman Lake and Yucca Lake, which lie in Frenchman and Yucca Flats, respectively. While water may stand on the playas for a few weeks before evaporating, the playas are dry most of the year. Surface water may leave the NNSS in only a few places, such as Fortymile Canyon in the southwestern NNSS.

Springs that emanate from local perched groundwater systems are the only natural sources of perennial surface water in the region. There are 28 known springs and seeps on the NNSS (Hall and Perry 2020) (Figure A-4). Spring discharge rates are low, ranging from 0.014 to 2.2 liters/second (0.22 to 35 gallons/minute) (International Technology Corporation [IT] 1997; Thordarson and Robinson 1971). Most water discharged from springs travels only a short distance from the source before evaporating or infiltrating into the ground. The springs are important sources of water for wildlife, but they are too small to be of use as a public water supply source.

Other surface waters on the NNSS include man-made impoundments constructed at several locations throughout the NNSS to support various operations. These are numerous and include open industrial reservoirs, containment ponds, and sewage lagoons. Surface water is not a source of drinking water on the NNSS.

A.2.2 Groundwater

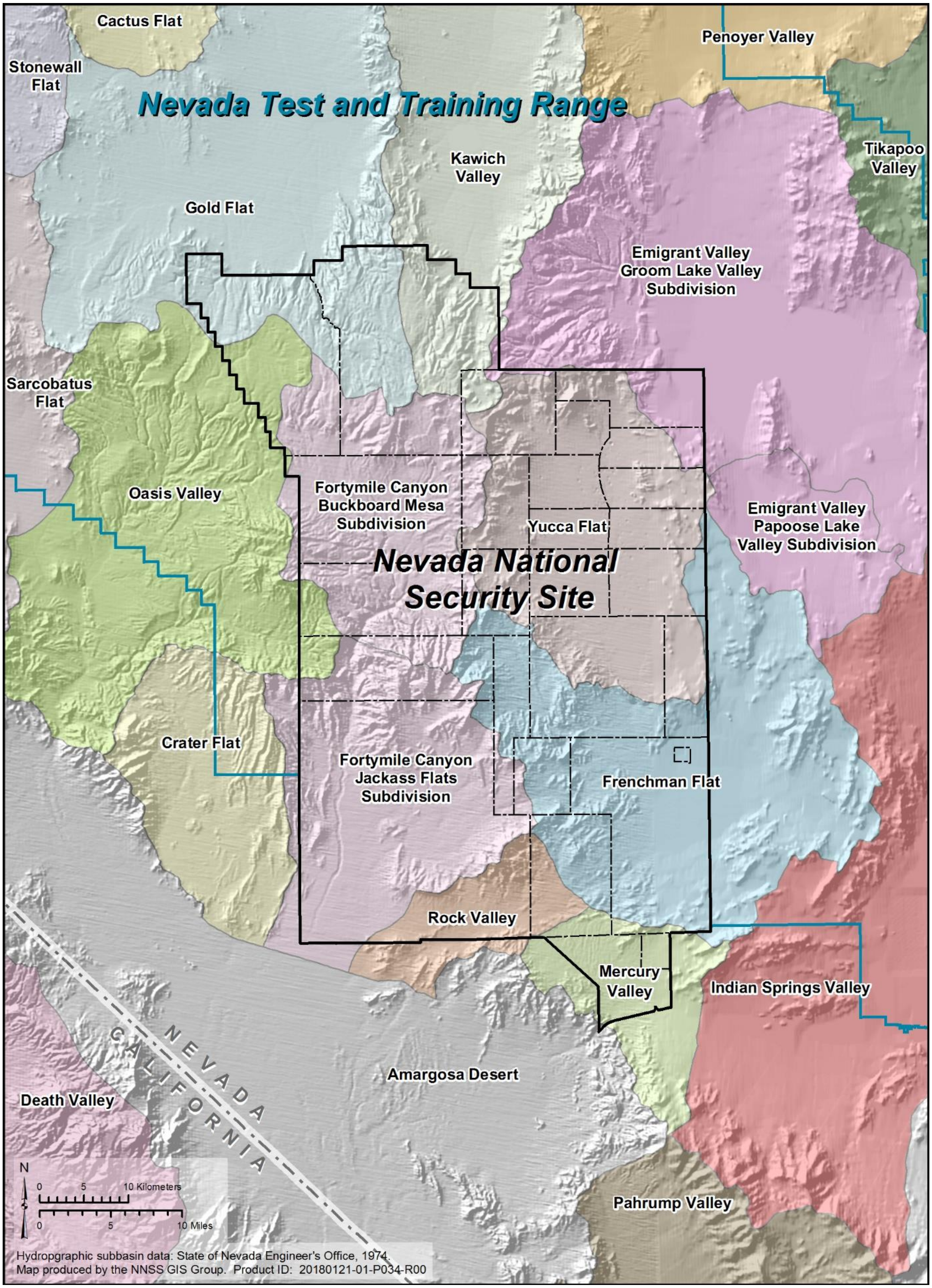
The NNSS is located within the Death Valley regional groundwater flow system, one of the major hydrologic subdivisions of the southern Great Basin (Waddell et al. 1984; Laczniak et al. 1996). Groundwater in southern Nevada is conveyed within several flow-system subbasins in the Death Valley regional flow system (a subbasin is defined as the area that contributes water to a major surface discharge area [Laczniak et al. 1996]). Three principal groundwater subbasins, named for their down-gradient discharge areas, have been identified within the NNSS region: the Ash Meadows, Oasis Valley, and Alkali Flat-Furnace Creek Ranch subbasins (Waddell et al. 1984; Fenelon et al. 2010) (Figure A-5).

The groundwater-bearing rocks at the NNSS have been classified into several hydrogeologic units (HGUs) (Section A.2.3), of which the most important is the lower carbonate aquifer, a thick sequence of Paleozoic-age carbonate rock. This unit extends throughout the subsurface of central and southeastern Nevada, and is considered to be a regional aquifer (Winograd and Thordarson 1975; Laczniak et al. 1996; IT 1996a). Various volcanic and alluvial aquifers are also locally important as water sources.

In general, the static water level across the NNSS is deep, but measured depths vary depending on the land elevation from which each well was drilled. The depth to groundwater in wells at the NNSS varies from about 210 m (690 ft) below the land surface under the Frenchman Flat playa in the southeastern NNSS, to more than 610 m (2,000 ft) below the land surface in the northwestern NNSS beneath Pahute Mesa (Reiner et al. 1995; Robie et al. 1995; IT 1996b; O’Hagan and Laczniak 1996; Bright et al. 2001; Locke and La Camera 2003; Fenelon 2005, 2007; Fenelon et al. 2010; Elliott and Fenelon 2013). Perched groundwater (isolated lenses of water lying above the regional groundwater level) occurs locally throughout the NNSS, mainly within the volcanic rocks.

Recharge areas for the Death Valley groundwater system are the higher mountain ranges of central and southern Nevada, where there can be significant precipitation and snowmelt. Groundwater flow is generally from these upland areas to natural discharge areas in the south and southwest. Groundwater at the NNSS is also derived from underflow from basins up-gradient of the area (Harrill et al. 1988). The direction of groundwater flow may locally be influenced by structure, rock type, or other geologic conditions. Based on existing water-level data (Hale et al. 1995; Reiner et al. 1995; IT 1996b; Fenelon et al. 2010; Elliott and Fenelon 2013) and flow models (IT 1996a; D’Agnese et al. 1997; Stoller-Navarro Joint Venture [SNJV] 2006a, 2006b, 2007; Navarro Nevada Environmental Services, LLC [NNES], 2010a, 2010b; Belcher et al. 2017), the general groundwater flow direction within major water-bearing units beneath the NNSS is to the south and southwest (Figure A-6).

Most of the natural discharge from the Death Valley flow system is via transpiration by plants or evaporation from soil and playas in the Amargosa Desert and Death Valley (Laczniak et al., 1996). Groundwater discharge at the NNSS is minor, consisting of small springs that drain perched water lenses and artificial discharge at a limited number of water supply wells.



Hydropgraphic subbasin data: State of Nevada Engineer's Office, 1974.
Map produced by the NNSS GIS Group. Product ID: 20180121-01-P034-R00

Figure A-3. Hydrographic subbasins on the NNSS (from State of Nevada Engineers Office 1974)

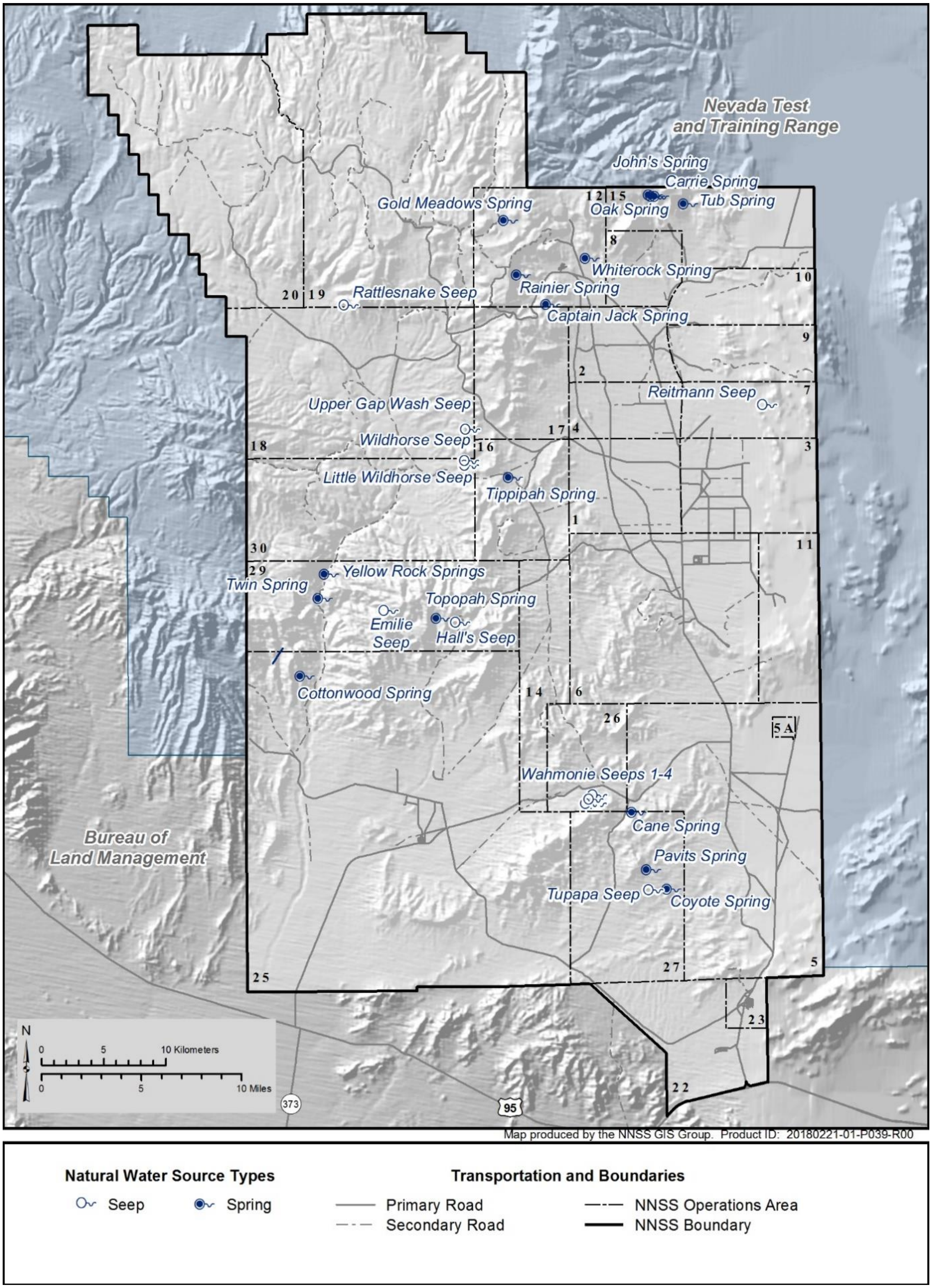


Figure A-4. Natural springs and seeps on the NNSS (adapted from Hall and Perry 2020)

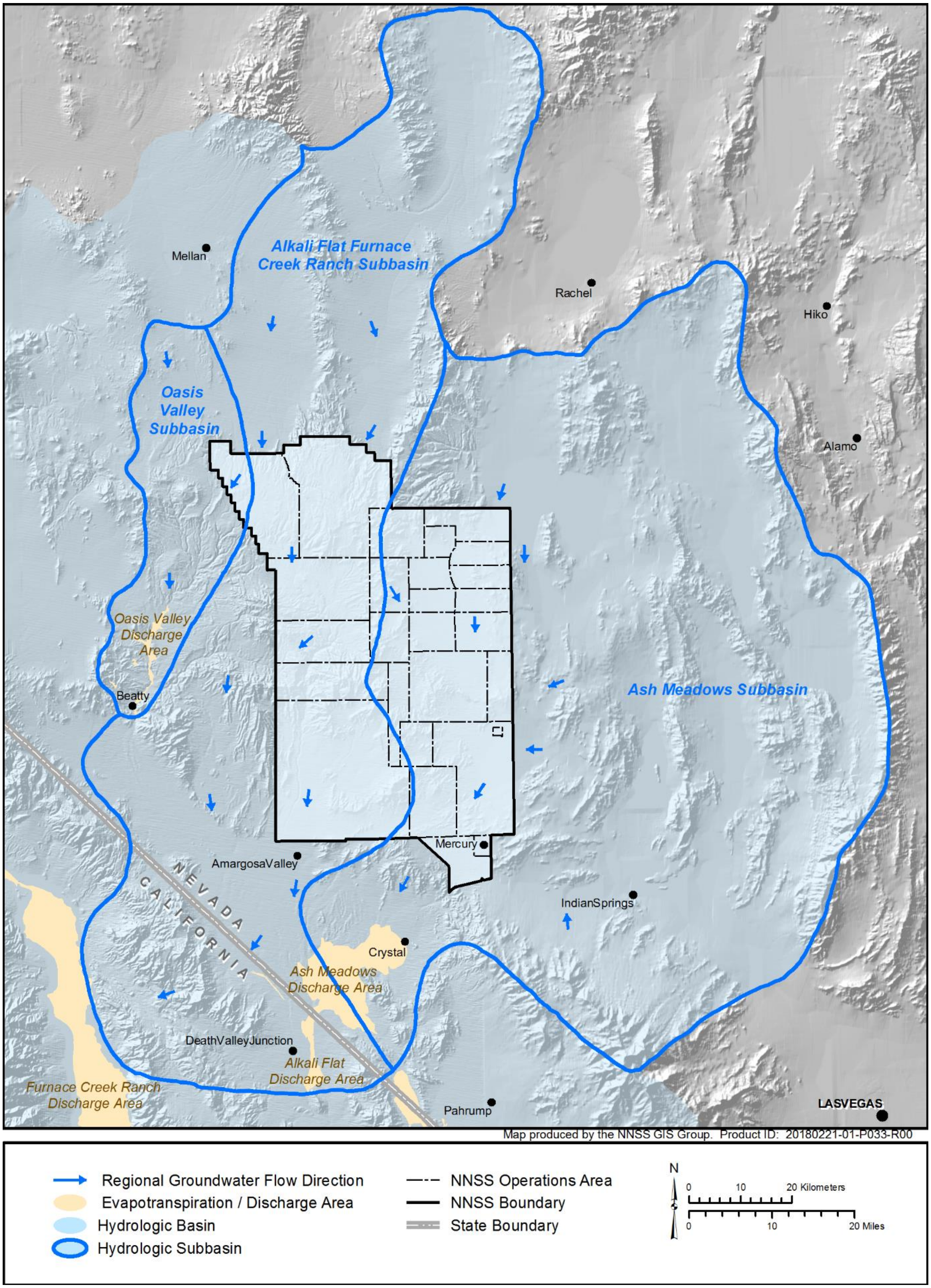
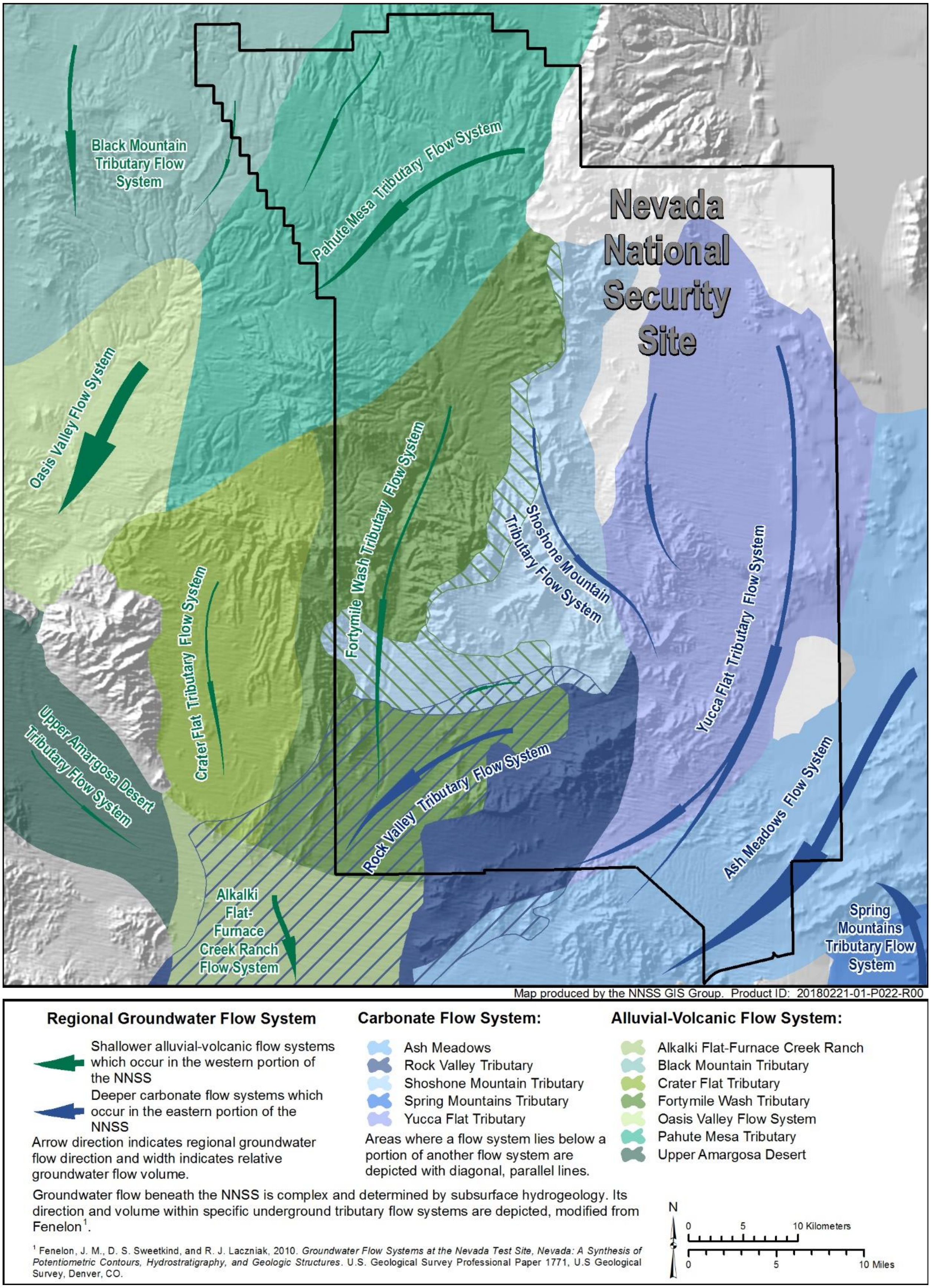


Figure A-5. Groundwater subbasins of the NNSS and vicinity (modified from Waddell et al. 1984; Laczniak et al. 1996, 2001)



Map produced by the NNSS GIS Group. Product ID: 20180221-01-P022-R00

Groundwater flow beneath the NNSS is complex and determined by subsurface hydrogeology. Its direction and volume within specific underground tributary flow systems are depicted, modified from Fenelon[1].

[1] Fenelon, J. M., D. S. Sweetkind, and R. J. Laczniak, 2010. *Groundwater Flow Systems at the Nevada Test Site, Nevada: A Synthesis of Potentiometric Contours, Hydrostratigraphy, and Geologic Structures*. U.S. Geological Survey Professional Paper 1771, U.S Geological Survey, Denver, CO.

Figure A-6. Groundwater flow systems on the NNSS

Groundwater is the only local source of potable water on the NNSS. The supply wells that make up the NNSS water system (Gillespie et al. 1996; U.S. Department of Energy, National Nuclear Security Administration Nevada Site Office [NNSA/NSO] 2008) and the other supply wells for the various water systems in the area (town of Beatty, small mines, and local ranches) produce water for human and industrial use from the carbonate, volcanic, and alluvial aquifers. Water chemistry varies from a sodium-potassium-bicarbonate type to a calcium-magnesium-carbonate type, depending on the mineralogical composition of the aquifer source. Groundwater quality within aquifers of the NNSS is generally acceptable for drinking water and industrial and agricultural uses (Chapman 1994) and meets Safe Drinking Water Act standards (Chapman and Lyles 1993; Rose et al. 1997; MSTS 2021).

A.2.3 Hydrogeologic Framework for the NNSS and Vicinity

When the need for testing nuclear devices underground was recognized in the 1950s, among the first concerns was the effect testing would have on the groundwater of the area. One of the earliest nuclear tests conducted below the groundwater table (the Bilby test conducted in 1963) was designed in part to study explosion effects on groundwater and the movement in groundwater of radioactive byproducts from the explosion (Hale et al. 1963; Garber 1971). Since that time, additional studies at various scales have been conducted to aid in the understanding of groundwater flow at the NNSS. The current understanding of the regional groundwater flow at the NNSS is derived from work by Winograd and Thordarson (1975), which was summarized and updated by Laczniak et al. (1996), and has further been developed by the UGTA activity hydrogeologic modeling team (IT 1996a; Bechtel Nevada [BN] 2002a, 2005, 2006a; NSTec 2007, 2009a) (Chapter 11 of the main report).

Winograd and Thordarson (1975) established a hydrogeologic framework, incorporating the work of Blankennagel and Weir (1973), who first defined HGUs to address the complex hydraulic properties of volcanic rocks. HGUs are used to categorize lithologic units according to their ability to transmit groundwater, which is mainly a function of their primary lithologic properties, degree of fracturing, and secondary mineral alteration. Hydrostratigraphic units (HSUs) for the NNSS volcanic rocks were first defined during the UGTA modeling initiative (IT 1996a). HSUs are groupings of contiguous stratigraphic units that have a particular hydrogeologic character, such as an aquifer (unit through which water moves readily) or confining unit (unit that generally is impermeable to water movement). The concept of HSUs is very useful in volcanic terrains where stratigraphic units can vary greatly in hydrologic character both laterally and vertically.

The rocks of the NNSS have been classified for hydrologic modeling using this two-level classification scheme in which HGUs are grouped to form HSUs (IT 1996a; NSTec 2009a). An HSU may consist of several HGUs, but is defined so that a single general type of HGU dominates (for example, mostly welded-tuff and vitric-tuff aquifers or mostly tuff confining units).

A.2.3.1 Hydrogeologic Units

All the rocks of the NNSS and vicinity can be classified as one of ten HGUs, which include the alluvial aquifer, a playa confining unit, four volcanic HGUs, two intrusive units, and two HGUs that represent the pre-Tertiary rocks (Table A-4).

The deposits of alluvium (alluvial aquifer) fill the main basins of the NNSS, and generally consist of a consolidated mixture of boulders, gravel, and sand derived from volcanic and Paleozoic sedimentary rocks through erosion (Slate et al. 1999). The finest sediments can be deposited as playa deposits (or dry lake beds) in some closed basins (e.g., Yucca and Frenchman Flats). Because of their silty/clayey nature, these fine-grained units tend to behave hydrologically as confining units (restrictive of groundwater flow).

Table A-4. Hydrogeologic units of the NNSS area

Hydrogeologic Unit (Symbol)	Typical Lithologies	Hydrologic Significance
Alluvial Aquifer (AA)	Unconsolidated to partially consolidated gravelly sand, eolian sand, and colluvium	Has characteristics of a highly conductive aquifer, but less so where lenses of clay-rich paleocolluvium or zeolitic alteration are present at depth.
Playa Confining Unit (PCU)	Clayey silt, sandy silt	Surface and near-surface confining unit at Yucca and Frenchman Lakes and within the lower portion of the alluvial section in the deepest portions of Frenchman Flat.
Welded-Tuff Aquifer (WTA)	Welded ash-flow tuff; vitric to devitrified	Degree of welding greatly affects interstitial porosity (less porosity as degree of welding increases) and permeability (greater fracture permeability as degree of welding increases).
Vitric-Tuff Aquifer (VTA)	Bedded tuff; ash-fall and reworked tuff; vitric	Constitutes a volumetrically minor hydrogeologic unit. Generally does not extend far below the static water level due to tendency to become zeolitized (which drastically reduces permeability) under saturated conditions. Significant interstitial porosity (20% to 40%). Generally insignificant fracture permeability.
Lava-Flow Aquifer (LFA)	Rhyolite, basalt, and dacite lava flows; includes flow breccias (commonly at base) and pumiceous zones (commonly at top)	Generally occurs as small, moderately thick (rhyolite) to thin (basalt) local flows. Hydrologically complex; wide range of transmissivities; fracture density and interstitial porosity differ with lithologic variations.
Tuff Confining Unit (TCU)	Zeolitic bedded tuff with interbedded, but less significant, zeolitic, nonwelded to partially welded ash-flow tuff	May be saturated but measured transmissivities are very low. May cause accumulation of perched and/or semi-perched water in overlying units.
Intracaldera Intrusive Confining Unit (IICU)	Highly altered, highly injected/intruded country rock and granitic material	Assumed to be impermeable. Conceptually underlies each of the SWNVF calderas and Calico Hills.
Granite Confining Unit (GCU)	Granodiorite, quartz monzonite	Relatively impermeable; forms local bulbous stocks, north of Rainier Mesa and Yucca Flat; may contain perched water.
Clastic Confining Unit (CCU)	Argillite, siltstone, quartzite	Clay-rich rocks are relatively impermeable; more siliceous rocks are fractured, but with fracture porosity generally sealed due to secondary mineralization.
Carbonate Aquifer (CA)	Dolomite, limestone	Transmissivity values differ greatly and are directly dependent on fracture frequency.

Note: Adapted from NSTec (2009a).

The volcanic rocks of the NNSS and vicinity can be categorized into four HGUs based on primary lithologic properties, degree of fracturing, and secondary mineral alteration (Table A-4). In general, the altered (typically zeolitized but hydrothermally altered near caldera margins) volcanic rocks act as confining units (tuff confining unit), and the unaltered rocks form aquifers. The volcanic aquifer units can be further divided into welded-tuff aquifers or vitric-tuff aquifers (depending upon the degree of welding) and lava-flow aquifers. The denser rocks (welded ash-flow tuffs and lava flows) tend to fracture more readily and therefore have relatively high permeability (Blankennagel and Weir 1973; Winograd and Thordarson 1975; Laczniak et al. 1996; IT 1996c, 1997; Prothro and Drellack 1997).

The pre-Tertiary sedimentary rocks at the NNSS and vicinity are also categorized as aquifer or confining unit HGUs based on lithology. The silicic clastic rocks (quartzite, siltstone, shale) tend to be aquitards or confining units, while the carbonates (limestone and dolomite) tend to be aquifers (Winograd and Thordarson 1975; Laczniak et al. 1996). The granite confining unit is considered to behave as a confining unit due to low primary porosity and low permeability, and because most fractures tend to be filled with secondary minerals (Walker 1962).

A.2.3.2 Hydrostratigraphic Units

The rocks at the NNSS and vicinity are grouped into more than 76 HSUs (NSTec 2009a). The more important and widespread HSUs in the area are discussed separately below, from oldest to youngest. Additional information regarding other HSUs is summarized in Section A.2.5, and can be found in the documentation packages for the UGTA corrective action unit (CAU)-scale hydrogeologic models (BN 2002a, 2005, 2006a; NSTec 2007).

Lower Clastic Confining Unit (LCCU) – The Proterozoic to Middle-Cambrian-age rocks are largely quartzite and silica-cemented siltstone. Although these rocks are brittle and commonly fractured, secondary mineralization has apparently greatly reduced formation permeability (Winograd and Thordarson 1975). These units make up the LCCU, which is considered to be the regional hydrologic basement (IT 1996a). The LCCU is interpreted to underlie the entire region, except at the calderas. Where it is in a structurally high position, the LCCU may act as a barrier to deep regional groundwater flow.

Lower Carbonate Aquifer (LCA) – The LCA consists of thick sequences of Middle Cambrian through Upper Devonian carbonate rocks. This HSU serves as the regional aquifer for most of southern Nevada and, locally, may be as thick as 5,000 m (16,400 ft) (Cole 1997; Cole and Cashman 1999). The LCA is present under most of the area, except where the LCCU is structurally high and at the calderas. Measured transmissivities of these rocks differ from place to place, apparently reflecting the observed differences in fracture and fault densities and characteristics (Winograd and Thordarson 1975; NSTec 2009b).

Upper Clastic Confining Unit (UCCU) – Upper Devonian and Mississippian silicic clastic rocks in the NNSS vicinity are assigned to the Eleana Formation and the Chainman Shale (Trexler et al. 1996, 2003; Cashman and Trexler 1991). Both formations are grouped into the UCCU. At the NNSS, this HSU is found mainly within a north-south band along the western portion of Yucca Flat. It is a significant confining unit and in many places forms the footwall of the Belted Range and CP thrust faults.

Lower Carbonate Aquifer - Upper Thrust Plate (LCA3) – Cambrian through Devonian, mostly carbonate rocks that occur in the hanging walls of the Belted Range and CP thrust faults are designated as LCA3. These rocks are equivalent stratigraphically to the LCA but are structurally separated from the LCA by the Belted Range thrust fault. The LCA3 is patchily distributed as remnant thrust blocks, particularly along the western and southern sides of Yucca Flat (at Mine Mountain and the CP Hills), at Calico Hills, and at Bare Mountain.

Mesozoic Granite Confining Unit (MGCU) – The Mesozoic era is represented at the NNSS only by intrusive igneous rocks. Cretaceous-age granitic rocks are exposed at two locations: in northern Yucca Flat at the Climax Stock, and the Gold Meadows Stock, which lies 12.9 km (8 mi) west of the Climax Stock, just north of Rainier Mesa (Snyder 1977; Bath et al. 1983) (Figure A-2). The two are probably related in both source and time and are believed to be connected at depth (Jachens 1999; Phelps et al. 2004). Because of its low intergranular porosity and permeability, and the lack of inter-connecting fractures (Walker 1962), the MGCU is considered a confining unit. The Climax and Gold Meadows intrusives are grouped into the MGCU HSU.

Tertiary and Quaternary Hydrostratigraphic Units – Tertiary- and Quaternary-age strata at the NNSS are organized into dozens of HSUs. Nearly all are of volcanic origin, except the alluvial aquifer and playa confining unit, which are the uppermost HSUs. These rocks are important because (1) most of the underground nuclear tests at the NNSS were conducted in these units, (2) they constitute a large percentage of the rocks in the area, and (3) they are inherently complex and heterogeneous. As pointed out in Section A.2.3.1, the volcanic rocks are divided into aquifer or confining units according to lithology and secondary alteration. More detailed information can be found in the documentation packages for the UGTA CAU-scale hydrogeologic models (BN 2002a, 2005, 2006a; NSTec 2007, 2009b).

Alluvial Aquifer (AA) – The alluvium throughout most of the NNSS is a consolidated mixture of detritus derived from silicic volcanic and Paleozoic-age sedimentary rocks, ranging in particle size from clay to boulders. Sediment deposition is largely in the form of alluvial fans (debris flows, sheet wash, and braided streams), which coalesce to form discontinuous, gradational, and poorly sorted deposits. Eolian sand, playa deposits, and rare basalt flows are also present within the alluvial section of some valleys. The alluvium thickness in major valleys (e.g., Frenchman Flat and Yucca Flat) generally ranges from about 30 m (100 ft) to more than 1,128 m (3,700 ft) in the deepest subbasins. The AA HSU is restricted primarily to the basins of the NNSS. However, because the water table in the vicinity is moderately deep, the alluvium is generally unsaturated, except in the deep subbasins of some valleys. These sediments are porous and, thus, have high storage coefficients. Hydraulic conductivity may also be high, particularly in the coarser, gravelly beds.

A.2.4 General Hydraulic Characteristics of NNSS Rocks

Volcanic rocks at the NNSS are extremely variable in lithologic character both laterally and vertically. The rock characteristics that control the density and character of fractures are the primary determinants of their hydraulic properties, and most hydraulic heterogeneity ultimately is related to fracture characteristics such as fracture density, openness, orientation, and other properties. Secondary fracture-filling minerals can drastically obstruct the flow through or effectively seal an otherwise transmissive formation (IT 1996c; Drellack et al. 1997). Fracture density typically increases with proximity to faults, potentially increasing the hydraulic conductivity of the formation; however, the hydrologic properties of faults, per se, are not well known. Limited data suggest that the full spectrum of hydraulic properties, from barrier to conduit, may be possible (Blankennagel and Weir 1973; Faunt 1998).

Table A-5 presents a brief summary of the hydrologic properties of NNSS HGUs. The lowest transmissivity values in volcanic rocks at the NNSS are typically associated with nonwelded ash-flow tuff and bedded tuff (ash-fall and reworked tuffs). Although interstitial porosity may be high, the interconnectivity of the pore space is limited, and these relatively incompetent rocks tend not to support open fractures. Secondary alteration of these tuffs (most commonly, zeolitization) ultimately produces a very impermeable unit. As described in Section A.2.3.1 and in NSTec (2009a), these zeolitized tuffs are considered to be confining units (aquicludes and aquitards). The equivalent unaltered bedded and nonwelded tuffs are considered to be vitric-tuff aquifers, and have intermediate transmissivities.

In general, the most transmissive rocks tend to be moderately to densely welded ash-flow tuffs (welded-tuff aquifer), rhyolite lava flows (lava-flow aquifer), and carbonate rocks (limestone and dolomite). Although their interstitial porosity is low, these competent lithologies tend to be highly fractured, and groundwater flow through these rocks is largely through an interconnected network of fractures (Blankennagel and Weir 1973; GeoTrans, Inc. 1995).

Underground nuclear explosions affect hydraulic properties of the geologic medium, creating both long-term and short-term effects. Effects include enhanced permeability from shock-induced fractures, the formation of vertical conduits (e.g., collapse chimneys), and elevated water levels (mounding and over-pressurization of saturated low-permeability units). However, these effects tend to be localized (Borg et al. 1976; Brikowski 1991; Allen et al. 1997).

Table A-5. Summary of hydrologic properties for hydrogeologic units at the NNSS

Hydrogeologic Unit[a]			Fracture Density[b, c]	Relative Hydraulic Conductivity[c]
Alluvial Aquifer			Very low	Moderate to very high
Vitric-Tuff Aquifer			Low	Low to moderate
Welded-Tuff Aquifer			Moderate to high	Moderate to very high
Lava-Flow Aquifer[d]	Pumiceous Lava	Vitric	Low	Low to moderate
		Zeolitic	Low	Very low
	Stoney Lava and Vitrophyre		Moderate to high	Moderate to very high
	Flow Breccia		Low to moderate	Low to moderate
Tuff Confining Unit			Low	Very low
Intrusive Confining Unit			Low to moderate	Very low
Granite Confining Unit			Low to moderate	Very low
Carbonate Aquifer			Low to high (variable)	Low to very high
Clastic Confining Unit			Moderate	Very low to low[e]

(a) Refer to Table A-4 for hydrogeologic nomenclature.
(b) Including primary (cooling joints in tuffs) and secondary (tectonic) fractures.
(c) The values presented are from BN (2002a).
(d) Abstracted from Prothro and Drellack (1997).
(e) Fractures tend to be sealed by the presence of secondary minerals.
Note: Adapted from BN (2002a).

A.2.5 Hydrogeology of the NNSS Underground Test Areas

Most NNSS underground nuclear detonations were conducted in three main UGTAs (Figure A-7; NNSA/NFO 2015): (1) Yucca Flat, (2) Pahute Mesa, and (3) Rainier Mesa (including Aqueduct Mesa). Underground tests in Yucca Flat and Pahute Mesa typically were conducted in vertical drill holes, whereas almost all tests conducted in Rainier Mesa were tunnel emplacements. A total of 85 underground tests (85 detonations) were conducted on Pahute Mesa, including 18 high-yield detonations (more than 200 kt). Rainier Mesa hosted 61 underground tests (62 detonations), almost all of which were relatively low-yield (less than 20 kt), tunnel-based weapons-effects tests. Yucca Flat was the most extensively used UGTA, hosting 659 underground tests (747 detonations), 4 of which were high-yield detonations (Allen et al. 1997; NNSA/NFO 2015).

In addition to the three main UGTAs, underground nuclear tests were conducted in Frenchman Flat (ten tests), Shoshone Mountain (six tests), the Oak Spring Butte/Climax Mine area (three tests), the Buckboard Mesa area (three tests), and Dome Mountain (one test with five detonations) (Allen et al. 1997; NNSA/NFO 2015). It should be noted that these totals include nine cratering tests (13 total detonations) conducted in various areas of the NNSS. Table A-1 is a synopsis of information about the locations of UGTAs at the NNSS, and Figure A-7 shows the areal distribution of underground nuclear tests conducted at the NNSS.

The location of each underground nuclear test is classified as a corrective action site (CAS). These in turn have been grouped into five CAUs, according to the Federal Facility Agreement and Consent Order (FFACO; as amended), between the U.S. Department of Energy (DOE), the State of Nevada, and the U.S. Department of Defense. In general, the CAUs relate to the geographical UGTAs on the NNSS (Figure A-7).

The hydrogeology of the four main NNSS UGTAs is summarized in the following subsections. For detailed stratigraphic descriptions of geologic units at the NNSS (including each of the UGTAs), see Sawyer et al. (1994) and Slate et al. (1999).

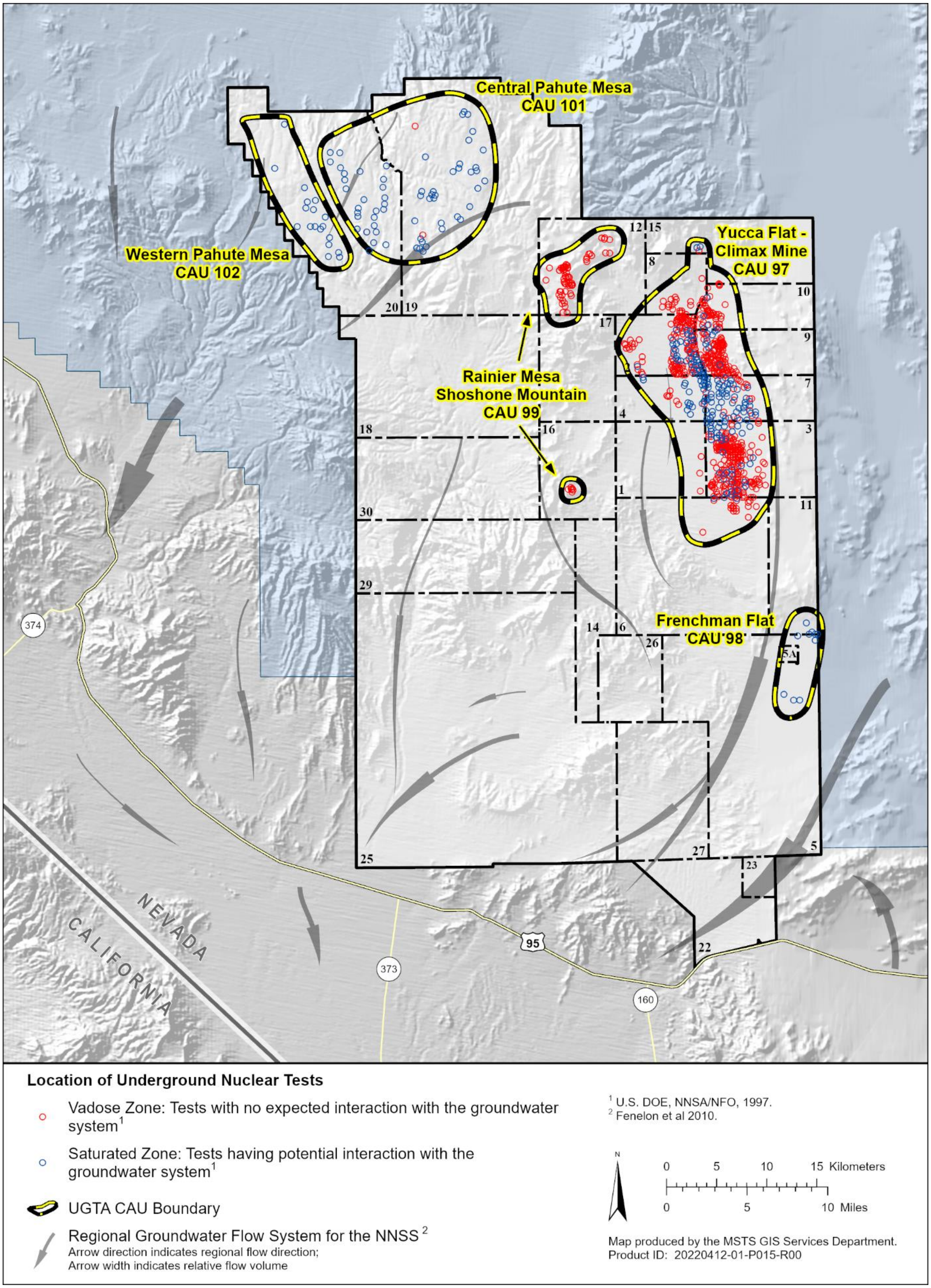


Figure A-7. Locations of UGTA CAUs and historical underground nuclear tests

A.2.5.1 Frenchman Flat Underground Test Area

The Frenchman Flat CAU consists of ten CASs located in the northern part of NNSS Area 5 and southern part of Area 11 (Figure A-7). The detonations were conducted in vertical emplacement holes and two mined shafts. Most of the tests were conducted in alluvium above the water table (BN 2005).

Physiography – Frenchman Flat is a closed intermontane basin located in the southeastern portion of the NNSS. It is bounded on the north by Massachusetts Mountain and the Halfpint Range, on the east by the Buried Hills, on the south by the Spotted Range, and on the west by the Wahmonie volcanic center (Figure A-2). The sparsely vegetated valley floor slopes gently toward a central playa lakebed. Ground-level elevations range from 938 m (3,078 ft) above sea level at the playa, to over 1,463 m (4,800 ft) in the nearby surrounding mountains.

Geology Overview – The stratigraphic section for Frenchman Flat consists of (from oldest to youngest) Proterozoic and Paleozoic clastic and carbonate rocks, Tertiary sedimentary and tuffaceous sedimentary rocks, Tertiary volcanic rocks, and Quaternary and Tertiary alluvium (Slate et al. 1999). In the northernmost portion of Frenchman Flat, the middle to upper Miocene volcanic rocks that are derived from calderas located to the northwest of Frenchman Flat unconformably overlie Ordovician-age carbonate and clastic rocks. To the south, these volcanic units, including the Ammonia Tanks Tuff, Rainier Mesa Tuff, Topopah Spring Tuff, and Crater Flat Group, either thin considerably, interfinger with coeval sedimentary rocks, or pinch out altogether (BN 2005). Upper-middle Miocene tuffs, lavas, and debris flows from the Wahmonie volcanic center located just west of Frenchman Flat dominate the volcanic section beneath the western portion of the valley. To the south and southeast, most of the volcanic units are absent, and Oligocene to middle Miocene sedimentary and tuffaceous sedimentary rocks, which unconformably overlie the Paleozoic rocks in the southern portion of Frenchman Flat, dominate the Tertiary section (Prothro and Drellack 1997). In most of the Frenchman Flat area, upper Miocene to Holocene alluvium covers the older sedimentary and volcanic rocks (Slate et al. 1999). Alluvium thicknesses range from a thin veneer along the valley edges to perhaps as much as 1,158 m (3,800 ft) in north central Frenchman Flat (BN 2005).

Structural Setting – The structural geology of Frenchman Flat is complex. In the late Mesozoic era, the region was subjected to compressional deformation, which resulted in folding, thrusting, uplift, and erosion of the pre-Tertiary rocks (Barnes et al. 1982). Approximately 11 Ma, the region underwent extensional deformation, during which the present basin-and-range topography was developed, and the Frenchman Flat basin was formed (Ekren et al. 1968; BN 2005). In the immediate vicinity of Frenchman Flat, extensional deformation has produced northeast-trending, left-lateral strike-slip faults and generally north-trending normal faults that displace the Tertiary and pre-Tertiary rocks. Beneath Frenchman Flat, major west-dipping normal faults merge and are probably contemporaneous with strike-slip faults beneath the southern portion of the basin (Grauch and Hudson 1995). Movement along the faults has created a relatively deep, east-dipping, half-graben basin elongated in a northeasterly direction (Figure A-8).

Hydrogeology Overview – The hydrogeology of Frenchman Flat is fairly complex but is typical of the NNSS area. Many of the HGU and HSU building blocks developed for models of the NNSS vicinity are applicable to the Frenchman Flat basin. The strata in the Frenchman Flat area have been subdivided into four Quaternary/Tertiary alluvium and playa HSUs, nine Tertiary-age volcanic HSUs, and three pre-Tertiary HSUs to serve as layers for the UGTA Frenchman Flat CAU groundwater model (BN 2005). The dominant units are listed in Table A-6.

Water-Level Elevation and Groundwater Flow Direction – The depth to the static water level (SWL) in Frenchman Flat ranges from 210 m (690 ft) near the central playa to more than 350 m (1,150 ft) at the northern end of the valley (SNJV 2004a, 2006a). The SWL is generally located within the AA, the Timber Mountain welded-tuff aquifer (TMWTA), the Topopah Spring aquifer (TSA), the Wahmonie confining unit (WCU), or the lower tuff confining unit (LTCU). In the deeper, central portions of the basin, more than half of the alluvium section is saturated. Water-level elevation data in the AA indicate a very flat water table (Blout et al. 1994; SNJV 2004a, 2006a; NNES 2010a).

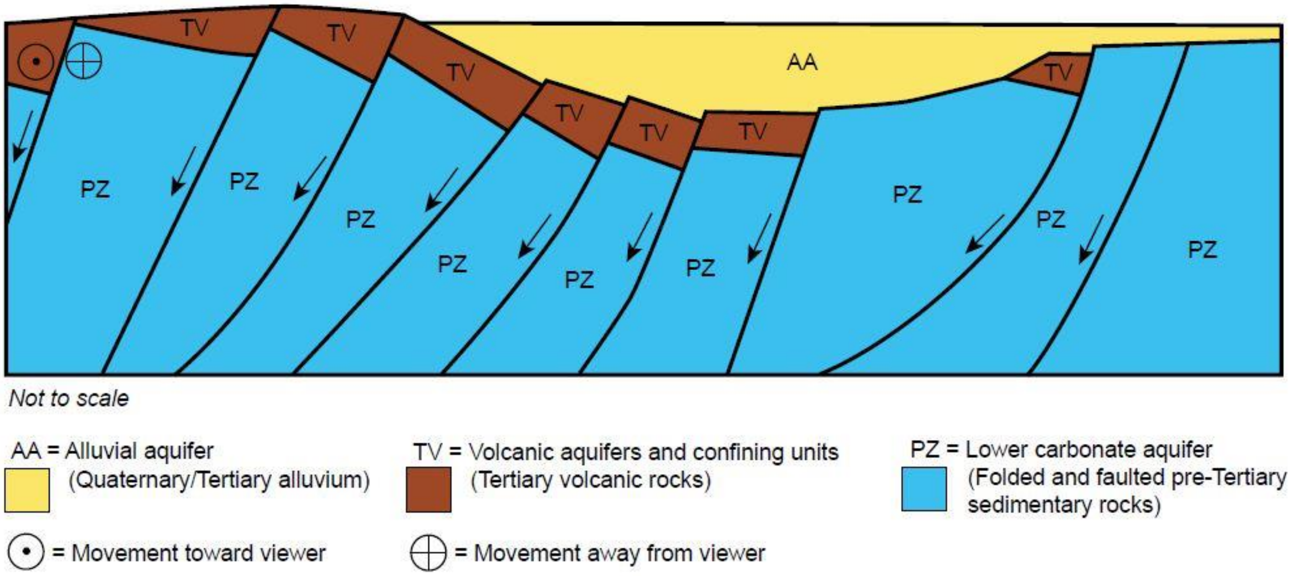


Figure A-8. Conceptual east-west cross section through Frenchman Flat

Table A-6. Dominant hydrostratigraphic units of the Frenchman Flat underground test area

Hydrostratigraphic Unit (Symbol)	Dominant Hydrogeologic Unit[(a)]	Typical Lithologies
Alluvial Aquifer (AA)	AA	Consists mainly of alluvium (gravelly sand) that fills extensional basins. Lower permeability layers, such as the older, altered alluvium and playa deposits, are differentiated as separate HSUs in the hydrogeologic models.
Timber Mountain Welded-Tuff Aquifer (TMWTA)	WTA, minor VTA	Welded ash-flow tuff and related nonwelded and ash-fall tuffs; vitric to devitrified
Timber Mountain Lower Vitric-Tuff Aquifer (TMLVTA)	VTA	Nonwelded ash-flow and bedded tuffs; vitric (unaltered)
Topopah Spring Aquifer (TSA)	WTA	Welded ash-flow tuff; vitric to devitrified
Wahmonie Confining Unit (WCU)	TCU, minor LFA	Ash-fall and reworked tuffs; debris and breccia flows; minor intercalated lava flows. Typically altered: zeolitic to argillic
Lower Tuff Confining Unit (LTCU and LTCU1)	TCU	Zeolitic bedded tuffs, with interbedded but less significant zeolitic, nonwelded to partially welded ash-flow tuffs
Volcaniclastic Confining Unit (VCU)	TCU, minor AA	Diverse assemblage of interbedded volcanic and sedimentary rocks including tuffs, shale, tuffaceous and argillaceous sandstones, conglomerates, minor limestones
Upper Clastic Confining Unit (UCCU)	CCU	Argillite, quartzite; present only in northwest portion of model in the CP Basin
Lower Carbonate Aquifer (LCA)	CA	Dolomite and limestone; the “regional aquifer”
Lower Clastic Confining Unit (LCCU)	CCU	Quartzites and siltstones; the “hydrologic basement”

(a) See Table A-4 for descriptions of HGUs
Note: Adapted from BN (2005).

Water-level data for the LCA in the southern part of the NNSS are limited, but indicate a fairly low gradient in the Yucca Flat, Frenchman Flat, and Jackass Flats areas. This gentle gradient implies a high degree of hydraulic continuity within the aquifer, presumably due to high fracture permeability (Laczniak et al. 1996). Furthermore, the similarity of the water levels measured in Paleozoic rocks (LCA) in Yucca Flat and Frenchman Flat implies that, at least for deep interbasin flow, there is no groundwater barrier between the two basins. Inferred regional groundwater flow through Frenchman Flat is to the south-southwest toward discharge areas in Ash Meadows (Figure A-5). An increasing westward flow vector in southern NNSS may be due to preferential flow paths subparallel to the northeast-trending Rock Valley fault (Grauch and Hudson 1995) and/or a northward gradient from the Spring Mountain recharge area (IT 1996a, 1996b).

Groundwater elevation measurements for wells completed in the AA and the volcanic aquifers (e.g., TMWTA, TSA) are higher than those in the underlying LCA (IT 1996b; BN 2005; SNJV 2006a). This implies a downward gradient. This apparent semi-perched condition is believed to be due to the presence of intervening LTCU and VCU.

A.2.5.2 Yucca Flat/Climax Mine Underground Test Area

The Yucca Flat/Climax Mine CAU consists of several hundred CASs located in NNSS Areas 1, 2, 3, 4, 6, 7, 8, 9, and 10, and three CASs located in Area 15 (Figure A-7). These tests were typically conducted in vertical emplacement holes and a few related tunnels (Table A-1).

The Yucca Flat and Climax Mine UGTAs were originally defined as two separate CAUs (CAU 97 and CAU 100) in the FFACO because the geologic frameworks of the two areas are distinctly different. The Yucca Flat underground nuclear tests were conducted in alluvial, volcanic, and carbonate rocks, whereas the Climax Mine tests were conducted in an igneous intrusion (granite) in northern Yucca Flat. However, particle-tracking simulations performed during the regional evaluation (IT 1997) indicated that the local Climax Mine groundwater flow system merges into the much larger Yucca Flat groundwater flow system during the 1,000-year time period of interest, so the two areas were combined into the single CAU 97.

Yucca Flat was the most heavily used UGTA on the NNSS (Figure A-7). The alluvium and tuff formations provide many characteristics advantageous to the containment of nuclear explosions. They are easily mined or drilled. The high-porosity overburden (alluvium and vitric tuffs) will accept and depressurize any gas that might escape the blast cavity. The deeper tuffs are zeolitized, which creates a nearly impermeable confining unit. The zeolites also have adsorptive and “molecular sieve” attributes that severely restrict or prevent the migration of radionuclides (Carle et al. 2008). The deep water table (greater than 503 m [1,650 ft] depth) provides additional operational and environmental benefits.

This section provides brief descriptions of the geologic and hydrogeologic setting of the Yucca Flat/Climax Mine UGTA, as well as a discussion of the hydrostratigraphic framework. This summary was compiled from various sources, including Winograd and Thordarson (1975), Byers et al. (1989), Laczniak et al. (1996), Cole (1997), IT (2002), and BN (2006a), where additional information can be found.

Physiography – Yucca Flat is a topographically closed basin with a playa at its southern end. The geomorphology of Yucca Flat is typical of the arid, inter-mountain basins found throughout the Basin and Range province of Nevada and adjoining states. Faulted and tilted blocks of Tertiary-age volcanic rocks and underlying Precambrian and Paleozoic sedimentary rocks form low ranges around the basin (Figure A-2). These rocks also compose the “basement” of the basin, which is now covered by alluvium.

Ground elevation in the Yucca Flat area ranges from about 1,195 m (3,920 ft) above mean sea level at Yucca Lake (playa) in southern Yucca Flat to about 1,463 m (4,800 ft) in the northern portion of the valley. The highest regions of the surrounding mountains and hills range from less than 1,500 m (5,000 ft) in the south to over 2,316 m (7,600 ft) at Rainier Mesa in the northwest corner of the area. Yucca Flat is bounded by the Halfpint Range to the east, by Rainier Mesa and the Belted Range to the north, by the Eleana Range and Mine Mountain to the west, and by the CP Hills, CP Hogback, and Massachusetts Mountain to the south.

Geology Overview – The Precambrian and Paleozoic rocks of the NNSS area consist of approximately 11,300 m (37,000 ft) of carbonate and silicic clastic rocks (Cole 1997). These rocks were severely deformed by compressional movements during Mesozoic time, which resulted in the formation of folds and thrust faults (e.g., Belted Range and CP thrust faults). In the middle Late Cretaceous, granitic bodies (such as the Climax Stock in northern Yucca Flat) intruded these deformed rocks (Houser and Poole 1960; Maldonado 1977).

A total of 22 pre-Tertiary formations (including the Mesozoic granitic intrusives) has been recognized in the Yucca Flat region (Table A-3). These rocks range in age from Precambrian to Cretaceous and are the result of primarily carbonate and silicic shallow- to deep-water sedimentation near a continental margin. Some of these units are widespread throughout southern Nevada and California, though complex structural deformation has created many uncertainties in determining the geometric relationships of these units around Yucca Flat.

In Cenozoic time, the sedimentary and intrusive rocks were buried by thick sections of volcanic material deposited in several eruptive cycles from source areas in the SWNVF. The Cenozoic stratigraphy of the Yucca Flat area, though not structurally complicated, is very complex. Most of the volcanic rocks of the Yucca Flat area were deposited during many eruptive cycles of the SWNVF (Section A.1.1). The source areas of most units (Volcanics of Oak Spring Butte, Tunnel Formation, Belted Range Group, Crater Flat Group, Calico Hills Formation, Paintbrush Group, and Timber Mountain Group) are located to the west and northwest of Yucca Flat; the Wahmonie source area is located southwest of Yucca Flat. Table A-2 includes the Tertiary stratigraphic units common to the Yucca Flat basin.

The volcanic rocks include primarily ash-flow tuffs, ash-fall tuffs, and reworked tuffs, whose thicknesses and extents vary partly due to the irregularity of the underlying depositional surface, and partly due to the presence of topographic barriers and windows between Yucca Flat and the source areas to the north and west.

Over the last several million years, gradual erosion of the highlands that surround Yucca Flat has deposited a thick blanket of alluvium on the tuff section. The alluvium in Yucca Flat, and throughout most of the NNSS, is a consolidated mixture of detritus derived from silicic volcanic and Paleozoic sedimentary rocks, ranging in particle size from clay to boulders. Sediment deposition is largely in the form of alluvial fans (debris flows, sheet wash, and braided streams) that coalesce to form discontinuous, gradational, and poorly sorted deposits. Eolian sand, playa deposits, and rare basalt flows are also present within the alluvium section of Yucca Flat. The alluvium thickness in Yucca Flat generally ranges from about 30 m (100 ft) to over 914 m (3,000 ft) (Drellack and Thompson 1990).

Structural Setting – The structure of the pre-Tertiary rocks in Yucca Flat is complex and poorly known (Cole 1997), but it is important because the pre-Tertiary section is very thick and extensive and includes units that form regional aquifers. The main pre-Tertiary structures in the Yucca Flat area are related to the east-vergent Belted Range thrust fault, which has placed Late Proterozoic to Cambrian-age rocks over rocks as young as Late Mississippian (Cole 1997; Cole and Cashman 1999). In several places along the western and southern portions of Yucca Flat, east-vergent structures related to the Belted Range thrust were deformed by younger west-vergent structural activity (Cole and Cashman 1999). This west-vergent deformation is related to the CP thrust fault, which also placed Cambrian and Ordovician rocks over Mississippian and Pennsylvanian-age rocks beneath western Yucca Flat (Caskey and Schweickert 1992).

Large-scale normal faulting began in Yucca Flat in response to regional extensional movements near the end of this period of volcanism. This faulting formed the Yucca Flat basin. As fault movement continued, blocks between faults were down-dropped and tilted, creating subbasins within the Yucca Flat basin.

The major basin-forming faults generally strike in a northerly direction, and relative offset is typically down to the east (e.g., Yucca, Topgallant, and Carpetbag faults). Movement along the Yucca fault in central Yucca Flat indicates deformation in the area has continued into the Holocene (Hudson 1992). Specific details regarding these faults are lacking because of the underground testing program's preference to avoid known and inferred faults during drilling of emplacement holes for underground nuclear tests.

The configuration of the Yucca Flat basin is illustrated on the generalized west-east cross section shown in Figure A-9. The cross section is simplified to show the positions of only the primary lithostratigraphic units in the region. This cross section provides a conceptual illustration of the irregular Precambrian and Paleozoic rocks overlain by the Tertiary volcanic units, and the basin-filling alluvium at the surface. The main Tertiary-age, basin-forming large-scale normal faults are also shown.

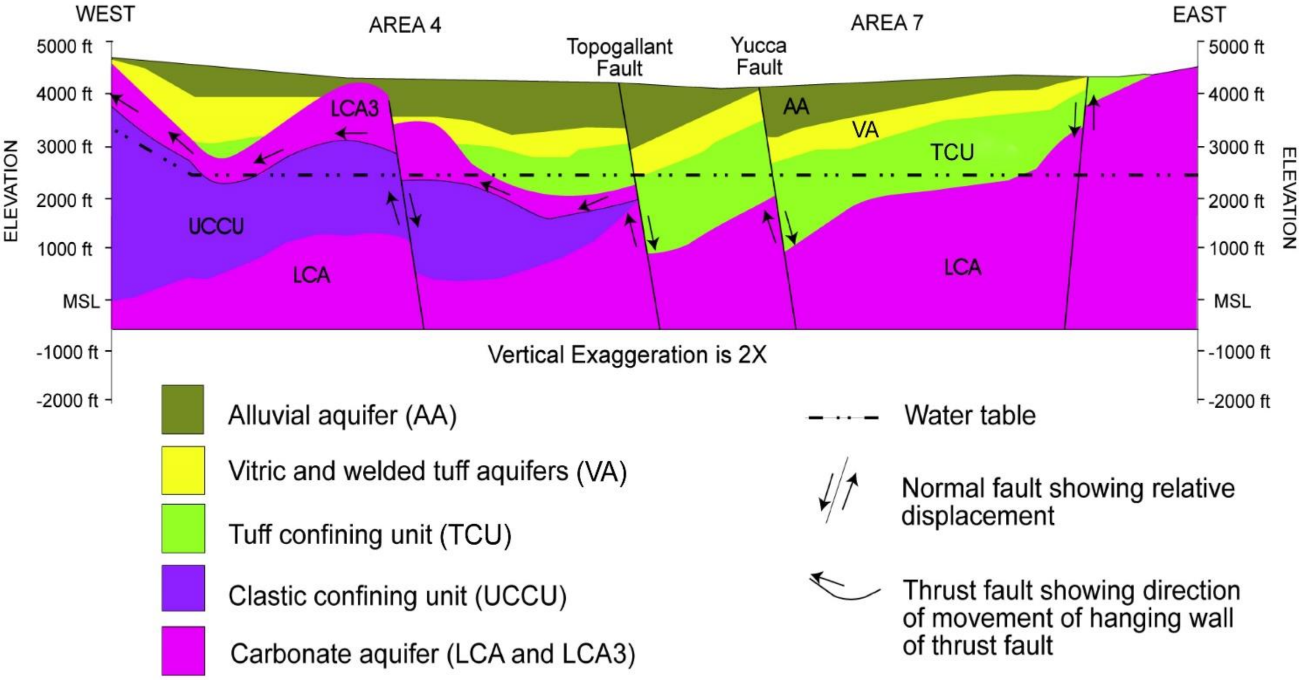


Figure A-9. Generalized west-east hydrogeologic cross section through central Yucca Flat
MSL=mean sea level

Hydrogeologic Overview – All the rocks of the Yucca Flat underground test area can be classified as one of eight HGUs (Table A-4), which include the AA, four volcanic HGUs, an intrusive unit, and two HGUs that represent the pre-Tertiary rocks.

The strata in Yucca Flat have been subdivided into 11 Tertiary-age HSUs (including the Tertiary/Quaternary alluvium), 1 Mesozoic intrusive HSU, and 6 Paleozoic HSUs (BN 2006a). These units are listed in Table A-7, and several of the more important HSUs are discussed in the following paragraphs. The alluvium and pre-Tertiary HSUs in Yucca Flat are as defined in Section A.2.3.2.

The hydrostratigraphy for the Tertiary-age volcanic rocks in Yucca Flat can be simplified into two categories: zeolitic tuff confining units and (nonzeolitic) volcanic aquifers.

The zeolitic TCUs in Yucca Flat have been grouped into three HSUs: the upper tuff confining unit (UTCU), the lower tuff confining unit (LTCU), and the Oak Spring Butte confining unit (OSBCU) (Table A-7). The LTCU and OSBCU are important HSUs in the Yucca Flat region (stratigraphically similar to the LTCU in Frenchman Flat) because they separate the volcanic aquifer units from the underlying regional LCA. Almost all zeolitized tuff units in Yucca Flat are grouped within the LTCU and OSBCU, which comprises mainly zeolitized bedded tuff (ash-fall tuff, with minor reworked tuff). The LTCU and OSBCU are saturated in much of Yucca Flat; however, measured transmissivities are very low.

The LTCU and OSBCU are generally present in the eastern two-thirds of Yucca Flat. They are absent over the major structural highs, where the volcanic rocks have been removed by erosion. Areas where the LTCU and OSBCU are absent include the "Paleozoic bench" in the western portion of the basin. In northern Yucca Flat, the LTCU and OSBCU tend to be confined to the structural subbasins. Outside the subbasins and around the edges of Yucca Flat, the volcanic rocks are thinner and are not zeolitized.

The unaltered volcanic rocks of Yucca Flat are divided into three Timber Mountain HSUs. The hydrogeology of this part of the geologic section is complicated by the presence of one or more ash-flow tuff units that are quite variable in properties both vertically and laterally.

Table A-7. Hydrostratigraphic units of the Yucca Flat underground test area

Hydrostratigraphic Unit (Symbol)	Dominant Hydrogeologic Units[(a)]	Typical Lithologies
Alluvial Aquifer (AA)	AA, minor LFA	Alluvium (gravelly sand); also includes one or more thin basalt flows, playa deposits and eolian sands
Timber Mountain Upper Vitric-Tuff Aquifer (TMUVTA)	WTA, VTA	Includes vitric nonwelded ash-flow and bedded tuff
Timber Mountain Welded-Tuff Aquifer (TMWTA)	WTA	Partially to densely welded ash-flow tuff; vitric to devitrified
Timber Mountain Lower Vitric-Tuff Aquifer (TMLVTA)	VTA	Nonwelded ash-flow and bedded tuff; vitric
Upper Tuff Confining Unit (UTCU)	TCU	Zeolitic bedded tuff
Topopah Spring Aquifer (TSA)	WTA	Welded ash-flow tuff; present only in extreme southern Yucca Flat
Belted Range Aquifer (BRA)	WTA	Welded ash-flow tuff
Belted Range Confining Unit (BRCU)	TCU	Zeolitic bedded tuffs
Pre-Grouse Canyon Tuff Lava-Flow Aquifer (Pre-Tbg-LFA)	LFA	Lava flow
Lower Tuff Confining Unit (LTCU)	TCU	Zeolitic bedded tuffs with interbedded but less significant zeolitic, nonwelded to partially welded ash-flow tuffs
Tub Spring Aquifer (TUBA)	WTA	Welded ash-flow tuff
Oak Spring Butte Confining Unit (OSBCU)	TCU	Zeolitic bedded tuffs with interbedded but less significant zeolitic, nonwelded to partially welded ash-flow tuffs
Argillic Tuff Confining Unit (ATCU)	TCU	Includes the argillic, lowermost Tertiary volcanic units and paleocolluvium that immediately overlie the pre-Tertiary rocks
Mesozoic Granite Confining Unit (MGCU)	GCU	Granodiorite and quartz monzonite
Upper Carbonate Aquifer (UCA)	CA	Limestone
Lower Carbonate Aquifer - Yucca Flat Upper Thrust Plate (LCA3)	CA	Limestone and dolomite
Lower Clastic Confining Unit - Yucca Flat Upper Plate (LCCU1)	CCU	Quartzite and siltstone
Upper Clastic Confining Unit (UCCU)	CCU	Argillite and quartzite
Lower Carbonate Aquifer (LCA)	CA	Dolomite and limestone; "regional aquifer"
Lower Clastic Confining Unit (LCCU)	CCU	Quartzite and siltstone; "hydrologic basement"

(a) See Table A-4 for description of HGUs.
Note: Adapted from BN (2006a).

The Timber Mountain Group includes ash-flow tuffs that can be either WTAs or VTAs, depending on the degree of welding (refer to Sections A.2.3.1 and A.2.3.2). In Yucca Flat, these units are generally present in the central portions of the basin. They can be saturated in the deepest structural subbasins.

The AA is confined primarily to the basins of the NNSS. However, because the water table in the vicinity is moderately deep, the alluvium is generally unsaturated, except in the deep subbasins of some valleys. These sediments are porous and, thus, have high storage coefficients. Transmissivities may also be high, particularly in the coarser, gravelly beds.

The more recent large-scale extensional faulting in the Yucca Flat area is significant from a hydrologic perspective because the faults have profoundly affected the hydrogeology of the Tertiary volcanic units by controlling to a large extent their alteration potential and final geometry. In addition, the faults themselves may facilitate migration of potentially contaminated groundwater from sources in the younger (volcanic) rocks into the underlying regional aquifers. Final geometry of formations may be such that rocks of very different properties are now juxtaposed (e.g., altered volcanic rocks against a Paleozoic carbonate scarp).

Water-Level Elevation and Groundwater Flow Direction – Water-level data are abundant for Yucca Flat, as a result of more than 60 years of drilling in the area in support of the weapons testing program. However, water-level data for the surrounding areas are scarce. These data are listed in the potentiometric data package prepared for the UGTA regional-scale groundwater model (Hale et al. 1995; IT 1996b) and in the more recent Yucca Flat-CAU–specific data reports (Fenelon 2005; SNJV 2006b; Navarro-Intera [NI] 2013).

The SWL in the Yucca Flat basin is relatively deep, ranging in depth from about 183 m (600 ft) in extreme western Yucca Flat to more than 580 m (1,900 ft) in north-central Yucca Flat (Hale et al. 1995; Laczniak et al. 1996). Elevation of the water table within Yucca Flat proper is relatively flat and varies from 773 m (2,535 ft) in the north to 730 m (2,400 ft) at the southern end of Yucca Flat (Hale et al. 1995; Laczniak et al. 1996; Fenelon 2005; SNJV 2006b; Fenelon et al. 2012; NI 2013). Throughout much of the Yucca Flat area, the SWL typically is located within the lower portion of the volcanic section, in the LTCU and OSBCU. Beneath the hills surrounding Yucca Flat, the SWL can be within the Paleozoic-age units, while in the deeper structural subbasins of Yucca Flat, the Timber Mountain Tuff and the lower portion of the alluvium are also saturated. It is interesting to note that the water level just north of Yucca Flat in western Emigrant Valley is at an elevation of 1,340 m (4,400 ft), about 305 m (2,000 ft) higher than in Yucca Flat. This is due to a hydrologic barrier around the north end of Yucca Flat formed by the LCCU in the Halfpint Range and the Climax granite stock.

Water levels measured in wells completed in the AA and volcanic units in the eastern two-thirds of Yucca Flat are typically about 20 m (70 ft) higher than in wells completed in the LCA (Winograd and Thordarson 1975; IT 1996b; Fenelon 2005; SNJV 2006b). The hydrogeology of these units suggests that the higher elevation of the water table in the overlying Tertiary rocks is related to the presence of low permeability zeolitized tuffs of the LTCU and OSBCU (aquitards) between the Paleozoic and Tertiary aquifers (SNJV 2006b). Detailed water-level data indicate the existence of a groundwater trough along the axis of the valley. The semi-perched water within the AA and volcanic aquifers eventually moves downward to the carbonate aquifer in the central portion of the valley. Water-level elevations in western Yucca Flat are also well above the regional water level. The hydrology of western Yucca Flat is influenced by the presence of the Mississippian clastic rocks, which directly underlie the carbonate aquifer of the upper plate of the CP thrust (locally present), AA, and volcanic rocks west of the Topgallant fault. This geometry is a contributing factor in the development of higher (semi-perched) water levels in this area. The Climax Stock also bears perched water (Walker 1962; Laczniak et al. 1996) well above the regional water level.

The present structural interpretation for Yucca Flat depicts the LCCU at great depth, except in the northeast corner of the study area. The Zabriskie Quartzite and Wood Canyon Formation, which are both classified as clastic confining units, are exposed in the northern portion of the Halfpint Range. The high structural position of the LCCU there (and in combination with the Climax Stock) may be responsible for the steep hydrologic gradient observed between western Emigrant Valley and Yucca Flat.

Based on the existing data as interpreted from the UGTA regional-scale groundwater flow model (DOE/NV 1997) and the CAU-scale flow and transport model for Yucca Flat (NNES 2010a; NI 2013), the overall groundwater flow direction in Yucca Flat is to the south and southwest (Hershey and Acheampong 1997; Figure A-6). Groundwater ultimately discharges at Ash Meadows and Alkali Flat to the south and Death Valley to the southwest.

A.2.5.3 Pahute Mesa Underground Test Area

This section provides descriptions of the geologic and hydrologic settings of the Pahute Mesa UGTA. This summary was compiled from various sources, including Winograd and Thordarson (1975), Byers et al. (1976, 1989), Laczniak et al. (1996), Cole (1997), and BN (2002a). Additional information can be found in these documents. For detailed stratigraphic descriptions, see Sawyer et al. (1994) and Slate et al. (1999).

The Western and Central Pahute Mesa CAUs, encompassing Areas 19 and 20 of the NNSS, were the site of 85 underground nuclear tests (NNSA/NFO 2015) (Figure A-7). These detonations were all conducted in vertical emplacement holes (Table A-1). The Western Pahute Mesa CAU is separated from the Central Pahute Mesa CAU by the Boxcar fault and is distinguished by a relative abundance of tritium (DOE/NV 1999). For hydrogeologic studies and modeling purposes, these two CAUs are treated together.

Hydrogeologically, these CAUs are considered to be part of a larger region that includes areas both within and outside the boundaries of the NNSS, designated as the Pahute Mesa–Oasis Valley (PM-OV) study area. Because most of the underground nuclear tests at Pahute Mesa were conducted near or below the SWL, test-related contaminants are available for transport via a groundwater flow system that may extend to discharge areas in Oasis Valley. Similar to the UGTAs of Frenchman Flat and Yucca Flat, a CAU-scale hydrostratigraphic framework model (BN 2002a) has been developed for the PM-OV study area to support modeling of groundwater flow and contaminant transport for the UGTA activity (SNJV 2006c, 2009; Jackson and Fenelon 2018).

Physiography – Pahute Mesa is a structurally high volcanic plateau in the northwest corner of the NNSS (Figure A-2). Ground-level elevations in the area range from below 1,650 m (5,400 ft) off the mesa to the north and south, to over 2,135 m (7,000 ft) on eastern Pahute Mesa. Pahute Mesa proper is composed of flat-topped buttes and mesas separated by deep canyons. This physiographic feature covers most of NNSS Areas 19 and 20, which are the second-most used testing real estate at the NNSS. Consequently, a substantial amount of subsurface geologic and hydrologic information is available from numerous drill holes (Warren et al. 2000a, 2000b; BN 2002a).

Geology Overview – Borehole and geophysical data from Pahute Mesa indicate the presence of several nested calderas (Figure A-2) that produced thick sequences of rhyolite tuffs and lavas. The older calderas are buried by ash-flow units produced from younger calderas. Most of eastern Pahute Mesa is capped by the voluminous Ammonia Tanks and Rainier Mesa ash-flow tuff units, which erupted from the Timber Mountain Caldera, located immediately to the south of Pahute Mesa (Byers et al. 1976). The western portion is capped by ash-flows of the Thirsty Canyon Group from the Black Mountain caldera (9.4 Ma). A typical geologic cross section for Pahute Mesa is presented in Figure A-10. For a more detailed geologic summary, see Ferguson et al. (1994), Sawyer et al. (1994), Warren et al. (2000b), and BN (2002a).

The most widespread and significant Quaternary and Tertiary (mainly volcanic) units of the Pahute Mesa area are included in Table A-2. Refer to Table A-3 for a list of Mesozoic (granitic), Paleozoic (sedimentary), and Precambrian (sedimentary and metamorphic) stratigraphic units.

Underlying the Tertiary-age volcanic rocks (exclusive of the caldera complexes) are Paleozoic and Proterozoic sedimentary rocks consisting of dolomite, limestone, quartzite, and argillite. In Precambrian and Paleozoic time, as much as 10,000 m (32,800 ft) of these marine sediments were deposited in the NNSS region (Cole 1997). For detailed stratigraphic descriptions of these rocks, see Slate et al. (1999). The only occurrence of Mesozoic age rocks in the Pahute Mesa area is the Gold Meadows Stock, a granitic intrusive mass located at the eastern edge of Pahute Mesa, north of Rainier Mesa (Gibbons et al. 1963; Snyder 1977).

The Silent Canyon caldera complex (SCCC) lies beneath Pahute Mesa. This complex contains two of the older known calderas within the SWNVF, and is completely buried by volcanic rocks erupted from younger nearby calderas. It was first identified from gravity observations that indicated a deep basin below the topographically high Pahute Mesa. Subsequent drilling on Pahute Mesa indicated that the complex consists of at least two nested calderas, the Grouse Canyon caldera and younger Area 20 caldera (13.6 and 13.1 Ma, respectively) (Sawyer et al. 1994). For more information on the SCCC, see Ferguson et al. (1994), which is a comprehensive study of the caldera complex based on analysis of gravity, seismic refraction, drill hole, and surface geologic data.

Like the SCCC, the Timber Mountain caldera complex (TMCC) consists of two nested calderas: the Rainier Mesa caldera and the younger Ammonia Tanks caldera, 11.6 and 11.45 Ma, respectively (Sawyer et al. 1994). However, unlike the SCCC, the TMCC has exceptional topographic expression, consisting of an exposed topographic margin for more than half its circumference and a well-exposed central resurgent dome (Timber Mountain, the most conspicuous geologic feature in the western part of the NNSS). The complex truncates the older Claim Canyon caldera (12.65 Ma) (Sawyer et al. 1994), which is farther to the south. The calderas of the TMCC are the sources of the Rainier Mesa and Ammonia Tanks Tuffs, which form important and extensive stratigraphic units at the NNSS and vicinity.

The Black Mountain caldera is a relatively small caldera in the northwest portion of the Pahute Mesa area. It is the youngest caldera in the area, formed as a result of the eruption, 9.4 Ma, of tuffs assigned to the Thirsty Canyon Group (Sawyer et al. 1994).

Deep gravity lows and the demonstrated great thickness of tuffs in the Pahute Mesa area suggest the presence of older buried calderas. These calderas would pre-date the Grouse Canyon caldera and, thus, could be the source of some of the pre-Belted Range units.

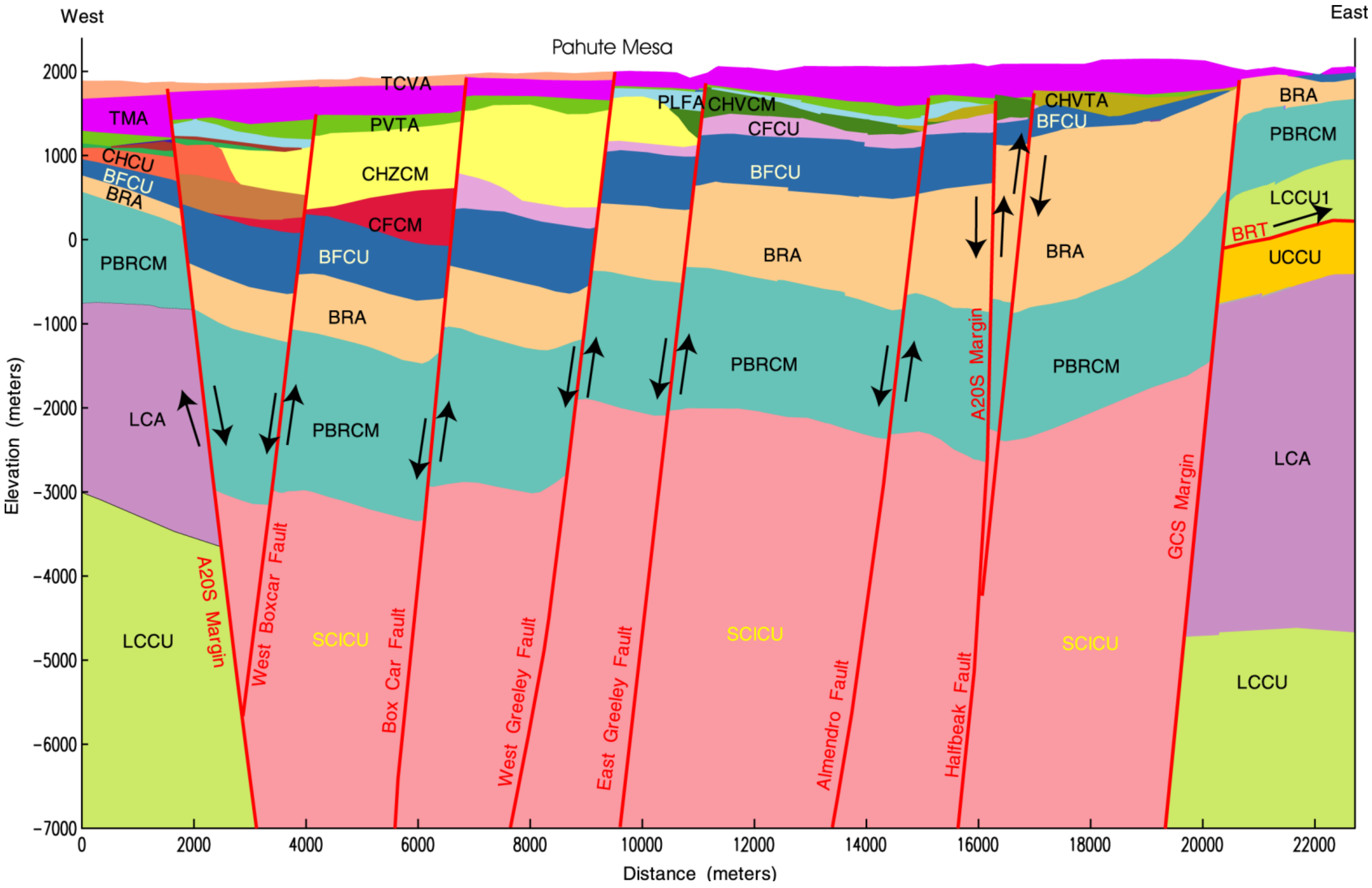
Structural Setting – The structural setting of the Pahute Mesa area is dominated by the calderas described in the previous paragraphs. Several other structural features are considered to be significant factors in the hydrology, including the Belted Range thrust fault (Section A.1.3), numerous normal faults related mainly to basin-and-range extension, and transverse faults and structural zones. However, many of these features are buried, and their presence is inferred from drilling and geophysical data. A typical geologic cross section for Pahute Mesa is presented in Figure A-10. For a more detailed geologic summary, see Ferguson et al. (1994), Sawyer et al. (1994), and BN (2002a).

Hydrogeology Overview – The hydrogeology of Pahute Mesa is complex. The thick section of volcanic rocks comprises a wide variety of lithologies that range in hydraulic character from aquifer to aquitard. The presence of several calderas and tectonic faulting further complicate the area, placing the various lithologic units in juxtaposition and blocking or enhancing the flow of groundwater in a variety of ways.

The general hydrogeologic framework for Pahute Mesa and vicinity was established in the early 1970s by U.S. Geological Survey geoscientists (Blankennagel and Weir 1973; Winograd and Thordarson 1975). As described in Section A.2.3, their work has provided the foundation for most subsequent hydrogeologic studies at the NNSS (IT 1996a; BN 2002a; NSTec 2009b; Jackson and Fenelon 2018).

All the rocks in the PM-OV study area can be classified as one of nine HGUs, which include the AA, four volcanic HGUs, two intrusive units, and two HGUs that represent the pre-Tertiary rocks (Table A-3).

The rocks within the PM-OV study area are grouped into 44 HSUs for the UGTA CAU-scale hydrogeology framework model (Table A-8; BN 2002a). The volcanic units are organized into 37 HSUs that include 13 aquifers, 13 confining units, and 11 composite units (comprising a mixture of hydraulically variable units). The underlying pre-Tertiary rocks are divided into six HSUs, including two aquifers and four confining units. HSUs that are common to several CAUs at the NNSS are briefly discussed in Section A.2.3.2.



A20S - Area 20 Caldera Structural Margin
BRT - Belted Range Thrust
GCS - Grouse Canyon Structural Margin

See Section A.2.3.2 and Table A-8 of this attachment for definitions of hydrostratigraphic units.
1.5 x vertical exaggeration

Figure A-10. Generalized hydrostratigraphic cross section through the Silent Canyon complex, Pahute Mesa

Table A-8. Hydrostratigraphic units of the Pahute Mesa-Oasis Valley area

Hydrostratigraphic Unit (Symbol)	Dominant Hydrogeologic Unit(s)[(a)]	Typical Lithologies
Alluvial Aquifer (AA)	AA	Alluvium (gravelly sand); also includes eolian sand
Younger Volcanic Composite Unit (YVCM)	LFA, WTA, VTA	Basalt, welded and nonwelded ash-flow tuff
Thirsty Canyon Volcanic Aquifer (TCVA)	WTA, LFA, lesser VTA	Partially to densely welded ash-flow tuff; vitric to devitrified
Detached Volcanics Composite Unit (DVCM)	WTA, LFA, TCU	Complex distribution of welded ash-flow tuff, lava, and zeolitic bedded tuff
Fortymile Canyon Composite Unit (FCCM)	LFA, TCU, lesser WTA	Lava flows and associated tuffs
Timber Mountain Composite Unit (TMCM)	TCU (altered tuffs, lavas) and unaltered WTA and lesser LFA	Densely welded ash-flow tuff; includes lava flows, and minor debris flows
Tannenbaum Hill Lava-Flow Aquifer (THLFA)	LFA	Rhyolitic lava
Tannenbaum Hill Composite Unit (THCM)	Mostly TCU lesser WTA	Zeolitic tuff and vitric, nonwelded to welded ash-flow tuffs
Timber Mountain Aquifer (TMA)	Mostly WTA, minor VTA	Partially to densely welded ash-flow tuff; vitric to devitrified
Subcaldera Volcanic Confining Unit (SCVCU)	TCU	Probably highly altered volcanic rocks and intruded sedimentary rocks beneath each caldera
Fluorspar Canyon Confining Unit (FCCU)	TCU	Zeolitic bedded tuff
Windy Wash Aquifer (WWA)	LFA	Rhyolitic lava
Paintbrush Composite Unit (PCM)	WTA, LFA, TCU	Welded ash-flow tuffs, rhyolitic lava and minor associated bedded tuffs
Paintbrush Vitric-tuff Aquifer (PVTA)	VTA	Vitric, nonwelded and bedded tuff
Benham Aquifer (BA)	LFA	Rhyolitic lava
Upper Paintbrush Confining Unit (UPCU)	TCU	Zeolitic, nonwelded and bedded tuff
Tiva Canyon Aquifer (TCA)	WTA	Welded ash-flow tuff
Paintbrush Lava-Flow Aquifer (PLFA)	LFA	Lava; lesser moderately to densely welded ash-flow tuff
Lower Paintbrush Confining Unit (LPCU)	TCU	Zeolitic nonwelded and bedded tuff
Topopah Spring Aquifer (TSA)	WTA	Welded ash-flow tuff
Yucca Mountain Crater Flat Composite Unit (YMCFCM)	LFA, WTA, TCU	Lava; welded ash-flow tuff; zeolitic, bedded tuff
Calico Hills Vitric-Tuff Aquifer (CHVTA)	VTA	Vitric, nonwelded tuff
Calico Hills Vitric Composite Unit (CHVCM)	VTA, LFA	Partially to densely welded ash-flow tuff; vitric to devitrified
Calico Hills Zeolitized Composite Unit (CHZCM)	LFA, TCU	Rhyolitic lava and zeolitic nonwelded tuff
Calico Hills Confining Unit (CHCU)	Mostly TCU, minor LFA	Zeolitic nonwelded tuff; minor lava
Inlet Aquifer (IA)	LFA	Lava
Crater Flat Composite Unit (CFCM)	Mostly LFA, intercalated with TCU	Lava and welded ash-flow tuff
Crater Flat Confining Unit (CFCU)	TCU	Zeolitic nonwelded and bedded tuff
Kearsarge Aquifer (KA)	LFA	Lava
Bullfrog Confining Unit (BFCU)	TCU	Zeolitic, nonwelded tuff
Belted Range Aquifer (BRA)	LFA and WTA, with lesser TCU	Lava and welded ash-flow tuff

Table A-8. Hydrostratigraphic units of the Pahute Mesa-Oasis Valley area

Hydrostratigraphic Unit (Symbol)	Dominant Hydrogeologic Unit(s)$^{(a)}$	Typical Lithologies
Pre-Belted Range Composite Unit (PBRCM)	TCU, WTA , LFA	Zeolitic bedded tuffs with interbedded but less significant zeolitic, nonwelded to partially welded ash-flow tuffs
Black Mountain Intrusive Confining Unit (BMICU)	IICU	These units are presumed to be present beneath the calderas of the SWNVF. Their actual character is unknown, but they may be igneous intrusive rocks or older volcanic and pre-Tertiary sedimentary rocks intruded to varying degrees by igneous rocks.
Ammonia Tanks Intrusive Confining Unit (ATICU)	IICU	
Rainier Mesa Intrusive Confining Unit (RMICU)	IICU	
Claim Canyon Intrusive Confining Unit (CCICU)	IICU	
Calico Hills Intrusive Confining Unit (CHICU)	IICU	
Silent Canyon Intrusive Confining Unit (SCICU)	IICU	
Mesozoic Granite Confining Unit (MGCU)	GCU	Granodiorite and quartz monzonite; Gold Meadows Stock
Lower Carbonate Aquifer-Thrust Plate (LCA3)	CA	Limestone and dolomite
Lower Clastic Confining Unit-Thrust Plate (LCCU1)	CCU	Quartzite and siltstone
Upper Clastic Confining Unit (UCCU)	CCU	Argillite and quartzite
Lower Carbonate Aquifer (LCA)	CA	Dolomite and limestone; “regional aquifer”
Lower Clastic Confining Unit (LCCU)	CCU	Quartzite and siltstone; “hydrologic basement”

(a) See Table A-4 for definitions of HGUs

Note: Adapted from BN (2002b).

Water-Level Elevation and Groundwater Flow Direction – Water-level data are relatively abundant for the Pahute Mesa UGTA as a result of more than 30 years of drilling in the area in support of the Weapons Testing Program. However, water-level data for the outlying areas to the west and south are sparse. These data are listed in the potentiometric data package prepared for the UGTA regional-scale groundwater flow model (IT 1996b), the Pahute Mesa water table map (O’Hagan and Laczniak 1996), and recent work in support of flow modeling (SNJV 2004b, 2006c).

The SWL at Pahute Mesa is relatively deep, at about 640 m (2,100 ft) below the ground surface. Groundwater flow at Pahute Mesa is driven by recharge in the east and subsurface inflow from the north. Local groundwater flow is influenced by the discontinuous nature of the volcanic aquifers and the resultant geometry created by overlapping caldera complexes and high-angle basin-and-range faults (Laczniak et al. 1996). Potentiometric data indicate that groundwater flow direction is to the southwest toward discharge areas in Oasis Valley and, ultimately, Death Valley (see Figures A-5 and A-6).

A.2.5.4 Rainier Mesa/Shoshone Mountain

The Rainier Mesa/Shoshone Mountain CAU consists of 61 CASs on Rainier Mesa and 6 CASs on Shoshone Mountain, which are located in NNSS Areas 12 and 16, respectively (see Figure A-7). Together, these two mesas constitute the third major area used for underground nuclear explosive testing at the NNSS between 1957 and 1992. Underground nuclear tests were conducted in horizontal, mined tunnels within these mesas, and two tests were conducted in vertical drill holes. All tests were conducted above the regional water table. Underground geologic mapping data from the six large and several smaller tunnel complexes, and lithologic and geophysical data from dozens of exploratory drill holes, provide a wealth of geologic and hydrologic information for this relatively small underground test area.

Physiography – The Rainier Mesa UGTA includes Rainier Mesa proper and the contiguous Aqueduct Mesa. Rainier Mesa and Aqueduct Mesa form the southern extension of the northeast trending Belted Range (see Figure A-2). This high volcanic plateau cuts diagonally across Area 12 in the north-central portion of the NNSS. Ground-level elevations on Rainier Mesa are generally over 2,225 m (7,300 ft). The highest point on the NNSS, 2,341 m (7,679 ft), is on Rainier Mesa. Aqueduct Mesa has slightly rougher and lower terrain, generally above 1,920 m (6,300 ft) in elevation. The edges of the mesas drop off quite spectacularly on the west, south, and east sides.

Shoshone Mountain is located in the middle of the NNSS, southwest of Syncline Ridge and about 20 km (12 mi) south of Rainier Mesa (see Figures A-2 and A-7). Ground-level elevations range from 1,707 to 2,012 m (5,600 to 6,600 ft) but are generally above 1,830 m (6,000 ft). Tippipah Point, above the Area 16a Tunnel, has an elevation of 2,015 m (6,612 ft).

Geology Overview – Both Rainier Mesa and Aqueduct Mesa are composed of Miocene-age ash-fall and ash-flow tuffs that erupted from nearby calderas to the west and southwest (NSTec 2007). As in Yucca Flat, these silicic volcanic tuffs were deposited unconformably on an irregular pre-Tertiary (upper Precambrian and Paleozoic age) surface of sedimentary rocks (Gibbons et al. 1963; Orkild 1963) and Mesozoic granitic rocks (at Rainier Mesa only). The stratigraphic units and lithologies are similar to those present in the subsurface of Yucca Flat (see Section A.2.5.2). The tunnel complexes used for underground nuclear testing at Rainier Mesa and Shoshone Mountain were excavated in zeolitized bedded tuff, though the upper part of this section is unaltered (vitric) in some areas. At both locations, the bedded tuffs are capped by a thick layer of welded ash-flow tuff. The Tertiary stratigraphic units and lithologies are similar to those present in the subsurface of Yucca Flat (see Section A.2.5.2).

Structural Setting – The geologic structure of the volcanic rocks of the Rainier Mesa is well documented. Several high-angle, normal faults have been mapped in the volcanic rocks. Faults with greater than about 30 m (100 ft) of displacement are notably absent in the volcanic rocks of Rainier Mesa. The Rainier and Aqueduct Mesa area was minimally extended during Basin and Range tectonism, thus accounting for the absence of larger faults and its relatively high elevation (NSTec 2007). At Shoshone Mountain, several faults have been mapped, but in general the structure is less well known there than at Rainier Mesa. The structure of the pre-Tertiary section at both locations is poorly known, though most workers agree on the framework in general, and that the trace of the Belted Range thrust fault is present in the pre-Tertiary rocks beneath Rainier Mesa. A broad synclinal feature mapped at the surface and in the tuffs of Rainier Mesa and Aqueduct Mesa roughly overlies the postulated location of the Belted Range thrust fault. It may reflect a paleo-topographic low or valley beneath the tuffs (Figure A-11), but the exact character of this feature is unknown.

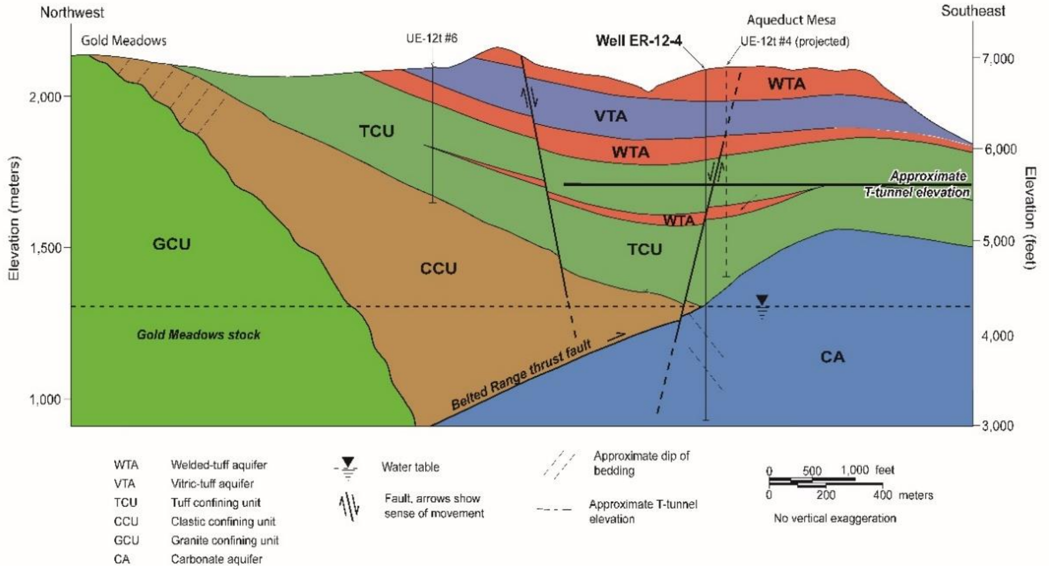


Figure A-11. Generalized hydrostratigraphic cross section through Aqueduct Mesa

Hydrogeology Overview – Construction of a UGTA CAU-scale hydrogeology model for the Rainier Mesa and Shoshone Mountain UGTAs was completed in 2007 (NSTec 2007). All the rocks in the Rainier Mesa–Shoshone Mountain (RM-SM) study area can be classified as one of nine HGUs, which include the AA, four volcanic HGUs, two intrusive units, and two HGUs that represent the pre-Tertiary rocks (see Table A-4). The geologic units within the RM-SM model area are grouped into 44 HSUs (NSTec 2007). Thirty Tertiary-age HSUs, including the Tertiary/Quaternary alluvium, older paleocolluvium, two caldera-related collapse breccias, five caldera-related intrusives, one Mesozoic intrusive HSU, and six Paleozoic/Precambrian HSUs, have been identified in the RM-SM CAU (Table A-9).

The hydrostratigraphy for the Tertiary-age volcanic rocks in the former UGTAs (Rainier Mesa, Aqueduct Mesa, and Shoshone Mountain) can be simplified into two categories: zeolitic, tuff confining units and (nonzeolitic) volcanic aquifers. Except for a few nomenclature complications due to embedded welded tuff aquifers, the TCUs belong to either the LTCU or the OSBCU HSU (similar to the hydrostratigraphic section in Yucca Flat; see Subsection A.2.5.2). The LTCU and OSBCU are important HSUs, as they separate the UGTAs from the underlying regional aquifer.

The hydrostratigraphy of the pre-Tertiary section at Shoshone Mountain is surmised from a single deep drill hole, Well ER-16-1 (NNSA/NSO 2006), and from surficial geology (Orkild 1963). From oldest to youngest, the hydrogeologic section for the Shoshone Mountain UGTA consists of the regional carbonate aquifer, the upper clastic confining unit, tuff confining units, vitric-tuff aquifers, and welded-tuff aquifers at the surface (Figure A-12). At Rainier Mesa, granitic rocks (GCU), related to the nearby Gold Meadows Stock), carbonate rocks (CA), silicic sedimentary rocks such as siltstone, and metamorphic rocks such as quartzite and schist (CCUs) have been encountered beneath the tuff section in the few existing drill holes that penetrate through the tuff section. This variability is indicative of the complex geology of the pre-Tertiary section, which is a consequence of the Gold Meadows intrusive and the Belted Range thrust fault.

Most of the tests in Shoshone Mountain and Rainier Mesa tunnels were conducted in the TCU, though a few were conducted in vitric bedded tuff higher in the stratigraphic section.

Table A-9. Hydrostratigraphic units of the Rainier Mesa-Shoshone Mountain area

Hydrostratigraphic Unit (Symbol)	Dominant Hydrogeologic Units[(a)]	Typical Lithologies
Alluvial aquifer (AA)	AA	Alluvium: Gravelly sand; also includes colluvium and older moat-filling sediments around the Timber Mountain caldera
Fortymile Canyon Composite Unit (FCCM)	LFA, TCU, lesser WTA	Lava flows, lesser ash-flow and bedded tuffs
Timber Mountain Upper Vitric-Tuff Aquifer (TMUVTA)	VTA, minor WTA	Includes vitric nonwelded to partially welded ash-flow and bedded tuff
Timber Mountain Welded-Tuff Aquifer (TMWTA)	WTA minor VTA	Partially to densely welded ash-flow tuff; vitric to devitrified, minor nonwelded tuff
Timber Mountain Lower Vitric-Tuff Aquifer (TMLVTA)	VTA	Nonwelded ash-flow and bedded tuff; vitric
Timber Mountain Composite Unit (TMCM)	TCU (altered tuffs, lavas) and unaltered WTA and lesser LFA	Welded ash-flow tuffs, lava flows
Rainier Mesa Breccia Confining Unit (RMBCU)	TCU/AA	Landslide breccias
Subcaldera Volcanic Confining Unit (SCVCU)	TCU	Highly altered pre-Tm volcanic units
Tiva Canyon Aquifer (TCA)	WTA	Welded ash-flow tuff
Paintbrush Vitric-Tuff Aquifer (PVTA)	VTA	Bedded tuff, vitric
Upper Tuff Confining Unit (UTCU)	TCU	Zeolitized bedded tuff
Topopah Spring Aquifer (TSA)	WTA minor VTA	Welded ash-flow tuff

Table A-9. Hydrostratigraphic units of the Rainier Mesa-Shoshone Mountain area

Hydrostratigraphic Unit (Symbol)	Dominant Hydrogeologic Units[(a)]	Typical Lithologies
Lower Vitric-Tuff Aquifer (LVTA)	VTA	Nonwelded and bedded tuff; vitric
Calico Hills Vitric-Tuff Aquifer (CHVTA)	VTA	Nonwelded and bedded tuff; vitric
Yucca Mountain Calico Hills Lava-Flow Aquifer (YMCHLFA)	LFA	Lava flow
Kearsarge Aquifer (KA)	LFA	Lava flow
Upper Tuff Confining Unit 2 (UTCU2)	TCU	Zeolitized bedded tuff
Stockade Wash Aquifer (SWA)	WTA minor VTA	Weakly welded ash-flow tuff
Lower Vitric-Tuff Aquifer 2 (LVTA2)	VTA	Nonwelded and bedded tuff; vitric
Bullfrog Confining Unit (BFCU)	TCU	Zeolitic nonwelded tuff
Upper Tuff Confining Unit 1 (UTCU1)	TCU	Zeolitized bedded tuff
Belted Range Aquifer (BRA)	LFA and WTA	Lava and welded ash-flow tuff
Lower Vitric-Tuff Aquifer 1 (LVTA1)	VTA	Bedded tuff; vitric
Belted Range Confining Unit (BRCU)	TCU	Zeolitized bedded tuff
Tub Spring Aquifer (TUBA)	WTA	Welded ash-flow tuff
Lower Tuff Confining Unit (LTCU)	TCU	Zeolitized bedded tuffs with interbedded but less significant zeolitized, nonwelded to partially welded ash-flow tuffs
Oak Spring Butte Confining Unit (OSBCU)	TCU	Devitrified to zeolitic nonwelded to partially welded tuffs and intervening bedded tuffs
Redrock Valley Aquifer (RVA)	WTA	Welded ash-flow tuff, devitrified
Redrock Valley Breccia Confining Unit (RVBCU)	TCU/AA	Landslide breccias
Lower Tuff Confining Unit 1 (LTCU1)	TCU	Zeolitized bedded tuffs
Twin Peaks Aquifer (TPA)	WTA	Welded ash-flow tuff
Argillic Tuff Confining Unit (ATCU)	TCU	Argillic bedded tuffs, minor paleocolluvium
Ammonia Tanks Intrusive Confining Unit (ATICU)	IICU	Intrusive (granite?) and altered, older host rocks
Rainier Mesa Intrusive Confining Unit (RMICU)	IICU	Intrusive (granite?) and altered, older host rocks
Calico Hills Intrusive Confining Unit (CHICU)	IICU	Intrusive (granite?) and altered, older host rocks
Silent Canyon Intrusive Confining Unit (SCICU)	IICU	Highly altered older volcanic rocks and pre-Tertiary sedimentary rocks and granitic intrusive masses.
Redrock Valley Intrusive Confining Unit (RVICU)	IICU	Highly altered injected/intruded country rock and granitic material
Mesozoic Granite Confining Unit (MGCU)	GCU	Granodiorite and quartz monzonite
Lower Clastic Confining Unit - Upper Thrust Plate (LCCU1)	CCU	Quartzite and siltstone
Lower Carbonate Aquifer - Upper Thrust Plate (LCA3)	CA	Limestone and dolomite
Upper Carbonate Aquifer (UCA)	CA	Limestone
Upper Clastic Confining Unit (UCCU)	CCU	Argillite and quartzite
Lower Carbonate Aquifer (LCA)	CA	Dolomite and limestone; “regional aquifer”
Lower Clastic Confining Unit (LCCU)	CCU	Quartzite and siltstone; “hydrologic basement”

(a) See Table A-4 for definitions of hydrogeologic units.
Note: Adapted from NSTec (2007).

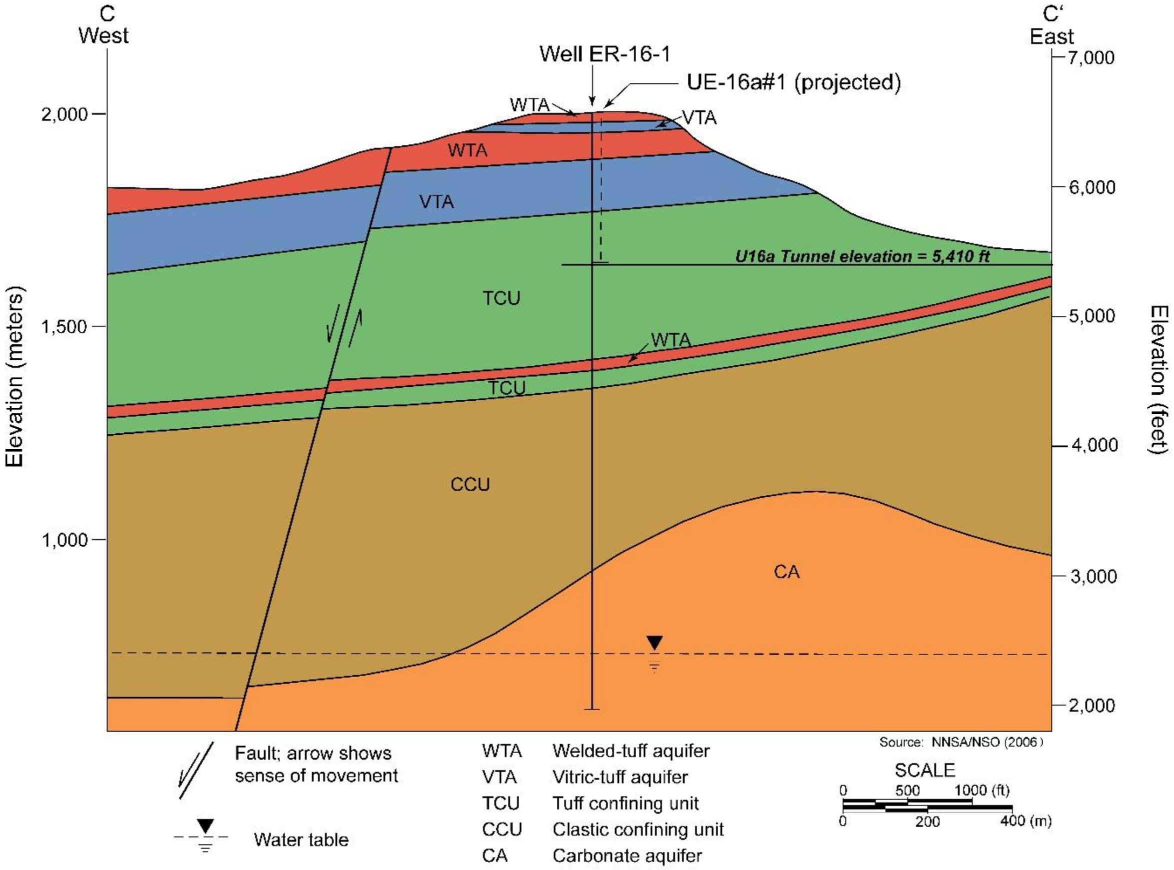


Figure A-12. West-east hydrogeologic cross section through Well ER-16-1

Water-level Elevation and Groundwater Flow Direction – Only a few boreholes on or in the vicinity of Rainier Mesa are deep enough to tag the regional water table. Most notable are UGTA Wells ER-12-3 (BN 2006b) and ER-12-4 (NNSA/NSO 2006 and BN 2006) located on Rainier Mesa and Aqueduct Mesa, respectively. The water levels in these wells are 949 m (3,114 ft) at ER-12-3 and 786 m (2,580 ft) at ER-12-4, or 1,302 m (4,271 ft) and 1,312 m (4,304 ft) elevation, respectively, in the thrusted Paleozoic-age carbonate rocks (LCA3) that underlie the volcanic section (Fenelon 2007). This is approximately 300 m (1,000 ft) below the average elevation of test locations in Rainier Mesa. The SWL, where measured in volcanic units at Rainier Mesa, is at an elevation of about 1,847 m (6,060 ft). This anomalously high water level relative to the regional water level reflects the presence of water perched above the regional aquifer within the tuff confining unit (Walker 1962; Laczniak et al. 1996; Fenelon et al. 2008). Water is present in the fracture systems of some of the tunnel complexes at Rainier Mesa. This water currently is permitted to flow from U12e Tunnel (also known as E-Tunnel); however, water has filled the open drifts behind barriers built near the portals of U12n and U12t Tunnels.

The water level at Shoshone Mountain was measured at 1,248 m (4,093 ft) true vertical depth from the mesa surface, or 761.7 m (2,499 ft) elevation, at UGTA Well ER-16-1 (NNSA/NSO 2006) in the Paleozoic-age carbonate rocks (LCA). This is the deepest water-level tag at the NNSS. No water was encountered during mining at Shoshone Mountain.

Regional groundwater flow from Rainier Mesa may be directed either toward Yucca Flat or, because of the intervening UCCU, to the south toward the Alkali Flat discharge area (Fenelon et al. 2008; see Figures A-5 and A-6). The groundwater flow direction beneath Shoshone Mountain is probably southward.

A.2.6 Conclusion

The hydrogeology of the NNSS and vicinity is complex and varied. Yet, the remote location, alluvial and volcanic geology, and deep water table of the NNSS provided a favorable setting for conducting underground nuclear explosive tests and containing radionuclides produced by the tests. Its arid climate and its setting in a region of closed hydrographic basins also are factors in stabilizing residual surficial contamination from atmospheric testing, and are considered positive environmental attributes for existing radioactive waste management sites.

Average groundwater flow velocities at the NNSS are generally slow, and flow paths to discharge areas or potential receptors (domestic and public water supply wells) are long. The water tables within local aquifers in the valleys and the underlying regional carbonate aquifer are relatively flat (low gradient). The zeolitic volcanic rocks (TCU) separating the shallower alluvial and volcanic aquifers and the regional carbonate aquifer (LCA) appear to form a viable aquitard (non-aquifer). Consequently, both vertical and horizontal flow velocities are low. Additionally, carbon-14 dates for water from NNSS aquifers are on the order of 10,000 to 40,000 years old (Rose et al. 1997). This indicates that there is considerable residence time in the aquifers, allowing contaminant attenuating processes such as matrix diffusion, sorption, and natural decay of radioactive isotopes to operate.

A.3 Climatology

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The NNSS is located in the extreme southwestern corner of the Great Basin. Consequently, the climate is arid, with limited precipitation, low humidity, intense sunlight, and large daily temperature ranges. The climatological data presented here were developed from the NNSS monitoring networks described below.

A.3.1 Monitoring Networks

Meteorological and climatological data are collected on the NNSS by the National Oceanic and Atmospheric Administration (NOAA) Air Resources Laboratory, Special Operations and Research Division (ARL/SORD). Data are collected through the Meteorological Data Acquisition (MEDA) system, a network of 24 mobile meteorological towers that became operational in 1981. The network was updated in 2005, and was totally replaced and expanded in 2016 and 2018. A standard MEDA station consists of a portable 10-m (32.8-ft) tower, meteorological instrumentation, a micro-processor/datalogger, and a UHF radio transmitter, all powered by a battery and solar recharging system (Figure A-13). Locations of the MEDA stations are shown in Figure A-14. All towers were sited according to standards set by the Federal Meteorological Handbook No. 1 (NOAA 2005) and the World Meteorological Organization (2008) so as not to be influenced by natural or man-made obstructions or by heat dissipation and generation systems. The selection of MEDA station locations is based on effective site weather characterization, site safety, project support, physical accessibility, and line-of-sight radio availability.

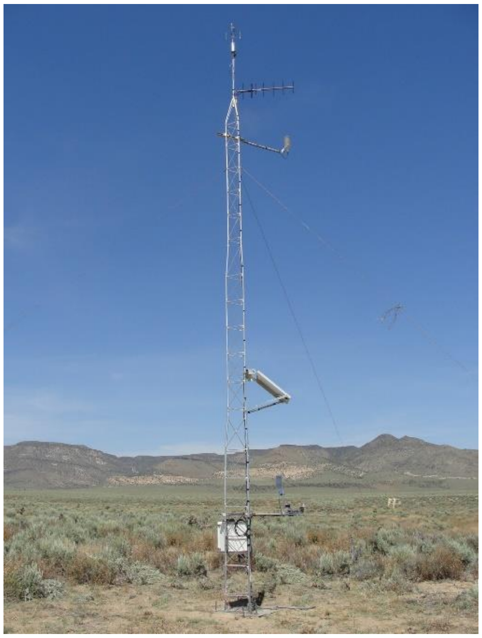

Figure A-13. Example of a typical MEDA station with a 10-meter tower

MEDA station instrumentation is located on top of the tower and on booms oriented into the prevailing wind direction at a minimum distance of two tower widths from the tower. The station configuration measures three-dimensional winds, two levels of temperature and relative humidity, atmospheric pressure, incoming solar radiation, Global Positioning System (GPS) data, and precipitation. Wind direction and speed are measured at the 10-m (32.8-ft) level, in accordance with the specifications of the American National Standard for Determining Meteorological Information at Nuclear Facilities (ANSI/ANS-3.11-2015, American Nuclear Society 2015). Ambient temperature and relative humidity measurements are taken at the approximate heights of 8.7 m (28.5 ft) and 2 m (6.6 ft) to be within the surface boundary layer.

Atmospheric pressure, solar radiation measurements, and GPS measurements are also taken in the surface boundary layer at a height of approximately 2 m (6.6 ft). In addition to the direct measured parameters, the datalogger calculates dew-point temperature, dT/dz (change in temperature with height), and total daily solar radiation. Wind data are 15-minute averages of speed and direction. The maximum and minimum wind speeds are the fastest and slowest, respectively, 3-second moving averages calculated within the 15-minute time interval. Temperature, relative humidity, solar radiation, and pressure are 15-minute averages. All observed and calculated parameters are collected and transmitted every 15 minutes on the quarter hours.

NOAA ARL/SORD also operates and maintains a climatological rain gauge network on the NNSS (Figure A-15). In 2021, the network consisted of 3 Belford Series 5-780 Universal Precipitation Gauges and 24 Hydrological Services America (HSA) TB3 Tipping Bucket Precipitation Gauges. The three Belford gauges are strip chart recorders that are manually read about once every 30 days. The HSA gauges are part of the MEDA network that report data every 15 minutes and are included in the ARL/SORD real-time weather database. Once read and certified, the strip chart

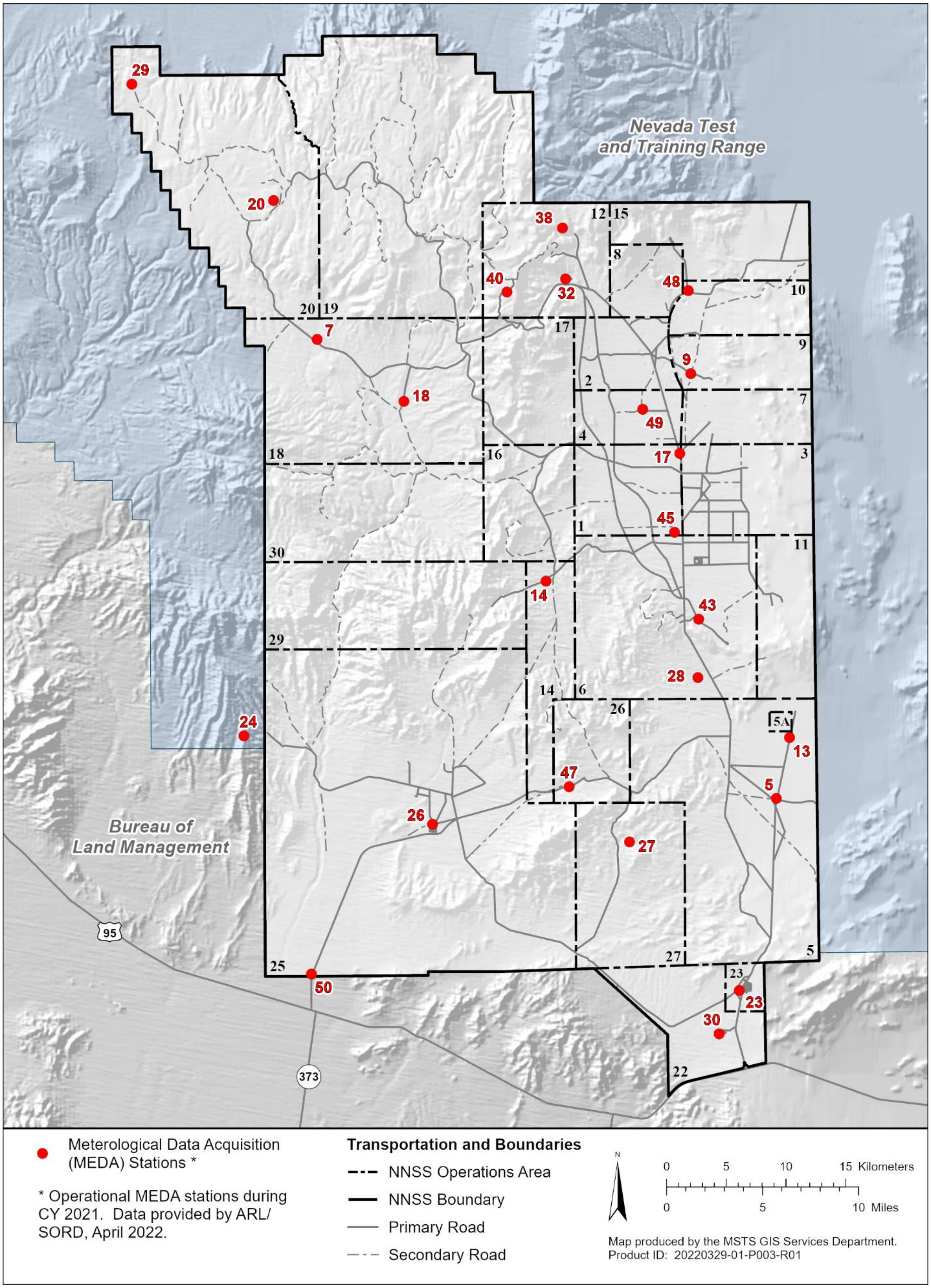

Figure A-14. MEDA station locations on the NNSS

data are entered into the SORD precipitation climatological database. Data are recorded as daily totals. Under special circumstances, 1- to 3-hour totals can be obtained.

MEDA data are used daily for operational support to a wide variety of projects on the NNSS and form the climatological database for the NNSS. The data are used in safety analysis reports, emergency response activities, radioactive waste remediation projects, environmental reports, and compliance assessments. For new NNSS projects and facility modifications that may produce radiological emissions, wind data from the MEDA stations are used to calculate potential radiological doses to members of the public. MEDA data are processed and archived in the NOAA ARL/SORD climatological database. An NNSS Climatological Report is posted on the NOAA ARL/SORD website, https://www.sord.nv.doe.gov, under the Climate section.

A.3.2 Precipitation

Two fundamental physical processes drive precipitation events on the NNSS: those resulting from cool-season, mid-tropospheric cyclones and those resulting from summertime convection. Cool-season precipitation is usually light and can consist of rain or snow. Although light, winter precipitation events can last for several days and result in significant precipitation totals per winter storm, especially in January and February. Summer is thunderstorm season. Precipitation from thunderstorms is usually light; however, some storms produce very heavy rain, flash floods, intense cloud-to-ground lightning, and strong surface winds. Thunderstorms generally occur in July and August when moist tropical air flows from the southeastern North Pacific Ocean and spreads over the desert southwest. This seasonal event is referred to as the southwestern U.S. monsoon.

Distinct winter and summer precipitation mechanisms produce a bimodal monthly precipitation cycle. Figure A-16 shows patterns of mean monthly precipitation recorded from 6 of the 25 climatological stations on the NNSS over the past 35+ years. Mean annual precipitation totals on the NNSS range from over 30 centimeters (cm) (12.02 inches [in.]) over the high terrain in the northwestern part of the NNSS to about 12 cm (4.83 in.) in Frenchman Flat. However, inter-annual variations can be significant. For example, annual totals of less than 2.54 cm (1.0 in., nearly a quarter of the average) have been measured on the lower elevations of the NNSS, but 24.6 cm (9.67 in., nearly double the average) occurred in Frenchman Flat in 1998, and 68.2 cm (26.87 in., over double the average) fell on Rainier Mesa in 1983. Daily precipitation totals can also be large and range from 5 to just over 9 cm (2 to over 3.5 in.). A storm-total precipitation amount of 8.9 cm (3.5 in.) is considered a 100-year, 24-hour, extreme precipitation event. Daily totals of 5.1 to 7.6 cm (2 to 3 in.) have been measured at several sites on the NNSS (Randerson 1997). The greatest daily precipitation event on the NNSS was 11.89 cm (4.68 in), which was measured in Jackass Flats on September 26–27, 2007.

Snow can fall on the NNSS any time between October and May. On Yucca Flat, the greatest daily snow depth measured was 25.4 cm (10 in.) in January 1974. The greatest daily depth measured at Desert Rock was 15.2 cm (6 in.) in February 1987. Maximum daily totals of 38 to 50 cm (15 to 20 in.) or more can occur on Pahute and Rainier Mesas. Hail, sleet, freezing rain, and fog are rare on the NNSS, but can cover the ground briefly during intense thunderstorms. Only 24 hailstorms have been observed on Yucca Flat between 1957 and 1978 (an average of about 1 event per year) and 9 at Desert Rock from 1978 to 2010 (an average of 1 event every 3 to 4 years). Manned observations ended on the NNSS in 2010.

A.3.3 Temperature

As is typical of an arid climate, the NNSS experiences large daily and annual ranges in temperature. In addition, temperatures vary with elevation. Sites above 1,524 m (5,000 ft) mean sea level can be quite cold in the winter and fairly mild during the summer months. At lower elevations, summertime temperatures frequently exceed 37.7 degrees Celsius (°C) (100 degrees Fahrenheit [°F]). On the dry lakebeds, average normal daily low and high temperatures can vary by as much as 22°C (40°F), with very cold morning temperatures in the winter and very hot afternoon temperatures in the summer. These temperature characteristics are shown in Figure A-17. These annual temperature plots describe the temperature extremes and average maximums and minimums throughout the year at six locations on the NNSS.

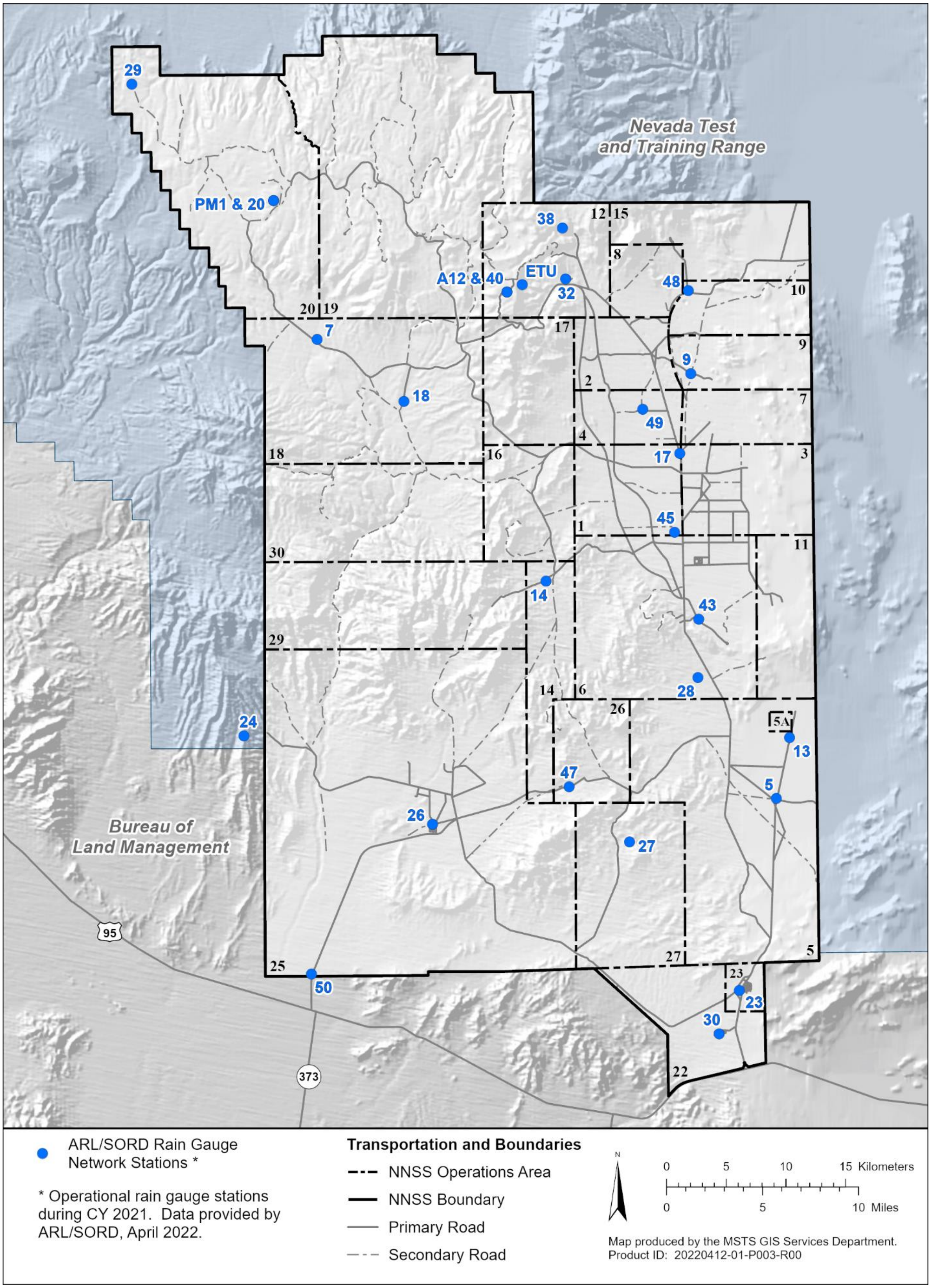

Figure A-15. Climatological rain gauge network on the NNSS

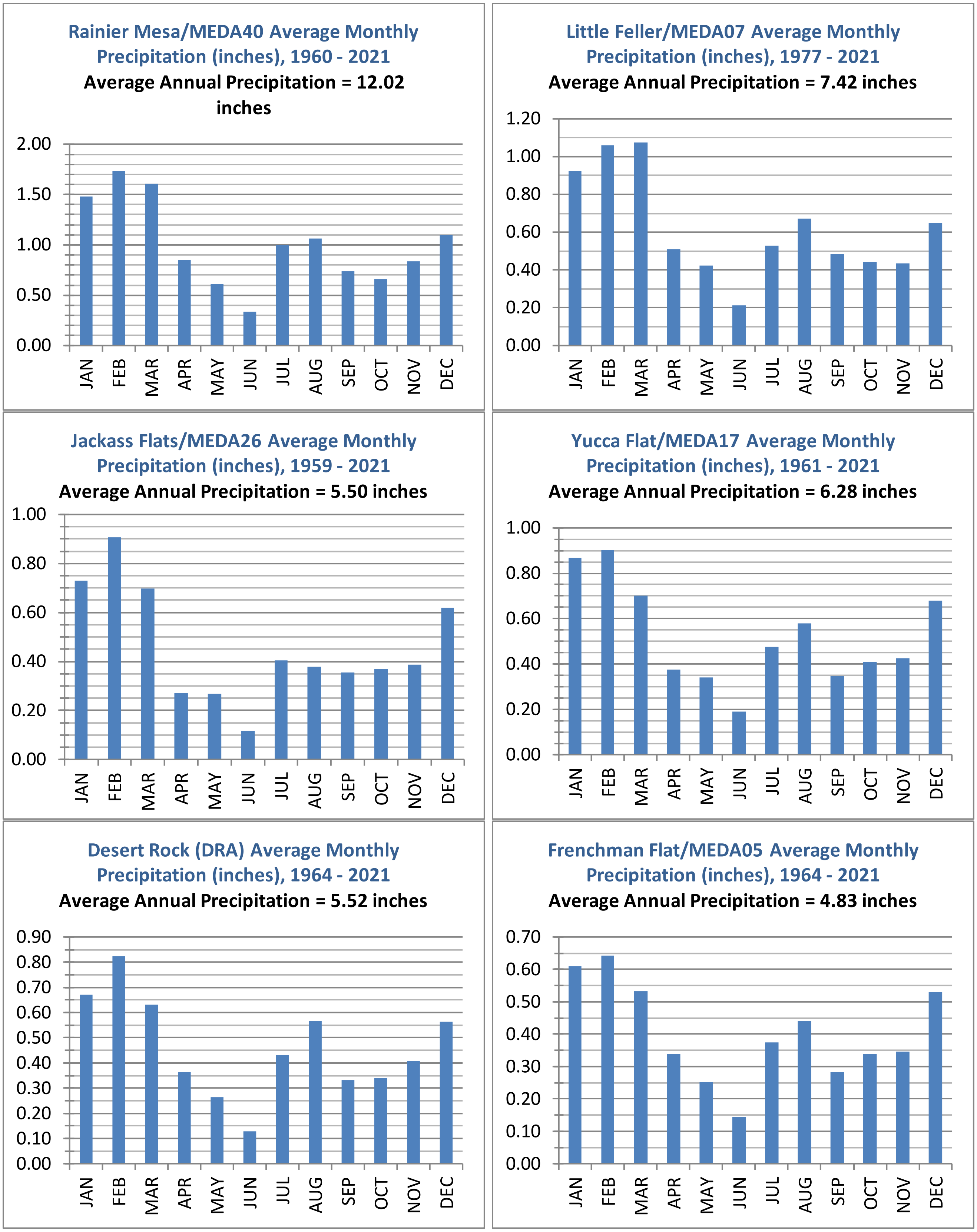

Figure A-16. Mean monthly precipitation at six NNSS rain gauge stations (locations of numbered stations are shown in Figure A-14)

In Frenchman Flat (MEDA 5), the average daily temperature minimum and maximum for January are −4.5°C and 13.8°C (24°F and 57°F), while in July they are 17.1°C and 38.6°C (63°F and 101°F). By contrast, on Rainier Mesa (MEDA 12/40), the minimum and maximum temperature for January are −3.9°C and 4.0°C (25°F and 39°F) and for July are 15.3°C and 26.7°C (60°F and 80°F). The highest maximum temperature measured on the NNSS is 46.1°C (115°F) in Frenchman Flat near Well 5B in July 1998 and in Jackass Flats near Lathrop Gate in July 2002. The coldest minimum temperature measured on the NNSS is −28.9°C (−20°F) in Area 19 in January 1970. The temperature extremes at Mercury are −11.7°C to 45°C (11°F to 113°F).

A.3.4 Wind

Complex topography, such as that on the NNSS, can influence wind speeds and directions. Furthermore, there is a seasonal as well as strong daily periodicity to local wind conditions. For example, in Yucca Flat, in the summer months, the wind direction is usually northerly (from the north) from 10 p.m. Pacific Daylight Time (PDT) to 8 a.m. PDT, and southerly from 10 a.m. PDT to 8 p.m. PDT. However, in January, the winds are generally from the north from 6 p.m. Pacific Standard Time (PST) to 11 a.m. PST, with some southerly winds developing between 11 a.m. PST and 5 p.m. PST. March through June tend to experience the fastest average wind speeds, 13 to 19 kilometers per hour (kph) (7 to 10 knots or 8 to 12 miles per hour [mph]), with the faster speeds occurring at the higher elevations. Peak wind gusts of 80 to 113 kph (43 to 61 knots or 50 to 70 mph) have occurred throughout the NNSS. Peak winds at Mercury have been as high as 135 kph (73 knots or 84 mph) during a spring wind storm. During the same windstorm, Frenchman Flat experienced wind gusts to 113 kph (61 knots or 70 mph). The peak wind speeds measured on the NNSS are above 145 kph (78 knots or 90 mph) on the high terrain with maximums of 204 kph (110 knots or 127 mph) at the Yucca Mountain Ridge-top (MEDA Station 24), and 185 kph (100 knots or 115 mph) on Tippipah Point in south-central Area 16 (former MEDA Station 19, which is no longer in service) during a wind event on February 13, 2008.

Wind speed and direction data have been summarized for all the meteorological sites (MEDAs) on the NNSS. These climatological summaries are referred to as wind roses. Annual wind roses for 16 stations on the NNSS for the years 2005 through 2021 are shown in Figure A-18. These wind roses describe the strong seasonal and diurnal effects on the surface air flow pattern across the NNSS as described above. In general, winter and pre-sunrise winds tend to be northerly, while summer and afternoon flow tends to be southerly.

A.3.5 Relative Humidity

The air over the NNSS tends to be dry. On average, June is the driest month, with the humidity ranging from 10% to 35%. Humidity readings of 35% to 70% are common in the winter. The reason for this variability is that relative humidity is temperature dependent. The relative humidity tends to be higher with cold temperatures and lower with hot temperatures. Consequently, there is not only a seasonal variation but also a marked diurnal rhythm. Early in the morning the humidity ranges from 25% to 70%, and in mid-afternoon it ranges from 10% to 40%, with the larger readings occurring in winter. Humidity readings of more than 75% are observed during thunderstorms and frontal passages with precipitation, but are not otherwise common on the NNSS.

A.3.6 Atmospheric Pressure

Atmospheric pressure is measured at all the MEDA stations on the NNSS (Figure A-14). These measurements show that atmospheric pressure has marked annual and diurnal cycles. In addition, pressure decreases with elevation. Consequently, stations at high elevations have lower atmospheric pressures than do stations at lower elevations. Moreover, because pressure depends on temperature, the larger pressure readings occur during the winter months and the smaller readings in the summer months. The diurnal cycle is bimodal; it is driven by the diurnal tide of the entire atmosphere and by the diurnal heating/cooling cycle. In general, maximum daily surface pressure on the NNSS occurs between 8 and 10 a.m. PST (later in winter, earlier in summer), and minimum pressure tends to occur between 2 and 6 p.m. PST (earlier in winter, later in summer). Weaker secondary maxima occur at approximately midnight PST and minima near 3 a.m. PST. In Yucca Flat (elevation 1,195 m [3,920 ft]), the atmospheric pressure varies from 857 to 908 millibars (mb) annually; however, the daily variation is only approximately 3.4 mb in summer and 2.7 mb in winter.

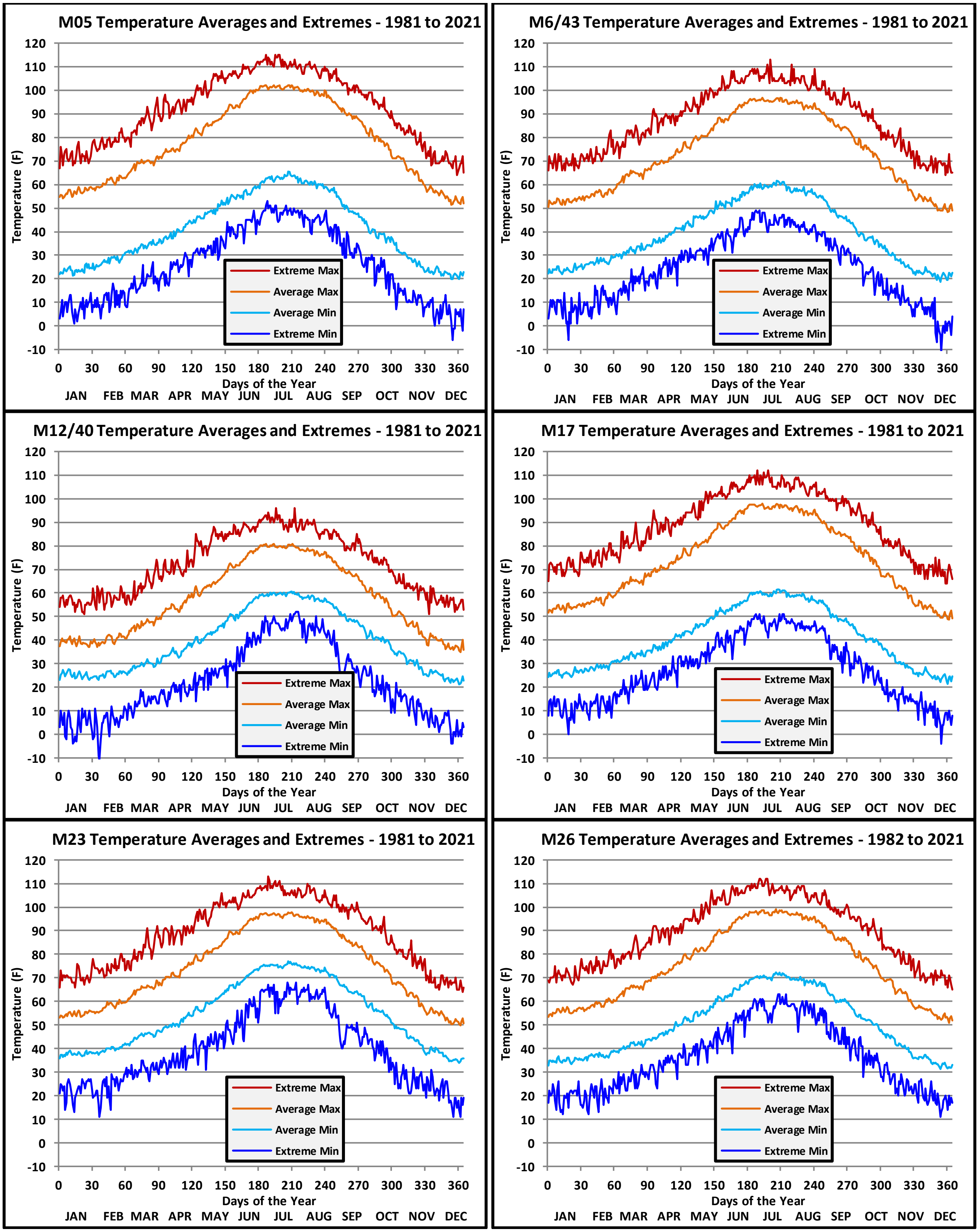

Figure A-17. Temperature extremes and average maximums and minimums at six NNSS MEDA stations (locations of numbered stations are shown in Figure A-14)

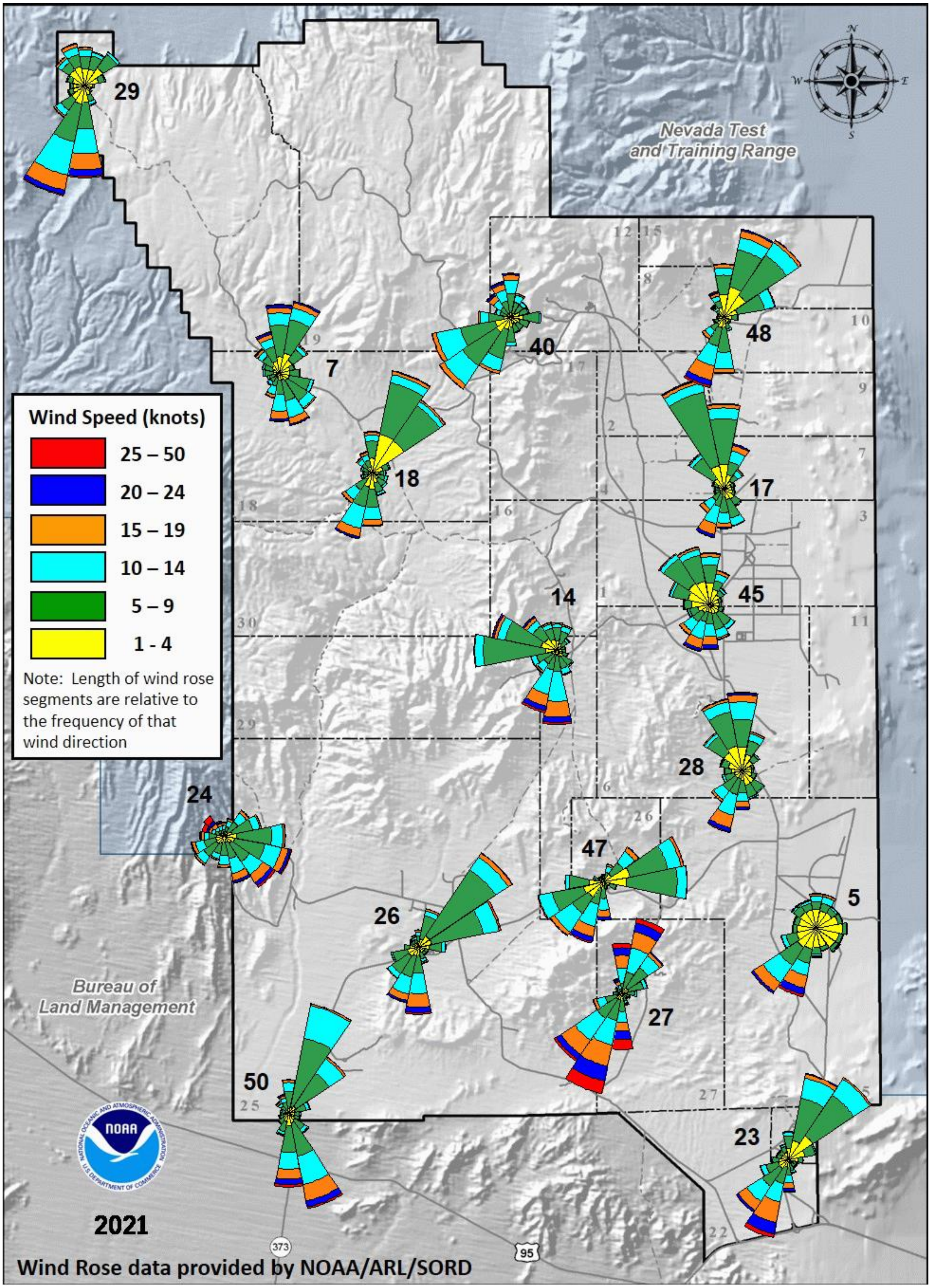

Figure A-18. Annual wind rose climatology for the NNSS (2005–2021)

A phenomenon referred to as atmospheric or barometric pumping can occur as atmospheric pressure decreases. When this happens, gases trapped below ground can seep upward through the soil and enter the atmosphere. Barometric pumping was observed on the NNSS following some underground nuclear tests, and small concentrations of noble gases from the tests were detected for several months afterwards. Barometric pumping also contributes to the release of naturally occurring radionuclides (e.g., radon) from terrestrial sources.

A.3.7 Dispersion Stability Categories

Determination of the stability of the atmosphere near the ground is a key input requirement for atmospheric dispersion models. Such models are used to estimate the impacts of hazardous materials that might be accidentally released into the atmosphere or become airborne from radioactively contaminated soil sites on the NNSS. The dispersion models commonly used for this purpose are Gaussian plume models that require the specification of stability categories to account for effects of atmospheric turbulence on the dispersion process. The mountain-valley topography on the NNSS makes it impossible to calculate a single set of values that characterizes atmospheric turbulent mixing on the NNSS. Consequently, the stability categories for the NNSS are calculated from the average hourly wind speeds for each MEDA station, the solar angle, and the hourly cloud-cover observations reported at the Desert Rock Meteorological Observatory. This procedure follows regulatory guidance provided by the U.S. Environmental Protection Agency (2000) and the American Nuclear Society (2015). The stability category concept makes use of the letters “A” through “F” to define different turbulence regimes. Category “A” specifies free convection in statistically unstable air, “D” represents neutral stability, and “F” is very stable (dispersion suppressed) with little turbulent mixing. In Yucca and Frenchman Flats, in winter, F-stability tends to persist from 4 p.m. PST until 8 a.m. PST the next morning, with an abrupt transition to C- or B-stability near 9 a.m. PST, followed by C- or B-stability during the afternoon. In summer, E- or F-stabilities occur between 7 p.m. PST and 6 a.m. the next morning, with a rapid change to B-stability at 7 a.m. PST and, generally, C- or B-stabilities and some D-stability in late afternoon.

A.3.8 Other Natural Phenomena

Wind speeds in excess of 97 kph (60 mph) occur annually. Additional severe weather in the region includes occasional severe thunderstorms, lightning, hail, and dust storms. Severe thunderstorms may produce high precipitation rates that may create localized flash flooding. Few tornadoes have been observed in the region and are not considered a significant threat.

Cloud-to-Ground (CG) lightning can occur throughout the year but occurs primarily between June and September. Maximum CG lightning activity on the NNSS occurs between 11 a.m. and 5 p.m. PST, while minimum activity occurs between 11 p.m. and 1 a.m. PST. For safety analyses, the mean annual flash density on the NNSS is 0.4 flashes per square km. Randerson and Sanders (2002) have characterized CG lightning activity on the NNSS.

Much of the information presented here can be reviewed on the SORD website, https://www.sord.nv.doe.gov.

A.4 Ecology

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The NNSS lies on the transition between the Mojave and Great Basin deserts. As a result, elements of both deserts are found in a diverse and complex assemblage of flora and fauna (Ostler et al. 2000; Wills and Ostler 2001).

A.4.1 Flora

Biologists have identified over 800 species of vascular plants in ten major vegetation alliances and twenty associations (Figure A-19). Distributions of the Mojave Desert, transition zone, and Great Basin Desert ecoregions are linked to elevation, temperature extremes, precipitation, and soil conditions.

Mojave Desert vegetation associations dominate about a third of the NNSS in the south, on hillsides and mountain ranges at elevations below about 1,200 m (4,000 ft). Creosote bush (*Larrea tridentata*) is the dominant shrub within these associations except where the mean temperature is below −1.9°C (28.5°F) and average rainfall is 18.3 cm (7.2 in.) or less (Beatley 1974). Between elevations of about 1,200 to 1,500 m (4,000 to 5,000 ft), dominant vegetation shifts in the transition zone (22% of the NNSS) and is a blackbrush-Nevada jointfir (*Coleogyne ramosissima-Ephedra nevadensis*) shrubland (Ostler et al. 2000). Above about 1,500 m (5,000 ft), the vegetation is characteristic of the Great Basin Desert. Dominant shrub species are basin big sagebrush (*Artemisia tridentata tridentata*) and black sagebrush (*A. nova*). Distribution of Great Basin Desert associations appears to be limited by mean maximum temperature and by minimum rainfall tolerances of cold desert species (Beatley 1975).

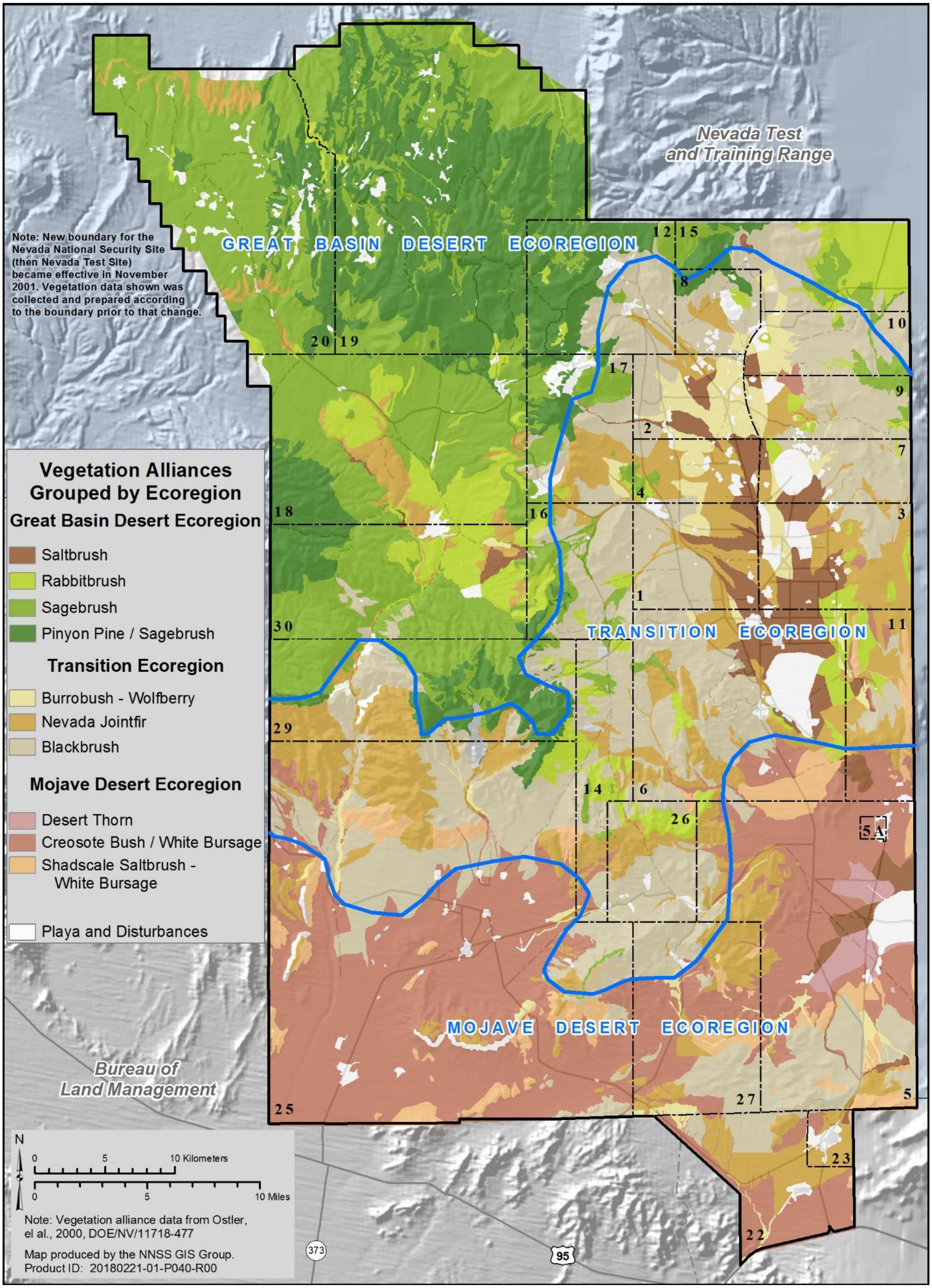
Above about 1,800 m (6,000 ft), singleleaf pinyon (*Pinus monophylla*) and Utah juniper (*Juniperus osteosperma*) mix with the sagebrush association where suitable moisture is present. Tree densities on the NNSS are often not high enough to create closed canopies but, rather, form an open woodland with a mix of shrub and tree cover.

A characterization of vegetation communities was established in the late 1950s, but botanical efforts began in earnest in the 1970s with the passing of the U.S. Department of the Interior, Endangered Species Act (ESA). Although none of the known plant species on the NNSS are listed as threatened or endangered under the ESA, numerous plants on the NNSS are considered sensitive by the Nevada Division of Natural Heritage (NDNH) and are included in the NDNH At-Risk Plant and Animal Tracking List, summarized in Table A-10. Sensitive species are those whose long-term viability is a concern to natural resource experts. Populations of sensitive plant species are well documented on the NNSS (Figure A-20) and the condition of those populations are monitored under the Ecological Monitoring and Compliance Program (Chapter 13 of the main report).

A.4.2 Fauna

At least 1,163 species of invertebrates within the phylum Arthropoda have been identified on the NNSS. Of the known arthropods, 78% are insects. Ants, termites, and ground-dwelling beetles are probably the most important groups of insects in regard to distribution, abundance, and functional roles. No native fish or amphibians are known to occur on the NNSS.

Among reptiles, the desert tortoise (*Gopherus agassizii*), 16 lizard species, and 17 snake species are known to occur on the NNSS (Wills and Ostler 2001). The rich reptile fauna is partly due to the overlapping ranges of plant species characteristic of the Mojave and Great Basin deserts. The most abundant, widely distributed lizards include the side-blotched lizard (*Uta stansburiana*), western whiptail (*Cnemidophorus tigris*), and desert horned lizard (*Phrynosoma platyrhinos*). The western shovel-nosed snake (*Chionactis occipitalis*) and gopher snake (*Pituophis catenifer*) are the most common snakes on the NNSS. There are four species of poisonous snakes: the Mohave Desert sidewinder (*Crotalus cerastes*), speckled rattlesnake (*Crotalus mitchellii*), night snake (*Hypsiglena torquata*), and Sonoran lyre snake (*Trimorphodon biscutatus*).



Note: New boundary for the Nevada National Security Site (then Nevada Test Site) became effective in November 2001. Vegetation data shown was collected and prepared according to the boundary prior to that change.

Note: Vegetation alliance data from Ostler, el al., 2000, DOE/NV/11718-477

Map produced by the NNSS GIS Group.
Product ID: 20180221-01-P040-R00

Figure A-19. Distribution of plant alliances on the NNSS

Table A-10. List of sensitive and protected/regulated plant and animal species known to occur on the NNSS

Plant Species	Common Names	Status[a]
Moss Species		
Entosthodon planoconvexus	Planoconvex cordmoss	S, H
Flowering Plant Species		
Arctomecon merriamii	White bearpoppy	S, M
Astragalus beatleyae	Beatley's milkvetch	S, H
Astragalus funereus	Black woollypod	S, H
Astragalus oophorus var. *clokeyanus*	Clokey eggvetch	S, W
Chylismia megalantha	Cane Spring suncup	S, M
Cryptantha clokeyi	Clokey's cryptantha	S, E
Cymopterus ripleyi var. *saniculoides*	Sanicle biscuitroot	S, W
Eriogonum concinnum	Darin buckwheat	S, M
Eriogonum heermannii var. *clokeyi*	Clokey buckwheat	S, W
Frasera pahutensis	Pahute green gentian	S, M
Galium hilendiae ssp. *kingstonense*	Kingston Mountains bedstraw	S, H
Hulsea vestita ssp. *inyoensis*	Inyo hulsea	S, W
Ivesia arizonica var. *saxosa*	Rock purpusia	S, H
Penstemon fruticiformis ssp. *amargosae*	Death Valley beardtongue	S, M
Penstemon pahutensis	Pahute Mesa beardtongue	S, W
Penstemon palmeri var. macranthus	Lahontan beardtongue	S, E
Phacelia beatleyae	Beatley scorpionflower	S, M
Phacelia filiae	Clarke phacelia	S, W
Phacelia mustelina	Weasel phacelia	S, W
Agavaceae	Yucca (3 species), Agave (1 species)	CY
Cactaceae	Cacti (17 species)	CY
Juniperus osteosperma	Utah juniper	CY
Pinus monophylla	Single-leaf pinyon	CY

Table A-10. List of sensitive and protected/regulated plant and animal species known to occur on the NNSS (continued).

Animal Species	Common Name	Status[a]
Mollusk Species		
Pyrgulopsis turbatrix	Southwest Nevada pyrg	S, A
Reptile Species		
Plestiodon gilberti rubricaudatus	Western red-tailed skink	S, IA
Gopherus agassizii	Desert tortoise	LT, S, NPT, A
Bird Species[b]		
Accipiter gentilis	Northern goshawk	S, NPS, A
Alectoris chukar	Chukar	G, IA
Aquila chrysaetos	Golden eagle	EA, NP, A
Asio flammeus	Short-eared owl	S, NP, A
Asio otus	Long-eared owl	S, NP, A
Callipepla gambelii	Gambel's quail	G, IA
Coccyzus americanus	Western yellow-billed cuckoo	LT, S, NPS, IA
Corvus brachyrhynchos	American crow	G, IA
Falco peregrinus	Peregrine falcon	S, NPE, A
Gymnorhinus cyanocephalus	Pinyon jay	S, NP, IA
Haliaeetus leucocephalus	Bald eagle	EA, S, NPE, A
Ixobrychus exillis hesperis	Least bittern	S, NP, IA
Lanius ludovicianus	Loggerhead shrike	NPS, A
Melanerpes lewis	Lewis woodpecker	S, NP, IA
Oreoscoptes montanus	Sage thrasher	NPS, IA
Riparia riparia	Bank swallow	S, NP, IA
Spinus pinus	Pine siskin	S, NP, IA
Spizella breweri	Brewer's sparrow	NPS, IA
Toxostoma lecontei	LeConte's thrasher	S, NP, IA
Mammal Species		
Antilocapra americana	Pronghorn antelope	G, A
Antrozous pallidus	Pallid bat	NP, A
Cervus elaphus nelsoni	Rocky Mountain elk	G, IA
Corynorhinus townsendii	Townsend's big-eared bat	S, NPS, A

Table A-10. List of sensitive and protected/regulated plant and animal species known to occur on the NNSS (continued).

Animal Species	Common Name	Status[a]
Equus asinus	Burro	H&B, A
Equus caballus	Horse	H&B, A
Euderma maculatum	Spotted bat	S, NPT, A
Lasionycteris noctivagans	Silver-haired bat	S, A
Lasiurus blossevillii	Western red bat	S, NPS, A
Lasiurus cinereus	Hoary bat	S, A
Lynx rufus	Bobcat	F, IA
Microdipodops megacephalus	Dark kangaroo mouse	NP, A
Microdipodops pallidus	Pale kangaroo mouse	S, NP, A
Myotis thysanodes	Fringed myotis	S, NP, A
Ovis canadensis nelsoni	Desert bighorn sheep	G, A
Odocoileus hemionus	Mule deer	G, A
Puma concolor	Mountain lion	G, A
Sorex tenellus	Inyo shrew	S, IA
Sylvilagus audubonii	Audubon's cottontail	G, IA
Sylvilagus nuttallii	Nuttall's cottontail	G, IA
Tadarida brasiliensis	Brazilian free-tailed bat	NP, A
Urocyon cinereoargenteus	Gray fox	F, IA
Vulpes macrotis	Kit fox	F, IA

[a] **Status Codes for Column 3**

Endangered Species Act, U.S. Fish and Wildlife Service

LT	Listed Threatened

U.S. Department of Interior

H&B	Protected under *Wild Free-Roaming Horses and Burros Act*
EA	Protected under *Bald and Golden Eagle Act*

State of Nevada – Animals

S	Nevada Division of Natural Heritage – At-Risk Plant and Animal Tracking List
NPE	Nevada Protected-Endangered, species protected under Nevada Administrative Code (NAC) 503
NPT	Nevada Protected-Threatened, species protected under NAC 503
NPS	Nevada Protected-Sensitive, species protected under NAC 503
NP	Nevada Protected, species protected under NAC 503
G	Regulated as game species under NAC 503

F	Regulated as fur bearer species under NAC 503

State of Nevada – Plants

S	Nevada Division of Natural Heritage – At-Risk Plant and Animal Tracking List
CY	Protected as a cactus, yucca, or Christmas tree from unauthorized collection on public lands

NNSS Sensitive Plant Ranking

E	Evaluate
H	High
M	Moderate
W	Watch

Long-term Animal Monitoring Status for the NNSS

A	Active
IA	Inactive

[b] All bird species on the NNSS are protected by the *Migratory Bird Treaty Act* except for chukar, Gambel's quail, English house sparrow, rock dove, Eurasian collared dove and European starling. Most bird species are also protected under NAC 503.

Sources used: NDNH 2022, NAC 2022, U.S. Fish and Wildlife Service (FWS) 2022

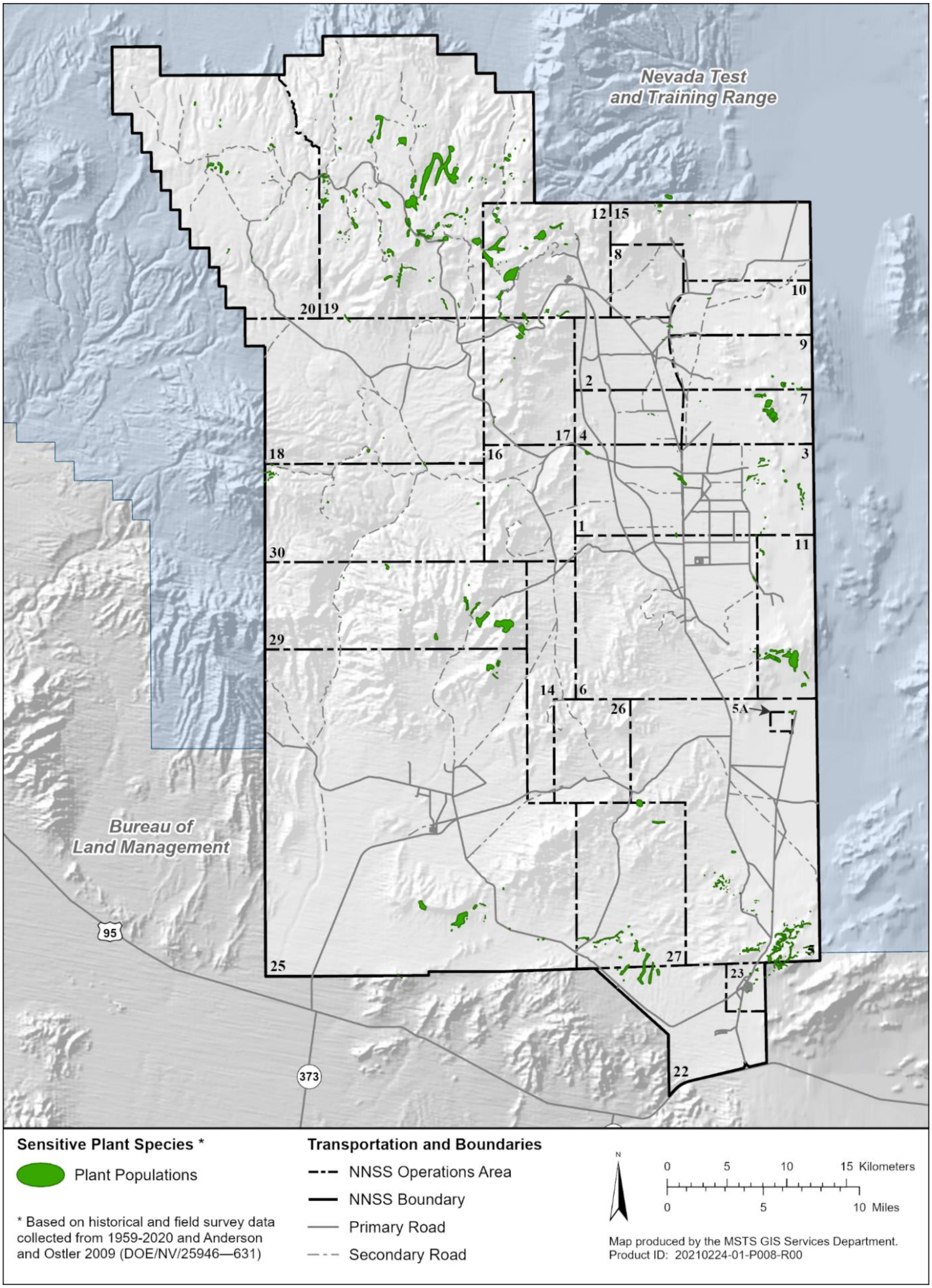


Figure A-20. Known locations of sensitive plant species on the NNSS (Anderson and Ostler 2009)

There are records of 246 species of birds observed on the NNSS (Hall and Perry 2022). Approximately 80% of the bird species are migrants or seasonal residents. To date, 26 species, including 9 raptor species (birds of prey), are known to breed on the NNSS. Raptors that breed on the NNSS include the golden eagle (*Aquila chrysaetos*), long-eared owl (*Asia otus*), red-tailed hawk (*Buteo jamaicensis*), Swainson's hawk (*Buteo swainsoni*), prairie falcon (*Falco mexicanus*), American kestrel (*Falco sparverius*), western burrowing owl (*Athene cunicularia hypugaea*), barn owl (*Tyto alba*), and great-horned owl (*Bubo virginianus*) (BN 2002b).

There are 44 terrestrial mammals and 15 bat species known to occur on the NNSS. Rodents account for about 40% of known mammals and, in terms of distribution and relative abundance, are the most important group of mammals on the NNSS (Wills and Ostler 2001). An apparent correlation exists between production by winter annual plants and reproduction in desert rodents on the NNSS. Larger mammals on the site include black-tailed jackrabbit (*Lepus californicus*), desert cottontail (*Sylvilagus audubonii*), feral horse (*Equus caballus*), mule deer (*Odocoileus hemionus*), pronghorn antelope (*Antilocapra americana*), Rocky Mountain elk (*Cervus elaphus nelsoni*), coyote (*Canis latrans*), kit fox (*Vulpes macrotis*), grey fox (*Urocyon cinereoargenteus*), badger (*Taxidea taxus*), bobcat (*Lynx rufus*), mountain lion (*Puma concolor*), feral burro (*Equus asinus*), and desert bighorn sheep (*Ovis canadensis nelsoni*). Mule deer herds occur mainly on the higher elevation, forested portions of the NNSS, and surrounding bajadas. A herd of 30–50 feral horses roams the north-central portion of the NNSS and a population of 50-60 pronghorn antelope are found primarily in Frenchman Flat and Yucca Flat. A reproducing population of about 30 desert bighorn sheep occurs in the Yucca Mountain/Fortymile Canyon area. A small number of feral burros are resident in Yucca Flat and Frenchman Flat, while a growing number inhabit Jackass Flats and Fortymile Canyon/Yucca Mountain areas. Elk are rare visitors to the high mesas.

The desert tortoise is the only resident species on the NNSS listed as threatened under the ESA. Habitat of the desert tortoise is in the southern third of the NNSS (Chapter 13). No other federally threatened or endangered animal is known to occur routinely on the NNSS. All bird species on the NNSS are protected by the Migratory Bird Treaty Act except for six species: English house sparrow (*Passer domesticus*), European starling (*Sturnus vulgaris*), Gambel's quail (*Callipepla gambelii*), chukar (*Alectoris chukar*), Eurasian collared dove (*Streptopelia decaocto*), and rock dove (*Columba livia*). Most non-rodent mammals of the NNSS are protected by the State of Nevada and managed as either game or furbearing mammals, and eight bats on the NNSS are considered sensitive or protected species. Table A-10 identifies the important animal species on the NNSS that are either classified as sensitive, protected, and/or regulated by state or federal agencies. They are the species commonly evaluated for inclusion in long-term monitoring activities on the NNSS.

A.4.3 Natural Water Sources

Biological communities on the NNSS that are associated with springs or other natural sources of water are important resources. They are rare, localized habitats that are important to regional wildlife and to isolated populations of water-loving plants and aquatic organisms. They include 16 springs and 12 seeps. In addition, there are 14 tank sites (natural rock depressions that catch and hold surface runoff), and 15 ephemeral ponds (Hall and Perry 2020) (Figure A-21). The ephemeral ponds occur in low elevation areas on playas or within natural drainages that may have been modified during historical NNSS operations (e.g., road construction, excavation), resulting in well-defined catchments for surface water runoff. Twelve of these occur on Frenchman Flat Playa and are referred to as earthen sumps.

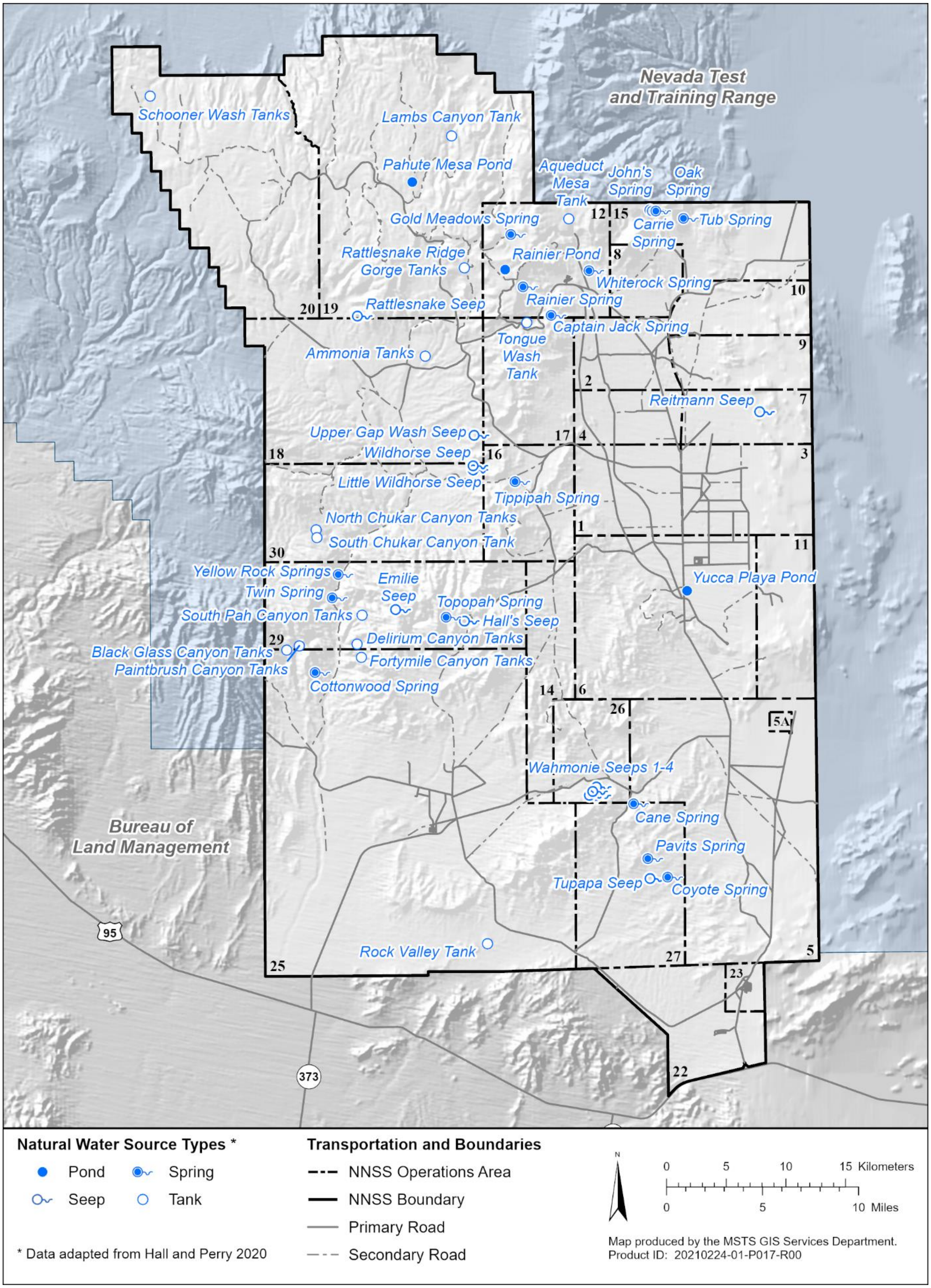


Figure A-21. Natural water sources on the NNSS (Hall and Perry 2020)

A.5 Cultural Resources

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A.5.1 Cultural Resources Investigations on the NNSS

Archaeological and cultural research pertaining to the NNSS region has been conducted since at least the 1930s. The most notable are reconnaissance surveys of the area by S. M. Wheeler in 1940 and Richard Shutler in 1955, and the extensive early studies conducted by Frederick Worman for the Atomic Energy Commission (AEC) (Shutler 1961; Worman 1969). In the late 1970s, with strengthened federal laws and regulations supporting historic preservation, systematic cultural resources investigations on the NNSS were carried out on a regular basis. The Desert Research Institute (DRI) became the cultural resources support contractor at that time, and DRI has continued to perform many archaeological and historical surveys and data recovery efforts ever since, as well as records management and curation of artifacts. Documentation and protection of Cold War-era structures and buildings on the NNSS have become a key part of the cultural resources program since the 1990s, with the increased recognition that Cold War-era nuclear testing and other activities carried out on the NNSS comprise a historic period of major national and international importance (Fehner and Gosling 2002, 2006; Titus 1986).

Cultural resources on the NNSS range from the earliest known prehistoric societies in North America ca. 13,000 years ago, through the millennia to historic times including Native American occupations, early Euroamerican exploration and emigration, mining booms and busts, ranching, military training, and AEC and DOE nuclear weapons testing.

A.5.2 Prehistory

The oldest cultural remains discovered on the NNSS come from what is generically called the Paleoamerican period, about 13,000–10,000 years ago (Graf et al. 2013). In the Great Basin, this period is commonly called the Paleoindian or the Paleoarchaic, depending on how evidence for early subsistence activities is interpreted (Graf and Schmitt 2007; Davis et al. 2012). Archaeological sites dating to this period contain two major distinctive types of stone tool weaponry: first, fluted lanceolate bifacial spear points that are clearly related to the Clovis points of the Southwest and eastern North America, and secondly, a variety of spear point and knife forms having long stems for hafting that are collectively known as Western Stemmed points (Beck and Jones 1997). The two point types apparently represent different methods of stone tool production, and they may represent two different groups of early occupants in the region (Beck and Jones 2010, 2012; Davis et al. 2012). Only a few Clovis-like point fragments have been found on the NNSS, along the alluvial terraces of Fortymile Canyon in Area 25, and in the upper reaches of the Fortymile drainage system between Timber Mountain and Rainier Mesa (Jones and Edwards 1994; Reno 1985; Worman 1969). Western Stemmed points and sites are much more common in the region, occurring especially along Fortymile Wash (Haynes 1996; Buck et al. 1998).

The basic economic strategy during this period was a wide-ranging hunting and gathering orientation, generalized in the collection of an array of animal and plant food resources and a common focus on the exploitation of resource-rich habitats such as shallow lakes, deltas, and marshes (Grayson 2011; Madsen 2002; Madsen et al. 2015; Warren and Crabtree 1986). No evidence indicates that the basins on the NNSS supported pluvial lakes (Grayson 2011; Mifflin and Wheat 1979), but they could have been filled with small seasonal wetlands. The Fortymile Wash drainage, where Paleoamerican sites are most common, may have been used as a travel route between lowland marshy areas near Ash Meadows and highlands such as Pahute and Rainier Mesas where deer and elk could be procured (Pippin 1998). Archaeological sites dating to this time period often contain artifacts made of obsidian and other raw materials that were transported from very distant source areas, indicating people traveled very widely in their migrations (Jones et al. 2003). In the Paleoamerican period and unlike later periods, small seeds do not appear to have been a major part of subsistence pursuits, as very few seed-grinding tools such as grinding slabs (metates) and handstones (manos) have been found at archaeological sites dating to this time period; such implements only become common after the Paleoindian interval comes to a close (Rhode et al. 2006).

After ca. 10,000 years ago, the climate became significantly warmer and dryer, with long periods of drought (Grayson 2011; Lachniet et al. 2017). Many regional wetlands dried up (Grayson 2011). Woodlands began to retreat upslope and were replaced in the lowlands by creosote bush and saltbush desert scrub (Rhode and Adams 2016; Spaulding 1990; Thompson 1990), and desert-adapted fauna replaced animals more suited to cooler climes (Grayson 2011; Hockett 2000). The middle Holocene period from ca. 8,000–4,500 years ago was marked by continued aridity (Antevs 1948; Grayson 2011; Lachniet et al. 2017; Wigand and Rhode 2002). As environmental conditions changed in the Great Basin, human population numbers appear to have declined in several areas, and some evidence suggests that entire areas were abandoned (Grayson 2011; Louderback et al. 2011; Warren and Crabtree 1986). The people in this period may have aggregated at springs and other dependable water sources, and only briefly entered more arid locales during times of greater effective moisture. In the NNSS area, higher elevation zones became an important part of the subsistence base. People expanded their food resource base to incorporate more abundant but more costly to process plant food resources such as small seeds (Rhode et al. 2006). This general trend appears to have occurred on the NNSS (Pippin 1998), but intensification of food-getting pursuits and expansion of the range of habitats exploited did not translate into permanent residential bases in the uplands. The small populations of people roaming the arid landscape apparently continued to be highly mobile, though likely tethered to the scattered springs throughout the region (Warren and Crabtree 1986).

The late Holocene period from ca. 4,500–1,900 years ago was cooler and wetter than the middle Holocene in the region (Wigand and Rhode 2002; Lachniet et al. 2017). Subsequent periods in the late Holocene fluctuated between dry and wet episodes, with notable arid episodes from 1,900–1,000 and 700–500 years ago (Wigand and Rhode 2002). Culturally, the late Holocene is marked by an increase in the number of people as indicated by the abundance of archaeological sites, and an even greater range of food resources exploited (Bettinger 1999; Grayson 2011). In some areas of the southern Great Basin, people began to inhabit large, semi-sedentary communities on valley floors with frequent seasonal use of the highlands (Pippin 1998). An increase in the frequency of grinding implements indicates a greater reliance on seeds than previously practiced (Warren and Crabtree 1986). Rock features interpreted as pine nut caches begin to appear in higher elevation woodlands on the NNSS (Pippin 1998), exhibiting a greater expenditure of effort and permanence in these sites than had occurred previously. This late Holocene intensification of the use of pinyon pine nuts has also been observed elsewhere in the southern Great Basin, notably Owens Valley to the west (Bettinger 1976, 1989; Madsen 1986a). One of the most conspicuous technological changes is the introduction of the bow and arrow, ca. 1,500 years ago (Bettinger 2013; Bettinger and Eerkens 1999). Examples of projectile points from the late Holocene period found on the NNSS are shown in Figure A-22. Another important technological introduction was brownware pottery (Figure A-23), ca. 700 to 1,000 before present (Lockett and Pippin 1990; Madsen 1986b; Pippin 1986; Rhode 1994), indicating a change in the way food was prepared and stored. Eerkens (2005) notes that pots were conducive to boiling over a fire and, based on residues found adhering to pot interiors, were used to boil seeds. They also served as private storage vessels for family groups, which may have resulted in greater private ownership of food stores and a stronger family-group economic orientation of the kind noted in historic times (Steward 1938), rather than a larger communal group pattern of sharing of public goods that might have prevailed in earlier times (Bettinger 1994, 1999).

A.5.3 Ethnohistoric American Indian

Early explorers and immigrants in the southern Great Basin during the nineteenth century encountered widely scattered groups of Numic-speaking hunters and gatherers currently known as Southern Paiute (Kelly and Fowler 1986) and Western Shoshone (Thomas et al. 1986). The areas traditionally claimed by these tribal entities encompassed a large region and were bound in territories of ethnic or political groups (Inter-Tribal Council of Nevada 1976; Stoffle et al. 1990, 2001). These territorial boundaries, even between subgroups, were stronger, with less mixing or movement between them prior to Euroamerican intrusion into the region and its deleterious effects on the local native peoples. Subsistence strategies mainly revolved around movements between environmental zones (e.g., highlands and lowlands) within their territories according to seasonal availability of food resources (Steward 1938; Wheat 1967). The normal range of travel for resources was up to 32 km (20 mi) of the primary residential base camp, but most could be found within a short distance of the camp. Criteria for the location of the primary residential base camp was proximity to stored or cached foods, availability of water, wood for fuel and house construction, and relatively warm winter temperatures like that found in canyon mouths or in the woodlands (Steward 1938).

The communal Western Shoshone group around Rainier Mesa and the southern end of the Belted Range ca. 1875–1880 was known as *Ĕso* (little hill). The *Ĕso* were closely linked linguistically with people to the east, but maintained close relationships with groups all around them, particularly to the north and west. They established winter residential camps at Captain Jack Spring, Oak Springs, Tippipah Springs (Figure A-24), Topopah Spring, White Rock Springs, and on Pahute and Rainier Mesas (Pippin 1997). Captain Jack Spring is named after One-eyed Captain Jack, who resided there at various times with his wives in the late 1800s and early 1900s (Steward 1938; Stoffle et al. 1990). At White Rock Springs lived *Wandagwana,* headman for the *Ĕso*. He directed the annual fall rabbit drive in Yucca Flat, in which various camps from around the region gathered and interacted. Sweat houses, also serving as gathering places for local groups, were located at White Rock Springs and at Oak Springs. They were used by both women and men for smoking, gambling, sweating, and as dormitories.

Another Western Shoshone group, the *Ogwe'pi* (creek), lived primarily based in Oasis Valley to the west (Pippin 1997; Steward 1938; Stoffle et al. 1990). Most of their winter camps and residential bases were located north of Beatty, but their territory or use area extended eastward and included Pahute Mesa and Fortymile Canyon, with the latter forming the boundary abutting the territory of the *Ĕso* to the east and the Southern Paiute to the south. The *Ogwe'pi* had strong ties to the Timbisha people in Death Valley, and they traveled to the Grapevine and Funeral Mountains and valleys to the west and south for certain resources or when areas to the east were less productive.

A fandango, or group gathering festival, was usually held by the *Ĕso* at the winter camp of *Wungiakuda* off the southeast edge of Pahute Mesa near Landmark Rock (Johnson et al. 1999; Steward 1938). The *Ogwe'pi* also hosted an annual regional fandango, alternating with the *Ĕso*. This fandango was held in Oasis Valley instead of at *Wungiakuda*. The fandango lasted about 5 days, and provided opportunity for the exchange of goods and information, as well as courtship and merry-making.

The southern portion of the NNSS, southward from Yucca and Shoshone Mountains, including the Cane Spring site, was part of the territory occupied by mixed Western Shoshone and Southern Paiute people centered on Ash Meadows (*Toi'oits*) (Kelly and Fowler 1986; Stoffle et al. 1990). The Ash Meadows group interacted with both Southern Paiutes to the south and east as well as Western Shoshone to the north and west. The Ash Meadows group practiced some horticulture at the spring sites to supplement their primary subsistence base of hunting and gathering; crops included maize, squash, bean, and sunflower (Steward 1938). At Cane Spring, the stubble of a corn field and a cache of squash were found by immigrants traveling through Death Valley in 1849 (Manly 1927). The only standing structure at the spring at that time was a wickiup. Steward (1938) documents a small family of five people living at Cane Spring ca. 1880. Today, there are remnants of two cabins and a corral at the spring (Jones 2001).

A.5.4 Euroamerican Emigration, Exploration, and Settlement

Euroamerican explorers and emigrants began entering the NNSS area by the late 1840s. A stone block with the name "R. J. BYOR" and the date "1847" carved in it was found and used in the fireplace of a stone cabin at Cane Spring. The name on the stone remains a mystery, but may have been a member of the Mormon Battalion traveling from San Diego to Salt Lake City in that year.

More concrete evidence of Euroamerican travelers passing through the NNSS are the diaries and publications of the famed Death Valley Expedition of 1849 (Long 1950; Manly 1927). Part of that expedition, deciding to follow a rumor of a shorter route than the Old Spanish Trail to southern California, found themselves in unknown territory of the NNSS. The group split in two at Papoose Lake, north of Indian Springs. One party, the Bennett-Arcanes, went southwest toward Skull Mountain, stopped at Cane Spring, and then continued south to Ash Meadows. The other party, the Jayhawkers, headed west from Papoose Lake to Tippipah Spring, then split up again and followed two separate routes, one proceeding south between Skull Mountain and Fortymile Canyon and then on to the Amargosa Valley. The other offshoot (Reverend James Brier and family) traveled west of Tippipah

Spring down Fortymile Canyon where the Briers had to abandon their wagons; they ultimately walked on foot down the canyon, found the trail of their fellow Jayhawkers, and all three parties ultimately reunited to follow Furnace Creek Canyon into Death Valley and endure many further tribulations (Long 1950; Manly 1927). Remains of the Brier's old abandoned wagons have been found in Fortymile Canyon (Worman 1969).

The great topographic and exploring surveys of the American West conducted by George Wheeler, John Wesley Powell, and others after the Civil War skirted the margins of the NNSS in southern Nevada (Winslow 1996). Subsequent Euroamerican settlement in the NNSS area during the nineteenth and early twentieth century was scanty and involved ranching, wild horse hunting, mining, and relay stations for stage and freight lines. Initially ranching operations were small-scale individual settlements centered on the few springs in the region, but in the early twentieth century these were taken over by larger entities such as the Clay Spring Cattle Company and its successor the Naquinta Cattle Company. Ultimately, however, the poor quality of the rangeland prevented these larger operations from being profitable and ranching languished. Most of the springs bear remains of ranching operations and spring improvements.

A.5.5 Historic Mining on and near the NNSS

Around the beginning of the twentieth century, substantial gold and silver deposits were discovered in southwestern Nevada, with major strikes at Tonopah, Goldfield, and Rhyolite (Elliott 1966, 1973; McCracken 1992; Zanjani 1992). The overall population of Nevada doubled as a consequence. Within the confines of the NNSS no permanent settlement appeared, just marginal ranching and mining operations (Ball 1907). The great mining boom was short-lived, however, and quickly entered the bust phase. The Las Vegas and Tonopah rail line, constructed in 1906, lasted until 1918. The rails were removed in 1919, and the line was sold to the Nevada Department of Transportation for use as a highway (Myrick 1963). Still evident on the NNSS today are some of the abandoned ties reused for corrals and other structures at a number of the springs. Around the Beatty area, the ties were used in some of the later mining operations for shoring tunnels (McCracken 1992).

As mining explorations continued in the region, fanning out from the earlier strikes, small mining districts were founded (Cornwall 1972; Lincoln 1923; Tingley 1984). The mining town of Wahmonie around Mine and Skull Mountains was founded in 1928 (Jones et al. 1996; McLane 1995; Quade and Tingley 1984). It grew into a small town with boarding houses, tent stores, and cafes. The Silver Dollar Saloon and the Northern Club were but two of the enterprises (Long 1950). Most of the miners lived in small tents. George Wingfield, a well-known mine owner and banker in Nevada, became interested and incorporated the Wahmonie Mining Company. However, the strike was apparently not as rich as had first been thought, and by early 1929 optimism faded and people began leaving. Small amounts of prospecting in the district continued into the 1930s and 1940s, but few ore deposits were ever discovered.

The Oak Spring mining district was located at the north edge of the NNSS (Drollinger 2003). Documents at the Recorder's Office in Tonopah indicate the first claims were by Antonio Aguayo and W.S. Bennett dating to 1886. Most of the early mining activity in the district, however, is from the early twentieth century and coincides with the Tonopah-Goldfield-Rhyolite mining boom (Ball 1907; Lincoln 1923; McLane 1995; Quade and Tingley 1984; Stager and Tingley 1988). Like other similar mining districts in the region during this time, the main objectives were gold and silver. Overall, the early Oak Spring mining district was not very productive and not rich enough to offset shipping costs to process the ores (Hall 1981).

B. M. Bower (a.k.a. Bertha Muzzy Sinclair), a noted author, with husband (Bud Cowan) and family, moved to Nevada from Los Angeles, California, in 1920 and took up residence at an abandoned silver mine near Oak Spring (Drollinger 2003; Engen 1973; McLane 1996). An accomplished and prolific writer, B. M. Bower published 57 novels as well as short stories and screenplays over a 40-year career, with many becoming the basis for early western-themed movies in Hollywood. While living at the camp (Figure A-25), Bower wrote 11 novels, incorporating some of the surrounding geographic features, such as Oak Butte and the camp itself, into a few of the stories. The family formed the El Picacho Mining Company, with B. M. Bower serving as president, and filed assessment work for the claims from 1922 to 1928. The family moved to Las Vegas around 1926 and still worked the mining claims sporadically over the next couple years, but eventually the Great Depression forced them to move to Oregon. Fittingly, in keeping with the theme for some of the novels, the abandoned camp was used in the early 1930s by outlaws from Utah and Arizona whose escapades were later featured in a Death Valley Days radio episode narrated by Ronald W. Reagan. B. M. Bower died in Los Angeles 1940 and was inducted into the Western Writers of America Hall of Fame in 1994.

In 1937, a source of tungsten was discovered in the Oak Spring district (Kral 1951; Quade and Tingley 1984; Stager and Tingley 1988). Workings of the Climax tungsten mine included several mines, shafts, adits, trenches, an open pit, roads, and a processing mill. These operations ended when the area was closed with the founding of the bombing and gunnery range by the Federal government. The last known mining operation was from December 1956 to May 1957 involving a co-use agreement between the owners of the Climax Tungsten Corporation and the AEC, who now had control of the area for nuclear testing (Drollinger 2003; Quade and Tingley 1984).

A.5.6 The Cold War, Nuclear Testing, and Nuclear Research on the NNSS

A.5.6.1 The Cold War

The Cold War was a global conflict pivoting around themes of ideology, imperialism, strategic issues, and the nuclear arms race (Puzio 2013). It was a war fought via economic and cultural means, as well as a series of proxy wars by the United States and the former Soviet Union and their allies from 1947 to 1991 (Walker 1995; Gaddis 2005). After World War II, the U.S. and the former Soviet Union emerged as the only superpowers possessing intact heavy industry, large populations, and low international debt, as well as conflicting ideological outlooks (Gaddis 2005; Fink 2014). However, the U.S. was the only nuclear power in the world. This changed in August 1949 when the Soviets tested their first fission bomb. The U.S. response to the perceived Soviet threat was to expand production facilities and accelerate the development of nuclear weapons. On June 29, 1950, President Truman approved the development of a thermonuclear weapon, and then a plan for a test series in the Pacific (named Greenhouse) was initiated. However, while this plan was underway, the onset of the conflict in the Korean Peninsula began.

U.S. military involvement in Korea created technical and logistical problems for continuing with the Pacific test location. This led the AEC Chair Gordon Dean to declare that it was "wise to reexamine the question of a continental site with the objective of having available a definite and specific site which could be recommended for use" (Fehner and Gosling 2002). In December 1950, the U.S. Air Force approved a plan to allow the AEC to use the Las Vegas Bombing and Gunnery Range, a federal facility established in 1940 by President Roosevelt, for a proposed series of continental tests named Ranger (NNSA/NFO 2013). On December 18, 1950, President Truman approved the choice and construction began the following month. Camp Mercury, located at the southern end of the test area, was established as the main support, housing, and administrative base (Figure A-26). The new facility went through a series of name changes: Las Vegas Test Site in spring 1951; Nevada Test Site (NTS) on June 22, 1951; Nevada Proving Ground on February 25, 1952; and, finally reverting to the NTS on January 1, 1955. It remained the NTS throughout the rest of the Cold War until 2010, when the NTS was renamed to the current NNSS to reflect the diversity of nuclear, energy, and homeland security activities now conducted at the site. Additional land parcels were obtained under public orders and memorandums of agreement. A critical acquisition was made in August 1965, when Mercury and the nearby Camp Desert Rock were finally included in the NTS. Until then, they were still technically on land borrowed from the U.S. Air Force. This acquisition accounts for the southeastern boundary of the site, which extends out just enough to include these two facilities that were essential for site operations.

A.5.6.2 Nuclear Testing, Nuclear Research, and the Continental Test Site

The NNSS played a crucial role in the U.S. nuclear testing program during the Cold War with the former Soviet Union. An escalating arms race for nuclear weapons superiority led to numerous nuclear explosions worldwide by the U.S., the former Soviet Union, and other foreign nuclear powers. The AEC and the U.S. Department of

Defense conducted these tests for the U.S. Most of the tests occurred at the NNSS, where the operations included both atmospheric and underground tests. The major purposes of nuclear testing were weapons related (testing a device intended for a specific weapon system); weapons effects (evaluating the civil or military effects of a detonation); safety experiments (confirming a nuclear detonation would not occur from an accidental detonation of the high explosive associated with the device); joint U.S.–United Kingdom testing (storage-transportation); and Vela Uniform (improving the ability to detect, identify, and locate underground nuclear detonations) (NNSA/NFO 2015). In all, a total of 928 nuclear tests were conducted at the site, with 120 performed in the 1950s, and 808 after 1961 following a short moratorium between 1958 and 1961 agreed to by both the U.S. and the former Soviet Union (Friesen 1995). On August 5, 1963, the U.S. and former Soviet Union signed the Limited Test Ban Treaty. This treaty effectively banned testing of nuclear weapons in the atmosphere, ocean, or space, and atmospheric testing drew to an end, although there is evidence that some Soviet testing actually occurred after the treaty. In 1992, the U.S. established a second self-imposed moratorium on nuclear testing. In 1995, President Clinton announced a total ban on all critical U.S. nuclear weapons testing. In September 1996, the United Nations approved the Comprehensive Nuclear-Test-Ban Treaty, which prohibited any nuclear explosion. However, the U.S. Senate failed to ratify this treaty.

In addition to weapons testing, the NNSS served as the location for an array of notable non-defense related nuclear research and development programs. This other type of Cold War-era research ran the gamut from nuclear-powered space vehicles to experimental civil works projects to radiation dosimetry studies. In the mid-1950s, the AEC and the National Aeronautics and Space Administration (NASA) selected Jackass Flat as the site of the Nevada Rocket Development Station (NRDS) (Figure A-27) constructing a network of cutting-edge facilities interconnected by rail lines to develop and test nuclear thermal propulsion systems for missions to Mars and beyond (Dewar 2004). During the same period, the NNSS became a key component of the Eisenhower Administration's Plowshare Program. The concept focused on using nuclear explosives for peaceful purposes such as nuclear excavation for massive civil engineering projects (dam, harbor, road cut, and waterway construction) and industrial applications (oil and gas stimulation, geothermal power, underground storage/waste disposal cavities) (Beck et al. 2011). The Nevada facility was also the site of several landmark dosimetry studies focused on determining radiation dose rates and allowing more accurate risk assessments and health monitoring of the survivors of the Hiroshima and Nagasaki bombings. The data gleaned from all of these programs continue to inform contemporary research studies providing a foundation for future investigations (Bennett 2018; Cullings et al. 2006; Kerr et al. 2015; Short 2004; Williams 2017).

Figure A-22. Prehistoric projectile points from the NNSS (photo taken by DRI 1992)

Figure A-23. Brownware bowl recovered from archaeological excavations on Pahute Mesa (photo taken by DRI 1992)

Figure A-24. Overview of the Tippipah Spring area (photo taken by DRI 2004)

Figure A-25. Bower cabin on the NNSS (photo taken by DRI 2001)

Figure A-26. The town of Mercury, Nevada (photo taken by REECo May 1965)

Figure A-27. The NRDS Engine Maintenance and Disassembly Building (photo taken by Remote Sensing Laboratory 2013)

A.6 References

Allen, B. M., S. L. Drellack, Jr., and M. J. Townsend, 1997. *Surface Effects of Underground Nuclear Explosions*, DOE/NV/11718--122, Bechtel Nevada, Las Vegas, NV.

American Nuclear Society, 2015. *American National Standard for Determining Meteorological Information at Nuclear Facilities.* Approved August 20, 2015, ANSI/ANS-3.11-2015; American Nuclear Society, 555 North Kensington Avenue, La Grange Park, IL.

Anderson, D. C. and W. K. Ostler, 2009. *Distribution of Sensitive Plants on the Nevada Test Site*. DOE/NV/25946--631, Las Vegas, NV.

Antevs, E., 1948. Climatic Changes and Pre White Man, In: *The Great Basin with Emphasis on Glacial and Postglacial Times*, pp. 168–191, University of Utah Bulletin 38(20), Salt Lake City, UT.

Ball, S. H., 1907. *Mines of Silver Peak Range, Kawich Range, and other Southern Nevada Districts*. Nevada Publications, Las Vegas.

Barnes, H., F. N. Houser, and F. G. Poole, 1963. *Geologic Map of the Oak Spring Quadrangle, Nye County, Nevada,* U.S. Geological Survey Map GQ-214, scale 1:24,000, Washington, D.C.

Barnes, H., E. B. Ekren, C. L. Rodgers, and D. C. Hedlund, 1982. *Geology and Tectonic Maps of the Mercury Quadrangle, Nye and Clark Counties, Nevada*, U.S. Geological Survey, Miscellaneous Geologic Investigations Series Map I-1197, scale 1:24,000.

Bath, G. D., C. E. Jahren, J. G. Rosenbaum, and M. J. Baldwin, 1983. *Geologic and Geophysical Investigations of Climax Stock Intrusive, Nevada: Magnetic Investigations*, U.S. Geological Survey Open-File Report 83-377, pp. 40–57, Denver, CO.

Beatley, J. C., 1974. *Effects of Rainfall and Temperature on the Distribution and Behavior of Larrea tridentata (creosote-bush) in the Mojave Desert of Nevada*, Ecology 55:245–261.

———, 1975. *Climates and Vegetation Pattern Across the Mojave/Great Basin Desert Transition of Southern Nevada*, American Midland Naturalist 93:53–70.

Bechtel Nevada, 2002a. *A Hydrostratigraphic Model and Alternatives for the Groundwater Flow and Contaminant Transport Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nye County, Nevada*. DOE/NV/11718--706, Las Vegas, NV.

———, 2002b. *Ecological Monitoring and Compliance Program Fiscal Year 2002*, DOE/NV/11718--753, Las Vegas, NV.

———, 2005. *A Hydrostratigraphic Framework Model and Alternatives for the Groundwater Flow and Contaminant Transport Model of Corrective Action Unit 98: Frenchman Flat, Clark, Lincoln and Nye Counties, Nevada*, DOE/NV/11718--1064, Las Vegas, NV.

———, 2006a. *A Hydrostratigraphic Model and Alternatives for the Groundwater Flow and Contaminant Transport Model of Corrective Action Unit 97: Yucca Flat-Climax Mine, Lincoln and Nye Counties, Nevada*, DOE/NV/11718--1119, Las Vegas, NV.

———, 2006b. *Completion Report for Well ER-12-3, Corrective Action Unit 99: Rainier Mesa-Shoshone Mountain*, DOE/NV/11718--1182, Las Vegas, NV.

Beck, C. and G. T. Jones, 1997. *The terminal Pleistocene/early Holocene archaeology of the Great Basin*. Journal of World Prehistory 11:161-236.

———, 2010. Clovis and Western Stemmed: The meeting of two technologies in the Intermountain West. *American Antiquity* 75:81-116.

———, 2012. The Clovis-last hypothesis: Investigating early lithic technology in the Intermountain West. In *Meetings at the Margins: Prehistoric Cultural Interactions in the Intermountain West*, edited by D. E. Rhode, pp. 23-46. University of Utah Press, Salt Lake City.

Beck, C. M., S. R. Edwards and M. L. King, 2011. *The Off-Site Plowshare and Vela Uniform Programs: Assessing Potential Environmental Liabilities through an Examination of Proposed Nuclear Projects, High Explosive Experiments, and High Explosive Construction Activities*. Technical Report No. 111, 3 volumes, Desert Research Institute, Division of Earth and Ecosystem Sciences, Las Vegas, NV.

Belcher, W. R., Sweetkind, D. S., Faunt, C. C., Pavelko, M. T., and Hill, M. C., 2017. *An update of the Death Valley regional groundwater flow system transient model, Nevada and California: U.S. Geological Survey Scientific Investigations Report* 2016-5150, 74 p., 1 pl. https://doi.org/10.3133/sir20165150.

Bennett, J., 2018, "NASA's Nuclear Thermal Engine is a Blast from the Cold War Past." *Popular Mechanics*. 21 February 2018. https://www.popularmechanics.com/space/moon-mars/a18345717/nasa-ntp-nuclear-engines-mars/

Bettinger, R. L., 1976. *The development of pinyon exploitation in central eastern California*. Journal of California Anthropology 3:81-95.

———, 1989. *The Archaeology of Pinyon House, Two Eagles, and Crater Middens: Three Residential Sites in Owens Valley, Eastern California*. Anthropological Papers of the American Museum of Natural History vol. 67. New York.

———, 1994. *How, when, and why Numic spread*. In Across the West: Human Population Movement and the Expansion of the Numa, edited by D. B. Madsen and D. E. Rhode, pp. 44-55. University of Utah Press, Salt Lake City.

———, 1999. *What Happened in the Medithermal*. In Models for the Millenium: Great Basin Anthropology Today, edited by Charlotte Beck, pp. 62-74. University of Utah Press, Salt Lake City.

———, 2013. *Effects of the Bow on Social Organization in Western North America*. Evolutionary Anthropology 22:118-123.

Bettinger, R. L., and J. Eerkens, 1999. *Point typologies, cultural transmission, and the spread of bow-and-arrow technology in the prehistoric Great Basin*. American Antiquity 64:231-242.

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

Blout, D. O., D. P. Hammermeister, K. A. Zukosky, and K. D. Donnelson, 1994. *Site Characterization Data from the Area 5 Science Boreholes, Nevada Test Site, Nye County, Nevada,* Reynolds Electrical & Engineering Co., Inc., Las Vegas, NV.

BN, see Bechtel Nevada.

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

Bright, D. J., S. A. Watkins, and B. A. Lisle, 2001. *Analysis of Water Levels in the Frenchman Flat Area, Nevada Test Site*, U.S. Geological Survey Water-Resources Investigations Report 00-4272, Carson City, NV.

Brikowski, T. H., 1991. *The Hydrology of Underground Nuclear Tests: The Effect of Collapse-Chimney Formation*, Desert Research Institute Publication #45090, DOE/NV/10845--10, UC-703. Las Vegas, NV.

Buck, P. E., W. T. Harwell, G. Haynes, and D. E. Rhode, 1998. *Investigations at Two Early Holocene Sites Near Yucca Mountain, Nye County, Nevada*. Topics in Yucca Mountain Archaeology Number 2. Desert Research Institute, Las Vegas.

Byers, F. M., Jr., W. J. Carr, P. P. Orkild, W. D. Quinlivan, and K. A. Sargent, 1976. *Volcanic Suites and Related Cauldrons of the Timber Mountain-Oasis Valley Caldera Complex, Southern Nevada*, U.S. Geological Survey Professional Paper 919, 70 p. Washington, D.C.

Byers, F. M., Jr., W. J. Carr, and P. P. Orkild, 1989. *Volcanic Centers of Southwestern Nevada: Evolution of Understanding, 1960-1988*, Journal of Geophysical Research, 94(5):5,908–5,924.

Carle, S. F., M. Zavarin, and G. A. Pawloski, 2008. *Spatial Variability of Reactive Mineral and Radionuclide* K_d *Distributions in the Tuff Confining Unit: Yucca Flat, Nevada Test Site*, LLNL-TR-402227-DRAFT, Lawrence Livermore National Laboratory, Livermore, CA.

Cashman, P. H. and J. H. Trexler, Jr., 1991. *The Mississippian Antler Foreland and Continental Margin in Southern Nevada: The Eleana Formation Reinterpreted*, In: J. D. Cooper and C. H. Stevens, eds., Paleozoic Paleogeography of the Western United States II, Society of Economic Paleontologists and Mineralogists, Pacific Section, 67:271–280.

Caskey, S. J. and R. A. Schweickert, 1992. *Mesozoic Deformation in the Nevada Test Site and Vicinity: Implications for the Structural Framework of the Cordilleran Fold and Thrust Belt and Tertiary Extension North of Las Vegas*, Tectonics, 11(6):1,314–1,331.

Chapman, J. B., 1994. *Classification of Groundwater at the Nevada Test Site*, Desert Research Institute Report 45069, DOE/NV/10384--28, Las Vegas, NV.

Chapman, J. B. and B. F. Lyles, 1993. *Groundwater Chemistry at the Nevada Test Site: Data and Preliminary Interpretations*, Desert Research Institute Report 45100, DOE/NV/10845--16.

Cole, J. C., 1992. U.S. Geological Survey. Written communication to S. L. Drellack, Raytheon Services Nevada, regarding thickness of Paleozoic units at the Nevada National Security Site.

———, 1997. *Major Structural Controls on the Distribution of Pre-Tertiary Rocks, Nevada Test Site Vicinity, Southern Nevada*, U.S. Geological Survey Open-File Report 97-533.

Cole, J. C. and P. H. Cashman, 1999. *Structural Relationships of Pre-Tertiary Rocks in the Nevada Test Site Region, Southern Nevada*, U.S. Geological Survey Professional Paper 1607, U.S. Geological Survey, Denver, CO.

Cornwall, H. R., 1972. *Geology and Mineral Deposits of Southern Nye County, Nevada*, Bulletin No. 77, Nevada Bureau of Mines and Geology, Mackay School of Mines, University of Nevada, Reno.

Cullings, H. M., S. Fujita, S. Funamoto, E. J. Grant, G. D. Kerr, and D. L. Preston, 2006. "Dose Estimation for Atomic Bomb Survivor Studies: Its Evolution and Present Status." *Radiation Research* 166, no. 1, pp. 219-54. http://www.jstor.org/stable/4098767.

Davis, L G., S. C. Willis and S. J. Macfarlan, 2012. *Lithic technology, cultural transmission, and the nature of the far western Paleoarchaic/Paleoindian co-tradition*. In Meetings at the Margins: Prehistoric Cultural Interactions in the Intermountain West, edited by D. E. Rhode, pp. 47-64. University of Utah Press, Salt Lake City.

D'Agnese, F. A., C. C. Faunt, A. K. Turner, and M. C. Hill, 1997. *Hydrogeologic Evaluation and Numerical Simulation of the Death Valley Regional Ground-Water Flow System, Nevada and California*, U.S. Geological Survey Water-Resources Investigations Report 96-4300, Denver, CO.

Dewar, J. A., 2004. *To the End of the Solar System: The Story of the Nuclear Rocket*. University Press of Kentucky. Lexington.

DOE/NV, see U.S. Department of Energy, Nevada Operations Office.

Drellack, S. L., L. B. Prothro, K. E. Roberson, B. A. Schier, and E. H. Price, 1997. *Analysis of Fractures in Volcanic Cores from Pahute Mesa, Nevada Test Site*, DOE/NV/11718--160, Bechtel Nevada, Las Vegas, NV.

Drellack, S. L. and P. H. Thompson, 1990. *Selected Stratigraphic Data for Drill Holes in LANL Use Areas of Yucca Flat, NTS*, DOE/NV/10322-39, Fenix & Scisson, Inc., Las Vegas, NV.

Drollinger, H., 2003. *An Archaeological Investigation of the Bower Cabin Site, Nevada Test Site, Nye County, Nevada*, Cultural Resources Technical Report No. 100, Division of Earth and Ecosystem Sciences, Desert Research Institute, Las Vegas, NV.

Eerkens, J. W., 2005. *GC-MS analysis and fatty acid ratios of archaeological potsherds from the western Great Basin of North America*. Archaeometry 47(1):83-102.

Ekren, E. B., C. L. Rogers, R. E. Anderson, and P. P. Orkild, 1968. *Age of Basin and Range Normal Faults in Nevada Test Site and Nellis Air Force Range, Nevada*, In: Nevada Test Site: The Geological Society of America, Inc., Memoir 110, pp. 247–250.

Elliott, R. R., 1966. *Nevada's Twentieth Century Mining Boom*: *Tonopah, Goldfield, Ely,* University of Nevada Press, Reno, NV.

———, 1973. *History of Nevada,* University of Nevada Press, Reno, NV.

Elliott, P. E. and J. M. Fenelon, 2013. *Database of Groundwater levels and Hydrograph Descriptions for the Nevada Test Site Area, Nye County, Nevada* (version 4.0, November 2013). U.S. Geological Survey Data Series 533, 16 p. Reston, VA.

Engen, O. A., 1973. *Writer of the Plains: A Biography of B. M. Bower*. Pontine Press, Culver City, CA.

Faunt, C. C., 1998. *Effect of Faulting on Ground-Water Movement in the Death Valley Region, Nevada and California*, U.S. Geological Survey Report WRI 95-4132, U.S. Geological Survey, Denver, CO.

Fehner, T. R. and F. G. Gosling, 2002. *Origins of the Nevada Test Site*. Report DOE/MA-0518, U.S. Department of Energy, Washington, D.C.

———, 2006. *Atmospheric Nuclear Weapons Testing: 1951-963*. Report DOE/MA-0003, U.S. Department of Energy, Washington, D.C.

Fenelon, J. M., 2005. *Analysis of Ground-Water Levels and Associated Trends in Yucca Flat, Nevada Test Site, Nye County, Nevada, 1951-2003*, U.S. Geological Survey Scientific Investigations Report 2005-5171. Denver, CO.

———, 2007. *Database of Ground-Water Levels in the Vicinity of Rainier Mesa, Nevada Test Site, Nye County, Nevada, 1957-2005*, U.S. Geological Survey Data Series 190, Version 1.10, October 2007, 14 p.

Fenelon, J. M., R. J. Laczniak, and K. J. Halford, 2008. *Predevelopment Water-Level Contours for Aquifers in the Rainier Mesa and Shoshone Mountain Area of the Nevada Test Site, Nye County, Nevada*, Scientific Investigations Report 2008-5044, 38 p., Las Vegas, NV: U.S. Geological Survey.

Fenelon, J. M., D. S. Sweetkind, and R. J. Laczniak, 2010. *Groundwater Flow Systems at the Nevada Test Site, Nevada: A Synthesis of Potentiometric Contours, Hydrostratigraphy, and Geologic Structures*, U.S. Geological Survey Professional Paper 1771, 54 p., Reston, VA.

Fenelon, J. M., D. S. Sweetkind, P. E. Elliott, and R. J. Laczniak, 2012. *Conceptualization of the Predevelopment Groundwater Flow System and Transient Water-Level Responses in Yucca Flat, Nevada National Security Site, Nevada*. Scientific Investigations Report 20-12-5196, 61 p. https://pubs.er.usgs.gov/publication/sir20125196.

Ferguson, J. F., A. H. Cogbill, and R. G. Warren, 1994. *A Geophysical-Geological Transect of the Silent Canyon Caldera Complex, Pahute Mesa, Nevada,* Journal of Geophysical Research 99 (33):4323–4339.

Fiero, B., 1986. *Geology of the Great Basin*, University of Nevada Press, Reno, NV, 197 p.

Fink, C. K., 2014. *Cold War: An International History*. Westview, Boulder, Colorado.

Friesen, H. N., 1995. *A Perspective on Atmospheric Nuclear Tests in Nevada: Fact Book.* Report DOE/NV 296. U.S. Department of Energy, Nevada Operations Office, Las Vegas, Nevada.

FWS, see U. S. Fish and Wildlife Service.

Gaddis, J. L., 2005. *The Cold War: A New History*. Penguin, New York.

Garber, M. S., 1971. *Hydraulic-Test and Quality-of-Water Data from Hole U-3cn PS#2, Bilby Site, Nevada Test Site*, U.S. Geological Survey Report USGS-474--102 (NTS-230), Denver, CO.

GeoTrans, Inc., 1995. *A Fracture/Porous Media Model of Tritium Transport in Underground Weapons Testing Areas, Nevada Test Site*, Boulder, CO.

Gibbons, A. B., E. N. Hinrichs, W. R. Hansen, and R. W. Lemke, 1963. *Geology of the Rainier Mesa Quadrangle, Nye County, Nevada*, U.S. Geological Survey Map GQ-215, scale 1:24,000, Washington, D.C.

Gillespie, D., J. D. Donithan, and P. R. Seaber, 1996. *NTS Water-Supply Wells.* DOE/NV/10845-56 (DRI Publication No. 45138), Desert Research Institute, Las Vegas, NV.

Graf, K. E., C. V. Ketron, and M. R. Waters (eds.), 2013. *Paleoamerican Odyssey*. Center for the Study of the First Americans, Texas A & M University, College Station.

Graf, K. E. and D. N. Schmitt (eds.), 2007. *Paleoindian or Paleoarchaic? Great Basin Human Ecology at the Pleistocene-Holocene Transition.* University of Utah Press, Salt Lake City.

Grauch, V. J. S. and M. R. Hudson, 1995. *Preliminary Analysis of Major Structures and Lithologic Boundaries for the Frenchman Flat Model Area*, U.S. Geological Survey, Denver, CO.

Grayson, D. K., 2011. *The Great Basin: A Natural History.* University of California Press, Berkeley.

Hale, G. S., D. A. Trudeau, and C. S. Savard, 1995. *Water-Level Data from Wells and Test Holes Through 1991, and Potentiometric Contours as of 1991 for Yucca Flat, Nevada Test Site, Nye County, Nevada*, Water-Resources Investigations Report 95-4177, U.S. Geological Survey, Denver, CO.

Hale, W. E., I. J. Winograd, and M. S. Garber, 1963. *Preliminary Appraisal of Close-in Aquifer Response to the Bilby Event, Yucca Flat, Nevada*, U.S. Geological Survey Technical Letter NTS-63. Denver, CO.

Hall, D. B. and J. A. Perry, 2020. *Ecological Monitoring and Compliance Program 2019 Report*. DOE/NV/03624--0854. Mission Support and Test Services, LLC, Las Vegas, NV.

Hall, D. B. and J. A. Perry, 2022. *Ecological Monitoring and Compliance Program 2021 Report*. DOE/NV/03624--1420. Mission Support and Test Services, LLC, Las Vegas, NV.

Hall, Shawn, 1981. *Preserving the Glory Days: Ghost Towns and Mining Camps of Nye County, Nevada*. University of Nevada Press, Reno, NV.

Harrill, J. R., J. S. Gates, and J. M. Thomas, 1988. *Major Groundwater 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.

Haynes, G. M., 1996. *Evaluating Flake Assemblages and Stone Tool Distributions at a Large Western Stemmed Tradition Site near Yucca Mountain, Nye County, Nevada*, Journal of California and Great Basin Anthropology 18(1):104–130.

Hershey, R. L. and S. Y. Acheampong, 1997. *Estimation of Groundwater Velocities from Yucca Flat to the Amargosa Desert Using Geochemistry and Environmental Isotopes*, DOE/NV/11508--26, UC-703 (DRI Publication No. 45157), Desert Research Institute, Las Vegas, NV.

Hockett, B., 2000. *Paleobiogeographic changes at the Pleistocene-Holocene boundary near Pintwater Cave, southern Nevada*. Quaternary Research 53:263-269.

Houser, F. N. and F. G. Poole, 1960. *Preliminary Geologic Map of the Climax Stock and Vicinity, Nye County, Nevada*, U.S. Geological Survey Map I-328, scale 1:4,800, Washington, D.C.

Hudson, M. R., 1992. *Paleomagnetic Data Bearing on the Origin of Arcuate Structures in the French Peak-Massachusetts Mountain Area of Southern Nevada,* Geological Society of America Bulletin 104:581–594.

Inter-Tribal Council of Nevada, 1976. *Nuwuvi: A Southern Paiute History*. Inter-Tribal Council of Nevada, Reno.

International Technology Corporation, 1996a. *Regional Geologic Model Data Documentation Package (Phase I, Data Analysis Documentation, Volume I, Parts 1 and 2)*, ITLV/10972-181, Las Vegas, NV.

———, 1996b. *Potentiometric Data Task Documentation Package (Phase I, Data Analysis Documentation, Volume II)*, ITLV/10972-181, Las Vegas, NV.

———, 1996c. *Hydrologic Parameters Data Documentation Package (Phase I, Data Analysis Documentation, Volume IV)*, ITLV/10972-181, Las Vegas, NV.

———, 1997. *Groundwater Flow Model Documentation Package (Phase I, Data Analysis Documentation, Volume VI)*, prepared for the U.S. Department of Energy, Nevada Operations Office, Las Vegas, NV.

———, 2002. *Yucca Flat Hydrogeologic Investigation Wells Drilling and Completion Criteria*, ITLV/13052-164. Las Vegas, NV.

IT, see International Technology Corporation.

Jachens, R. C., 1999. Written communication, U.S. Geological Survey, Menlo Park, CA.

Jackson, T. R., and J. M. Fenelon, 2018. *Conceptual Framework and Trend Analysis of Water-Level Responses to Hydrologic Stresses, Pahute Mesa–Oasis Valley Groundwater Basin, Nevada, 1966-2016*. Scientific Investigations Report 2018-5064, 89 p. https://doi.org/10.3133/sir20185064.

Johnson, W. G., R. C. Jones, H. Drollinger, and A. DuBarton, 1999. *Archaeological Data Recovery at Site 26NY10133, Nevada Test Site, Nye County, Nevada*, Technical Report No. 95, Quaternary Sciences Center, Desert Research Institute, Las Vegas, NV.

Jones, G. T., C. Beck, E. E. Jones, and R. E. Hughes, 2003. *Lithic source use and Paleoarchaic foraging territories in the Great Basin*. American Antiquity 68:5-38.

Jones, R. C., 2001. *Results of Historic Research and Archaeological Investigations at Cane Spring, Nevada Test Site, Nye County, Nevada*. Cultural Resources Technical Report No. 98, Desert Research Institute, Las Vegas, Nevada.

Jones R. C., C. M. Beck, A. DuBarton, S. R. Edwards, N. Goldenberg, and J. Carroll, 1996. *A Class III Cultural Resources Reconnaissance of the Proposed Reentry Body Impact Fuze Flights (RBIFF), Area 26, Nevada Test Site, Nye County, Nevada*. Cultural Resources Reconnaissance Short Report No. SR121395-2, Desert Research Institute, Las Vegas, NV.

Jones, R. C. and S. R. Edwards, 1994. *A Clovis point on the Nevada Test Site,* Nevada Archaeologist 12:18–23.

Kelly, I. T. and C. S. Fowler, 1986. *Southern Paiute*. In Handbook of North American Indians, Volume 11, Great Basin, edited by W. L. d'Azevedo, pp. 135–148. Smithsonian Institution, Washington, D.C.

Kerr, G. D., S. D. Egbert, I. Al-Nabulsi, I. K. Bailiff, H. L Beck, I. G. Belukha, J. E. Cockayne, H. M. Cullings, K. F. Eckerman, E. Granovskaya, E. J. Grant, M. Hoshi, D. C. Kaul, V. Kryuchkov, D. Mannis, M. Ohtaki, K. Otani, S. Shinkarev, S. L. Simon, G.D. Spriggs, V.F. Stepanenko, D. Stricklin, J. F. Weiss, R. L. Weitz, C. Woda, P. R. Worthington, K. Yamamoto, and R. W. Young, 2015. "Workshop Report on Atomic Bomb Dosimetry—Review of Dose Related Factors for the Evaluation of Exposures to Residual Radiation at Hiroshima and Nagasaki." *Health Physics*, Vol 109, issue 6, pp. 582–600.

Kral, V. E., 1951. *Mineral Resources of Nye County, Nevada,* Nevada Bureau of Mines and Geology Bulletin 50, 45(3), Mackay School of Mines, University of Nevada, Reno.

Lachniet, M., Y. Asmerom, V. Polyak and Rhawn Denniston, 2017. *Arctic cryosphere and Milankovitch forcing of Great Basin paleoclimate.* Nature Scientific Reports 7:12955.

Laczniak, R. J., J. C. Cole, D. A. Sawyer, and D. A. Trudeau, 1996. *Summary of Hydrogeologic Controls on Ground-Water Flow at the Nevada Test Site, Nye County, Nevada*, Water Resources Investigation Report 96-4109, U.S. Geological Survey, Carson City, NV.

Laczniak, R. J., J. L. Smith, P. E. Elliott, G. A. DeMeo, M. A. Chatigny, and G. J. Roemer, 2001. *Ground-Water Discharge Determined from Estimates of Evapotranspiration, Death Valley Regional Flow System, Nevada and California*, U.S. Geological Survey Water-Resources Investigations Report 01-4195, Carson City, NV.

Lincoln, F. C., 1923. *Mining Districts and Mineral Resources of Nevada*, Nevada Newsletter Publishing Co., Reno, NV.

Locke, G. L., and R. J. La Camera, 2003. *Selected Ground-Water Data for Yucca Mountain Region, Southern Nevada and Eastern California*, *January 2000–December 2002*, U.S. Geological Survey Open-File Report 03-387, Carson City, NV.

Lockett, C. L. and L. C. Pippin, 1990. *Re-examining brownware ceramics in the central and southern Great Basin.* In Hunter-Gatherer Pottery from the Far West, edited by J. M. Mack, pp. 67–82. Anthropological Papers No. 23, Nevada State Museum, Carson City, NV.

Long, M., 1950. *The Shadow of the Arrow*, Caxton Printers, Caldwell, ID.

Louderback, L. A., D. K. Grayson, and M. Llobera, 2011. *Middle-Holocene climates and human population densities in the Great Basin, western USA*. The Holocene 21:366-373.

Madsen, D. B., 1986a. *Great Basin nuts: A short treatise on the distribution, productivity and prehistoric use of pinyon.* In Anthropology of the Desert West – Essays in Honor of Jesse D. Jennings, edited by C. Stout and D. D. Fowler, pp. 23–41, University of Utah Press, Salt Lake City, UT.

———, 1986b. *Prehistoric ceramics*. In Handbook of North American Indians, Volume 11, Great Basin, edited by W. L. d'Azevedo, pp. 206–214. Smithsonian Institution, Washington, D.C.

———, 2002. *Great Basin peoples and late Quaternary aquatic history*. In Great Basin Aquatic Systems History, edited by R. Hershler, D. B. Madsen and D. R. Currey, pp. 387-405. Smithsonian Contributions to Earth Sciences 33. Smithsonian Institution Press, Washington DC.

Madsen, D. B., D. N. Schmitt, and D. Page, 2015. *The Paleoarchaic Occupation of the Old River Bed Delta*. University of Utah Anthropological Papers 128. Salt Lake City.

Maldonado, F., 1977. *Summary of the Geology and Physical Properties of the Climax Stock, Nevada Test Site*, U.S. Geological Survey Open-File Report 77-356, Denver, CO.

Manly, W. L., 1927. *Death Valley in '49*. R.R. Donnelley & Sons Company, Lakeside Press, Chicago, Illinois.

McCracken, R. D., 1992. *A History of Beatty, Nevada,* Nye County Press, Tonopah, NV.

McLane, A. R., 1995. *The Silent Land: History of Yucca Mountain and the Fortymile Canyon Country, Nye County, Nevada*, Manuscript on file, Quaternary Sciences Center, Desert Research Institute, Reno, NV.

———, 1996. *El Picacho*. The Writing Cabin of B.M. Bower, Nevada 39(2):134–146.

Mifflin, M. D. and M. M. Wheat, 1979. *Pluvial Lakes and Estimated Pluvial Climates of Nevada*, Bulletin No. 94, Nevada Bureau of Mines and Geology, Mackay School of Mines, University of Nevada, Reno.

Mission Support and Test Services, LLC, 2021. *Nevada National Security Site Environmental Report 2020*, DOE/NV/03624--1210, Las Vegas, NV.

MSTS, see Mission Support and Test Services, LLC.

Myrick, D. F., 1963. *Railroads of Nevada and Eastern California*, Volume 2. Howell-North, Berkeley, CA.

NAC, see Nevada Administrative Code.

National Oceanic and Atmospheric Administration, 2005. *Surface Weather Observations and Reports*, FCM-H1-2005, U.S. Department of Commerce, Washington, D.C.

National Security Technologies, LLC, 2007. *A Hydrostratigraphic Model and Alternatives for the Groundwater Flow and Contaminant Transport Model of Corrective Action Unit 99: Rainier Mesa-Shoshone Mountain, Nye County, Nevada*, DOE/NV/25946--146, Las Vegas, NV.

———, 2009a. *A Hydrostratigraphic System for Modeling Groundwater Flow and Radionuclide Migration at the Corrective Action Unit Scale, Nevada Test Site and Surrounding Areas, Clark, Lincoln, and Nye Counties, Nevada*, DOE/NV/25946--630, Las Vegas, NV.

———, 2009b. *Observations on Faults and Associated Permeability Structures in Hydrogeologic Units at the Nevada Test Site*, DOE/NV/25946--690, Las Vegas, NV.

Navarro-Intera, 2013. *Phase I Flow and Transport Model Document for Corrective Action Unit 97: Yucca Flat/Climax Mine, Nevada National Security Site, Nye County, Nevada*, Revision 1, N-I/28091—080, Las Vegas, NV.

Navarro Nevada Environmental Services, LLC, 2010a. *Phase II Transport Model of Corrective Action Unit 98: Frenchman Flat, Nevada Test Site, Nye County, Nevada*, Revision 1, N-I/28091--004, S-N/99205--122, Las Vegas, NV.

———, 2010b. *Addendum to the Central and Western Pahute Mesa Phase II Hydrogeologic Investigation Wells Drilling and Completion Criteria*, Revision 0, N-I/28091--015-ADD, Las Vegas, NV.

Nevada Administrative Code, 2022. Chapter 503 - Hunting, Fishing and Trapping; Miscellaneous Protective Measures. Available at: http://www.leg.state.nv.us/NAC/NAC-503.html. Carson City, NV. [Accessed January 31, 2022]

Nevada Division of Natural Heritage, 2022. At-Risk Plant and Animal Tracking List, January 2022. Maintained by the Nevada Division of Natural Heritage Available at: https://heritage.nv.gov/assets/documents/2022-01-Track_List.pdf. Carson City, NV. [Accessed January 31, 2022]

NI, see Navarro-Intera.

NNES, see Navarro Nevada Environmental Services, LLC.

NDNH, see Nevada Division of Natural Heritage.

NNSA/NFO, see U.S. Department of Energy, National Nuclear Security Administration Nevada Field Office.

NNSA/NSO, see U.S. Department of Energy, National Nuclear Security Administration Nevada Site Office.

NOAA, see National Oceanic and Atmospheric Administration.

NSTec, see National Security Technologies, LLC.

O'Hagan, M. D. and R. J. Laczniak, 1996. *Ground-Water Levels Beneath Eastern Pahute Mesa and Vicinity, Nevada Test Site, Nye County, Nevada*, U.S. Geological Survey Water-Resources Investigations Report 96-4042, 1 sheet.

Orkild, P. P., 1963. *Geologic Map of the Tippipah Spring Quadrangle, Nye County, Nevada*, U.S. Geological Survey Map GQ-213, scale 1:24,000, Washington, D.C.

———, 1983. *Geologic and Geophysical Investigations of Climax Stock Intrusive, Nevada: Summary of Geologic and Geophysical Investigations*, U.S. Geological Survey Open-File Report 83-377, pp. 79–82, Denver, CO.

Ostler, W. K., D. J. Hansen, D. C. Anderson, and D. B. Hall, 2000. *Classification of Vegetation on the Nevada Test Site*, DOE/NV/11718--477, Bechtel Nevada, Ecological Services, Las Vegas, NV.

Phelps, G. A., R. C. Jachens, B. C. Moring, and C. W. Roberts, 2004. *Modeling of the Climax Stock and Related Plutons Based on the Inversion of Magnetic Data, Southwest Nevada*, U.S. Geological Survey Open-File Report 2004-1345, 21 p.

Pippin, L. C., 1986. *An Overview of Cultural Resources on Pahute and Rainier Mesas on the Nevada Test Site, Nye County, Nevada.* Technical Report No. 45, Desert Research Institute Social Sciences Center, Desert Research Institute, Reno, NV.

———, 1997. *Changing Adaptive Strategies of the Ethnohistoric Eso and Ogwei': Hunter and Gatherers in the Southern Great Basin*. Technical Report No. 94, Quaternary Sciences Center, Desert Research Institute, Reno, Nevada.

———, 1998. *Hunter-Gatherer Adaptations and Environmental Change in the Southern Great Basin: The Evidence from Pahute and Rainier Mesas,* Technical Report No. 92, Quaternary Sciences Center, Desert Research Institute, Reno, NV.

Prothro, L. B. and S. L. Drellack, 1997. *Nature and Extent of Lava-Flow Aquifers beneath Pahute Mesa, Nevada Test Site*, Bechtel Nevada, DOE/NV/11718--156, Las Vegas, NV.

Puzio, K., 2013. *Major Themes of the Cold War*. Electronic presentation, https://prezi.com/g_r04thwebuh/major-themes-of-the-cold-war.html, accessed June 16, 2016.

Quade, J. and J. V. Tingley, 1984. *A Mineral Inventory of the Nevada Test Site, and Portions of Nellis Bombing and Gunnery Range, Southern Nye County, Nevada*, Open File Report 84-2, Nevada Bureau of Mines and Geology, University of Nevada, Reno.

Randerson, D., 1997. *Analysis of Extreme Precipitation Events in Southern Nevada*, NOAA Technical Memorandum ERL ARL-221, Air Resources Laboratory, Silver Spring, MD.

Randerson, D. and J. B. Sanders, 2002. *Characterization of Cloud-to-Ground Lightning on the Nevada Test Site*, NOAA Technical Memorandum OAR ARL-242, Air Resources Laboratory, Silver Spring, MD.

Reiner, S. R., G. L. Locke, and L. S. Robie, 1995. *Ground-Water Data for the Nevada Test Site and Selected Other Areas in South-Central Nevada, 1992-1993*, U.S. Geological Survey Open-File Report 95-160, Las Vegas, NV.

Reno, R. L., 1985. *Clovis projectile points from Lahontan Reservoir and the Nevada Test Site, Nevada*. Nevada Archaeologist 5(1):7–9.

Rhode, D., 1994. *Direct dating of brown ware ceramics using thermoluminescence and its relation to the Numic spread*. In Across the West: Human Population Movement and the Expansion of the Numa, edited by D. B. Madsen and D. Rhode, pp. 124–130. University of Utah Press, Salt Lake City, UT.

Rhode, D. and K. D. Adams, 2016. *Paleoenvironmental Context for Lincoln County, Nevada.* Submitted to Bureau of Land Management, Caliente, NV, for Lincoln County Archaeological Initiative.

Rhode, D., D. B. Madsen, and K. T. Jones, 2006. *Antiquity of early Holocene consumption and processing at Danger Cave, Utah, USA*. Antiquity 80:328-339.

Robie, L. S., G. L. Locke, and S. R. Reiner, 1995. *Ground-Water Data for the Nevada Test Site, 1992, and for Selected Other Areas in South-Central Nevada, 1952-1992*, U.S. Geological Survey Open-File Report 95-284.

Rose, T. P., J. M. Kenneally, D. K. Smith, M. L. Davison, G. B. Hudson, and J. H. Rego, 1997. *Chemical and Isotopic Data for Groundwater in Southern Nevada*, Lawrence Livermore National Laboratory Report UCRL-ID-128000, Livermore, CA.

Sawyer, D. A., R. J. Fleck, M. A. Lanphere, R. G. Warren, and D. E. Broxton, 1994. *Episodic Caldera Volcanism in the Miocene Southwest Nevada Volcanic Field: Revised Stratigraphic Caldera Framework, ^{40}Ar/^{39}Ar Geochronology and Implications for Magnetism and Extension,* Geological Society of America Bulletin 67(10):1304–1318.

Short, N.M., 2004. "The Role of Nuclear Explosions in Studies of Impact Craters." *Meteoritics & Planetary Science,* Vol 39, issue 8, pp. 1405-1408. http://meteoritics.org

Shutler, R. Jr., 1961. *Lost City, Pueblo Grande de Nevada*, Anthropological Papers No. 5, Nevada State Museum, Carson City, NV.

Slate, J. L., M. E. Berry, P. D., Rowley, C. J. Fridrich, K. S. Morgan, J. B. Workman, O. D. Young, G. L. Dixon, V. S. Williams, E. H. McKee, D. A. Ponce, T. G. Hildenbrand, WC Swadley, S. C. Lundstrom, E. B. Ekren, R. G. Warren, J. C. Cole, R. J. Fleck, M. A. Lanphere, D. A. Sawyer, S. A. Minor, D. J. Grunwald, R. J. Laczniak, C. M. Menges, J. C. Yount, and A. S. Jayko, 1999. *Digital Geologic Map of the Nevada Test Site and Vicinity, Nye, Lincoln, and Clark Counties, Nevada, and Inyo County, California,* U.S. Geological Survey Open-File Report 99B554BA.

SNJV, see Stoller-Navarro Joint Venture.

Snyder, R. P., 1977. *Geology of the Gold Meadows Stock, Nevada Test Site*, U.S. Geological Survey Report 474-179, Denver, CO.

Spaulding, W. G., 1990. *Vegetational and climatic development of the Mojave Desert: The last glacial maximum to the present.* In Packrat Middens: The Last 40,000 Years of Biotic Change, edited by J. L. Betancourt, T. R. Van Devender, and P. S. Martin, pp. 166-199. University of Arizona Press, Tucson.

Stager, H. K. and J. V. Tingley, 1988. *Tungsten Deposits in Nevada*, Bulletin No. 105, Nevada Bureau of Mines and Geology, Reno, NV.

State of Nevada Engineers Office, 1974. *Static Groundwater Levels of Nevada*, Division of Water Resources, State Engineers Office, Carson City, NV.

Steward, J. H., 1938. *Basin-Plateau Aboriginal Sociopolitical Groups*, Bureau of American Ethnology Bulletin 120, Smithsonian Institution, Washington, D.C.

Stoffle, R. W., D. B. Halmo, J. E. Olmsted, and M. J. Evans, 1990. *Native American Cultural Resource Studies at Yucca Mountain, Nevada*. Institute for Social Research, the University of Michigan, Ann Arbor.

Stoffle, R. W., M. N. Zedeno, and D. B. Halmo, 2001. *American Indians and the Nevada Test Site: A Model of Research and Consultation*. DOE/NV Report 13046-2001-001, Office of Scientific and Technical Information, Oak Ridge, Tennessee.

Stoller-Navarro Joint Venture, 2004a. *Phase II Hydrologic Data for the Groundwater Flow and Contaminant Transport Model of Corrective Action Unit 98: Frenchman Flat, Nye County, Nevada*, S-N/99205-032, Rev. 0, Las Vegas, NV.

———, 2004b. *Hydrologic Data for the Groundwater Flow and Contamination Transport Model of CAU Units 101 and 102: Central and Western Pahute Mesa, Nye County, Nevada*, S-N/99205-002, Shaw/13052-204, Rev. 0, Las Vegas, NV.

———, 2006a. *Phase II Groundwater Flow Model of Corrective Action Unit 98: Frenchman Flat, Nye County, Nevada*, S-N/99205--074, Las Vegas, NV.

———, 2006b. *Phase I Hydrologic Data for Corrective Action Unit 97: Yucca Flat-Climax Mine, Lincoln and Nye County, Nevada*, S-N/99205--077, Las Vegas, NV.

———, 2006c. *Groundwater Flow Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nevada Test Site, Nye County, Nevada*, S-N/99205--076, Rev. 0, Las Vegas, NV.

———, 2007. *An Addendum to the Phase II Groundwater Flow Model of Corrective Action Unit 98: Frenchman Flat, Nevada Test Site, Nye County, Nevada*, S-N/99205--074, Las Vegas, NV.

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

Thomas, D. H., L. S. A. Pendleton, and S. C. Cappannari, 1986. *Western Shoshone*. In Handbook of North American Indians, Volume 11, Great Basin, edited by W. L. d'Azevedo, pp. 262–283. Smithsonian Institution, Washington, D.C.

Thompson, R.S., 1990. *Late Quaternary vegetation and climate in the Great Basin*. In Packrat Middens: The Last 40,000 Years of Biotic Change, edited by J. L. Betancourt, T. R. Van Devender, and P. S. Martin, pp. 200-239. University of Arizona Press, Tucson.

Thordarson, W. and B. P. Robinson, 1971. *Wells and Springs in Calif. And Nevada within 100 Miles of the Point 37° 15' N., 116° 25' W. on the Nevada Test Site*. U.S. Geological Survey Report USGS-474-85 (NTS-227). Denver, CO.

Tingley, J. V., 1984. *Trace Element Associations in Mineral Deposits, Bare Mountain (Flourine) Mining District, Southern Nye County, Nevada*, Report No. 39, Nevada Bureau of Mines and Geology, Reno, NV.

Titus, A. C., 1986. *Bombs in the Backyard: Atomic Testing and American Politics*. University of Nevada Press, Reno.

Trexler, J. H., Jr., J. C. Cole, and P. H. Cashman, 1996. *Middle Devonian-Mississippian Stratigraphy on and near the Nevada Test Site: Implications for Hydrocarbon Potential*, American Association of Petroleum Geologists Bulletin 80(11):1736–1762, Tulsa, OK.

Trexler, J. H., Jr., P. H. Cashman, J. C. Cole, W. S. Snyder, R. M. Tosdal, and V. I. Davydov, 2003. *Widespread Effects of Middle Mississippian Deformation in the Great Basin of Western North America*, Geological Society of America Bulletin 115(10):1278–1288.

U.S. Department of Energy, National Nuclear Security Administration Nevada Field Office, 2013. *Nuclear Timeline Fact Sheet*. NNSA/NFO Office of Public Affairs DOE/NV--1243.

———, 2015. *United States Nuclear Tests, July 1945 through September 1992*, DOE/NV-209-REV 16, Las Vegas, Nevada.

U.S. Department of Energy, National Nuclear Security Administration Nevada Site Office, 2008. *Groundwater Protection Program Plan for the National Nuclear Security Administration Nevada Field Office*, DOE/NV/25946--557, Las Vegas, NV.

———, 2006. *Completion Report for Well ER-16-1 Corrective Action Unit 99: Rainier Mesa - Shoshone Mountain.* DOE/NV-1180, Las Vegas, NV.

U.S. Department of Energy, National Nuclear Security Administration Nevada Site Office, and Bechtel Nevada., 2006. *Completion Report for Well ER-12-4. Corrective Action Unit 99: Rainier Mesa-Shoshone Mountain*, DOE/NV--1128, Las Vegas, NV.

U.S. Department of Energy, Nevada Operations Office, 1996. *Final Environmental Impact Statement for the Nevada Test Site and Off-Site Locations in the State of Nevada*, Volume 1, Chapters 1–9, DOE/EIS--0243, Las Vegas, NV.

———, Nevada Operations Office, 1997. *Regional Groundwater Flow and Tritium Transport Modeling and Risk Assessment of the Underground Test Area, Nevada Test Site, Nevada*, DOE/NV--477, Las Vegas, NV.

———, 1999. *Corrective Action Investigation Plan for Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nevada Test Site, Nevada*, DOE/NV--516, Las Vegas, NV.

U.S. Environmental Protection Agency, 2000. *On-Site Meteorological Program Guidance for Regulatory Modeling Applications*, EPA-450/4-87 013, Office of Air Quality Planning and Standards, Research Triangle Park, NC.

U.S. Fish and Wildlife Service. 2022. Endangered Species Program Home Page. Maintained at: http://www.fws.gov/endangered. [Accessed January 31, 2022]

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

Walker, G. E., 1962. *Groundwater in the Climax Stock, Nevada Test Site, Nye County, Nevada,* U.S. Geological Survey Trace Element Investigations Report TEI-813, Washington, D.C.

Walker, M., 1995. *The Cold War: A History*. Owl, New York.

Warren, C. N. and R. H. Crabtree, 1986. *Prehistory of the southwestern area.* In Handbook of North American Indians, Volume 11, Great Basin, edited by W. L. d'Azevedo, pp. 183–193. Smithsonian Institution, Washington, D.C.

Warren, R. G., G. L. Cole, and D. Walther, 2000a. *A Structural Block Model for the Three-Dimensional Geology of the Southwestern Nevada Volcanic Field*, Los Alamos National Laboratory Report LA-UR-00-5866.

Warren, R. G., D. A. Sawyer, F. M. Byers, Jr., and J. C. Cole, 2000b. *A Petrographic/Geochemical Database and Stratigraphic and Structural Framework for the Southwestern Nevada Volcanic Field,* Internet address: http://www.pggdb-swnvf.lanl.gov/, as accessed on September 20, 2004, LANL Report LA-UR-00-3791.

———, 2003. *A Petrographic/Geochemical and Geophysical Database, and Stratigraphic Framework for the Southwestern Nevada Volcanic Field*, LANL Report LA-UR-03-1503.

Wheat, M. M., 1967. *Survival Arts of the Primitive Paiutes.* University of Nevada Press, Reno.

Wigand, P. E. and D. Rhode, 2002. *Great Basin vegetation history and aquatic systems: The last 150,000 years*. In *Great Basin Aquatic Systems History*, edited by R. Hershler, D.B. Madsen, and D. R. Currey, pp. 309-368. Smithsonian Contributions to the Earth Sciences 33. Smithsonian Institution Press, Washington DC.

Williams, M., 2017. "NASA Reignites Program for Nuclear Thermal Rockets." *Universe Today* 11 August 2017. https://www.universetoday.com/136752/nasa-reignites-program-nuclear-thermal-rockets/

Wills, C. A. and W. K. Ostler, 2001. *Ecology of the Nevada Test Site: An Annotated Bibliography, with Narrative Summary, Keyword Index, and Species List*, DOE/NV/11718--594, Bechtel Nevada, Ecological Services, Las Vegas, NV.

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, U.S. Government Printing Office, Washington, D.C.

Winslow, D. L., 1996. *Restricted Reconnaissance: Wheeler's Nye County Explorations*, M.A. thesis, Department of Anthropology, University of Nevada, Las Vegas.

World Meteorological Organization, 2008. *WMO Guide to Meteorological Instrumentation and Methods of Observation*, WMO No. 8 (7th Edition), Secretariat of the World Meteorological Organization, Geneva, Switzerland.

Worman, F. C. V., 1969. *Archaeological Investigations at the U.S. Atomic Energy Commission's Nevada Test Site and Nuclear Rocket Development Station*, Report LA4125, University of California Los Alamos Scientific Laboratory, Los Alamos, NM.

Zanjani, S., 1992. *Goldfield: The Last Gold Rush on the Western Frontier*, Ohio University Press, Athens.

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